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INCREASING THE FUNCTIONING EFFICIENCY OF THE WORKING WAREHOUSE OF THE "UVK UKRAINE" COMPANY TRANSPORT AND LOGISTICS CENTER

Competition in the field of logistics and individual transport services requires the constant analysis of logistics chains and their individual links. Given analysis enables implementation of new approaches to logistics companies and networks trade marketing in the offtake of certain types of goods. Industrial and commercial enterprises have to expand their trade and economic relations with other regions with the aim to provide the necessary sales volumes in the domestic market of regions and to go beyond it. Integration of the country's economy and the free trade policy orientation greatly simplify the task of establishing the free trade and economic relations between producers and consumers. However, there is a question of how quickly and efficiently; with minimal logistics costs, the goods at the right region of the customer should be delivered.

The experiment on a one-storey closed warehouse No 3 of Brovary "UVK Ukraine", where a process of the cross-docking warehousing, with subsorting from a warehouse, has been conducted. The warehouse mainly works on trading networks. The loading of the warehouse has been performed with the input flow intensity within (12.3 ... 23.56 (t/h)). During the experiment, the number gain of loading and unloading machines (Electrostacks Reath Track OMG NEOS LAT 3.0) a pcs in the process of unloading, loading and moving consignments, has been examined. In addition, the increasing number of workers employed in non-mechanized forms of work, such as receiving and stacking cargo in the reception area (moving the relevant consignments to designated areas of the reception area and its arrangement), which in total is an increase of 4 employees in the technological process of the warehouse operation, has been investigated during the experiment. The growing of labor and mechanized resources makes it possible to better organize the work of the warehouse, reduce total costs and increase cargo output flow. Conducting the process of warehouse work optimization on the formed technology and corresponding labor and mechanized resources caused an increase of its efficiency. It has been found that the optimal values of intensity of the incoming cargo flow will be 17.93 (t/h); the number of employees engaged in non-mechanized labor - 12 workers, and loading and unloading machines - 3 (pcs). Under such conditions, the warehouse functioning according to the desirability level will reach value 0.792. In this case, the cost value of warehouse work is 181.07 US$/h and cargo output flow intensity is 10.23 (t/h). Results of experimental studies have shown that implementation of the proposed method of increasing the efficiency of warehouse work, based on the company "UVK Ukraine" may, on average, achieve a total cost reduction of 17.2% and an increase in output flow by 34.6% and the input flow by 10.3%.

Keywords: *warehouse logistics, transport and logistics center, labor resources, loading and unloading machines, warehouse, cargo flow, costs, optimization*

1 Introduction

The current state of the logistics market development of any country, including Ukraine, depends on the level of its economy. The volume of services provided in the field of logistics directly depends on the activity level of their customers, the dynamics of production, domestic and foreign trade. For example, in the European Union (EU) countries, the logistics sector in its broadest sense is ranked as the third among the economic sectors. Underestimating the role of logistics as a factor of influence on the efficiency and competitiveness of the economy, worsens Ukraine's position in international rankings. Thus, Ukraine in 2019 in the World Bank's Logistics Performance Index (LPI) is ranked 67 in the world, [1]. One should consider that the logistic component's share in the gross domestic product

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(GDP) is 11 - 16% in developed countries (in the EU and the United States - 13-17%, in China - 25%, in Japan - 7%). As for Ukraine, most experts relate the economy of the country to the level of the "third world" countries, in which logistics costs can reach 41% of the GDP. This figure in Ukraine ranges from 31 to 34%. At the same time, 69% of logistics costs accounted for transport (6.8 bln US$), 24% - for warehousing (2.3 bln US$) and about 6% - for logistics flow management (0.6 bln US$) [1-2]. Therefore, one of the main areas of the modern transport policy is transition to the transport logistics in the transport and logistics system (TLS). TLS allows to provide comprehensive services to consumers of transport services, to create conditions for the combined transport development, to reduce the environmental burden on the environment [3]. The TLS structure should consist of a set of interconnected elements interaction at the regional and local levels. Regional distribution centers, terminal complexes, transport and logistics centers (TLCs) are the main system elements of transport infrastructure objects [4].

The relevance of organization and increase of efficiency of the transport and logistics centers is significantly growing. This is evidenced by existence and creation of new large, modern companies that specialize in this type of cargo delivery organization. They compete with each other, offering customers better, more economical, faster and better ways of processing orders, both domestically and internationally. This necessitates the development of efficient warehouse technologies and the organization of warehouse operations and logistics management.

2 Literature review

Taking into consideration current trends in development of the logistics services, it can be stated that the TLC have become the basic elements of the cargo management and cargo flows [5]. In general, such centers play a coordinating and distributive role in cargo transportation. Introduction of the new modern technologies necessitates creation of a network of TLC infrastructural objects that perform functions of interaction between types of transport and organization of material distribution in the economic region [6]. They are the basic foundation of material flow management that provide interconnection with senders, consumers, carriers, etc.

Major trends, such as timeliness, containerization and e-commerce, lead to a steady increase in the volume of goods that have to be transported in accordance with regulated delivery schedules [7]. Supply chains in this case are formed in such a way as to use fully adaptive storage systems as one of the main components of the transportation process [8]. The baggage handling at airports, mixed with inclined conveyor trays in the distribution centers of the postal industry, warehouses formation of retailers consignments through implementation of the e-commerce is an example of the most successful implementations of such warehouse complexes [9]. Because of the diverse logistical and organizational problems associated with design and management of individual warehouses with different systems of their warehouse functions it is difficult to describe the wide range of issues and various options for solving them [10].

The warehouse logistics is a functionally important stage in warehouse operations and it has a direct impact on cost and performance in the supply chain [11-13]. Due to inefficient operation of the warehouse complex, freight and logistics companies may experience significant inconvenience associated with the expectation between arrival and shipment [14]. This, in turn, leads to unjustified costs for the company in the form of a delay fee (fine for delayed transportation and additional costs for keeping the truck driver in overtime) and delayed delivery of subsequent orders [15]. In addition, long idling trucks in queues is not environmentally sustainable as it increases the concentration of carbon dioxide [16-18], so it is advisable to organize transport and storage complexes with a standardized loading and a warehouse work efficiency. The main aim of transport and logistics centers is to minimize the cost of logistics centers operating and to reduce the cost of goods transportation [1, 19]. Implementation of the short-term strategies for realization of the cargo service functions in the transport and logistics complex will reduce logistics costs and increase the capacity of the warehouse [20]. The modeling approach and proposed warehouse scheduling rules are pre-developed and can be adopted by any enterprise.

Within the framework of forming an efficient TLS system, 3PL - TLC operators and cargo shippers have been considered and the quality of logistics services has been evaluated. Thus, the current state of the market can be determined: 41% of logistics is in a state of stagnation; 30% - at the stage of formation and development; 18% - at the stage of formation; 1.8% - at the redistribution stage [21]. Consequently, customers and logistics providers seek to optimize costs, implement new technologies, improve the quality of logistics services and establish effective communication between customers and logistics providers to increase the loyalty level of the end consumers [22]. International companies in Ukraine suggest that imperfect legislation - 74%; corruption factor - 51%; customs work - 59%; poor quality of infrastructure - 62%; lack of professional staff - 24%; market monopolization - 14% are the main obstacles in development of the TLS market. Ukrainian companies also gave to the factors of imperfect legislation and corruption factors the first place - 58 and 57%, then imperfect infrastructure - 49%, difficulties in customs work - 45%, problems with staff experience - 26%, and monopolization - 17%. Among the factors that can greatly influence the development of the TLS, experts point out to implementation of EU legal acts and regulations [1, 23-24].

Analysis of the complex interactions that occur between different components of the transport and logistics center is the main problem of warehouse work improving [25]. The basic condition is a uniform distribution associated with the loading and unloading work required for the flow of goods within the logistics network. Its analysis is performed using the Petri nets and sensitivity functions as the discrete event modeling and simulation structures [25-27]. The warehouse modeling work is aimed at identifying the innovative aspect of using both graph theory and elements of sensitivity theory [28-31] and statistical optimization [32-33]. With help of mathematical tools to support the functional characteristics of warehouse systems, their strengths and weaknesses have been identified. However, that aspect makes it possible to implement individual storage units for various technological processes. Therefore, it is desirable to identify the critical factors in the local logistics chain in the warehouse and to propose solutions to improve its efficiency [34]. Use of the warehouse database processing methods is well suited to set the basic characteristics of individual warehouse units. At the same time, the main logistic processes, involving both labor and machinery should not be damaged [35-36]. It should be noted that direct modeling of cargo flows together with quantitative analysis made it possible to identify delays in the logistics chain and to determine indicators that will allow increasing the efficiency of the resource usage. The last one will increase the productivity of warehouse work [30, 37].

With significant growth of interest in the logistics enterprises efficiency, the need for transport and logistics centers arises even more, so adaptation and high efficiency of their work for the diverse needs of logistics agents is a priority at present [25]. Nevertheless, this requires efficient coordination of warehouse work and formation of the warehouse technological process with the minimum required number of operations for human and mechanized resources [32].

Properly organized technological process of the TLC operation should ensure: accurate and timely carrying out of quantitative and qualitative acceptance of goods; effective use of mechanization of loading-unloading and transport-warehouse works; consistent and rhythmic performance of warehouse operations, which contributes to the systematic loading of warehouse workers and creation of favorable working conditions; rational warehousing of goods ensuring maximum use of warehouse volumes and areas; safety of goods; clear organization of centralized delivery of goods.

The aim of this study was to develop a methodology for formation of the warehouse work rational technology organization and warehouse work optimization.

3 Materials and methods of determining the rational technology of service orders

The transport and technological process is an important part of the transport and logistics network (TLN). It must be implemented to successfully complete the entire range of work and reduce the cost of operations in the TLC. In addition, it must be based on advanced technology and advanced methods. Solution to this problem involves optimizing the production process for efficient organization of material flow management and reducing the cost of operating the TLC in TLN. A one-storey closed warehouse No 3 of Brovary "UVK Ukraine" has been chosen for the experiment, where a process of cross-docking warehousing with subsorting from a warehouse, has been implemented. The total area of the warehouse is 1080 m^2 and its height is 9 m. Type of storage: 4 tier shelve rack. The warehouse mainly works on trading networks. This warehouse is part of the TLS where goods can be transported as by road transport and by rail through the container platform of the TLS. The railway and highway connections are brought to the container platform. From the container platform the required containers have been sent to the warehouse reception area and, if it is necessary the completed containers from the warehouse departure area have been moved, to the TLC container platform and further transport is already formed.

The technological process of the studied warehouse complex TLC functioning has the following sequence of operations:

1) Arrival of cargo to the warehouse: preparation of technical means for receiving cargo, documents, familiarization of warehouse workers with the unloading plan;
2) Check of cargo packing integrity in the vehicle: fastenings and presence of appropriate seals and markings are checked, external damages are revealed;
3) Unloading of cargo using the loading and unloading mechanisms (LUM);
4) Cargo reception and stacking in the reception area: moving the respective consignments of cargo to the designated places of the reception area and its arrangement;
5) Cargo reception by quantity and quality: opening of container, counting by quantity and verification of documentation, culling;
6) Selection and transfer of cargo to the storage and completing area;
7) Storage of cargo in a warehouse in two modes (1-2.5 days, 2.5 and more);
8) Completing and sending from the storage and reception areas: a consignment is formed for the relevant order, the quantity of the cargo and the type of container is determined, packaging and sealing is carried out, documents are being prepared;
9) Moving the finished cargo unit to the departure area;
10) Verification of cargo by quantity and compliance with documents;
11) Loading of cargo into the vehicle and transfer of documents.

Determination of the effective work organization is carried out by setting a value - total costs, which form a plurality of values corresponding costs for each element of the process.

In the process of active experiment influence of factors has been investigated: X_1 - the input flow intensity; X_2 - the number of employees and X_3 - the number of loading and unloading machines in the warehouse instead of

Table 1 Formation of factors and their levels for experiment

Factors	Levels	
	Lower (-1)	Upper (+1)
X_1 - cargo input flow intensity, t/h	12.3	23.56
X_2 - the number of employees engaged in non-mechanized labor, empl.	8	12
X_3 - the number of loading and unloading machines, pcs.	2	3

organizational and economic components of the warehouse activity. The testimonials or resulting features of experiment are as follows: Y_1 - total costs (US$) → min; Y_2 - cargo output flow intensity (t/h) → max. The set of factors and their levels are presented in Table 1.

For the experiment, it has been decided to investigate three factors and their two levels. The number of necessary experiments can be calculated by formula:

$$N_e = 2^{n_f}, \tag{1}$$

where:
2 - number of levels,
n_f - number of factors.

According to Equation (1) it was determined that it is necessary to carry out 8 experiments for solving the optimization problems. A plan for the full-scale experiment, indicating the levels and factors, as well as the response functions of the experiment, has been formed. In order to minimize the impact on response, experiments should be performed in random order.

The analysis of this experiment plan has been performed using portable software (Statistica v.10.0.1011.0). The processing of the experimental results began with the regression analysis, i.e. the model has been built and the unknown coefficients of the regression equation have been determined:

$$\begin{aligned} Y = b_0 + b_1 \cdot (X_1)^2 + b_2 \cdot (X_2)^2 + b_3 \cdot (X_3)^2 + \\ + b_4 \cdot X_1 \cdot X_2 + b_5 \cdot X_1 \cdot X_3 + b_5 \cdot X_2 \cdot X_3 \end{aligned}. \tag{2}$$

It has been determined that effects of the interaction of factors, based on their nature and content, are virtually absent and therefore, they have not been included in the overall appearance of the model (2). The unknown constant coefficients of the regression equation have been determined using the least squares method. The obtained model coefficients can be obtained by the following formulas:

$$\begin{aligned} & b_0 = \sum_{i=1}^{N} Y/N;\ b_j = \sum_{i=1}^{N} Y_i/N; \\ & b_{j^2} = \sum_{i=1}^{N} Y_i (X_{ji})^2/N; \ldots \end{aligned} \tag{3}$$

Description of factors and response using the mathematical model (2) is characterized by a coefficient of determination, which should be at least 0.95, for a qualitative description of the object of study. This coefficient is calculated by the formula:

$$R^2 = 1 - \frac{\sigma_{zl}^2}{\sigma_Y^2} = 1 - \left(\sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2 / \sum_{i=1}^{N} (Y_i - \bar{Y}_i)^2 \right), \tag{4}$$

where:
$\sigma_{zl}^2, \sigma_Y^2$ - dispersion of regression residues, response, respectively
$Y_i, \bar{Y}, \hat{Y}_i$ - actual, average, estimated value of the response.

The standard error that characterizes the standard deviation of the studied regression coefficients from the mean is calculated by the formula:

$$S_{b_{j^r}} = \sqrt{\frac{\sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{N} (X_{ij} - \bar{X}_j)^2} \cdot \frac{1}{n-2}} \tag{5}$$

where n - sample volume.

From a statistical point of view the regression coefficients evaluation is carried out by Student's criterion. This compares the calculated value to the table at a given confidence level of 0.05 and the calculated average values of levels:

$$|t_{\alpha f}| = \left| \frac{b_{j^r}}{S_{b_{j^r}}} \right| > t_{\alpha/2, ftb}, \tag{6}$$

where:
b_{j^r} - estimated regression coefficients,
α - probability 0.95,
f - average value of level.

With a significant regression coefficient, the Student's test is greater than a tabular one.

The calculation of the marginal error of deviation has been established from the following calculations:

$$\Delta_{j^r} = t_{\alpha, f \cdot tb} \cdot S_{b_{j^r}}. \tag{7}$$

The interval for each regression coefficient has been determined according to inequality:

$$b_{j^r} - \Delta_{j^r} \leq b_{j^r} \leq b_{j^r} + \Delta_{j^r}. \tag{8}$$

Mathematical model fit to the experimental data, that is, its adequacy has been defined by Fisher's criteria F. The calculation criterion should be greater than the table criterion:

$$F = \frac{\sigma_X^2}{\sigma_Y^2} = \frac{R^2}{1 - R^2} \cdot \frac{f_2}{f_1} \geq F_{\alpha, f \cdot tbl}, \tag{9}$$

where:

$\sigma_X^2 = \left(\sum_{i=1}^{N} (X_i - \bar{X})^2 \right) / f_1$ - dispersion factor,

f_1 - degree average value,

$\sigma_Y^2 = \left(\sum_{i=1}^{N} (Y_i - \bar{Y})^2 \right) / N - f_1 - 1$ - dispersion value,

N - experiments number,
R^2 - determination coefficient.

To solve the optimization problem, the desirability function approach, introduced by E. Harrington, has been used [38]. This method has useful properties of continuity, monotony and smoothness. The method converts specific parameters to abstract numeric values. A logical function as the basis for the calculation has been used:

$$d_i = \exp(-\exp(-Y_i)), \tag{10}$$

where: Y - function value.

Function (10) is characterized by the two saturation portions ($d \to 0$ and $d \to 1$) and a linear portion ($d \to 0.2$ and $d \to 0.63$). For a better abstract representation of a function, it is necessary to break it into ranges where the specific values of the scale correspond to the studied indicators. To form multivariate optimization, the function is formed by the following equation:

$$Z = \sqrt[n]{\prod_{i=1}^{n} d_i}\,. \tag{11}$$

Further study of this function should determine analysis of the investigated values and factors of the process. The value of the curve optimum condition is set outside the curve level, within these limits, the most relevant factor values are selected. The function method is visual.

To determine the objective function values, a warehouse restrictions system based on the experimental and organizational data with the relevant factors values have been studied. Thus, they have been determined during the statistics data analysis of the "UVK Ukraine" warehouse complex functioning.

$$\begin{cases} 12.3 \le X1 \le 23.56; \\ 8 \le X2 \le 12; \\ 2 \le X3 \le 3; \\ Y1 \to \min; \\ Y2 \to \max. \end{cases} \tag{12}$$

The research planning experiment of cargo flow at Brovary "UVK Ukraine" warehouse complex has been used to find the optimal conditions for the work organization. The following factors have been selected: the input flow intensity (t/h) X_1, the number of employees engaged in manual labor (work.) X_2, number of loading and unloading machines of Reath Track OMG NEOS LAT 3.0 stackers (pcs.) X_3. For this purpose, the experimental data normalization of cargo flows movement through the warehouse complex has been used. These operations are necessary to obtain reliable research data on changes in the cost of improving warehouse operations, namely the total cost ($) $Y_1 \to$ min; the output flow intensity (t/h) $Y_2 \to$ max. For the experiment, the Brovary "UVK Ukraine"" warehouse No 3 (for household goods) has been loaded in accordance with the data shown in Equation (12) and the experiment plan below (one experiment one working day of the warehouse) during the period from 04/15/2019 to 04/22/2019. The value functions have been calculated as averages over the entire experimental warehouse operating day. Increasing the number of employees engaged in non-mechanized labor has been used on operations: cargo reception and stacking in the reception area (moving the respective consignments of cargo to the designated places of the reception area and its arrangement) by changing the number of employees from 1 to 2; cargo reception by quantity and quality: (opening of container, counting by quantity and verification of documentation, culling) by changing the number of employees from 1 to 2; completing and sending from the storage and reception areas (a consignment is formed for the relevant order, the quantity of the cargo and the type of container is determined, packaging and sealing is carried out, documents are being prepared) increase from 1 person to 3 employees. Increases in loading and unloading machines have been made by increasing the number of Reath Track OMG NEOS LAT 3.0 electric stackers on unloading, loading and moving consignments from 2 pieces to 3. The full factorial experiment makes it possible for multiple measurements that meet certain conditions set optimal factors values. The number of measurements is 8 and the values of the factors are combined in all the possible variants. Advantages of a full factorial experiment are the simplicity of the solution of the task and the statistical redundancy of the number of measurements, which reduces the influence of errors of individual measurements on the estimation of unknown regression coefficients.

4 Results

4.1 Study results of the proposed approach to organization rational efficiency increase of the warehouse work

Based on the obtained and processed experimental data, a database has been formed (Table 2) to identify changes in the optimality criteria for the organization of a warehouse complex. The minimum and maximum values in the peak period of "UVK Ukraine" company have been used to form the flow of goods.

The experimental data processing using application software makes it possible to automate the calculations according to the formulas given. Regression analysis of the experimental results is shown in Tables 3 and 4, insignificant coefficients in the tables were not recorded.

***Table 2** Value of the input parameters of the experiment according to the basic variant during the peak load movement in the warehouse complex*

Experiment	The levels of variation			Total costs, US$	Cargo output flow intensity, t/h
	Cargo input flow intensity, t/h	The number of employees, empl.	The number of loading and unloading machines, pcs.		
	X_1	X_3	X_4	Y_1	Y_2
1	12.3	8	2	193.70	3.6
2	23.56	8	2	162.49	6.3
3	12.3	12	2	173.31	9.6
4	23.56	12	2	140.29	8.4
5	12.3	8	3	343.82	3.7
6	23.56	8	3	273.05	7.7
7	12.3	12	3	294.34	11.9
8	23.56	12	3	221.85	12.05

***Table 3** The Regression analysis of experimental results for the optimizing trait Y_1*

R^2 = 0.9988 - the determination coefficient of the regression model of the experimental data						
Regression coefficients	Regression coefficients (value)	Standard error	Student's coefficient	Significance level p, ($p<0.05$)	Average interval - 95%	Average interval - 95%
b_0	-23.80	$38.86\cdot10^{-2}$	61.25	$10.39\cdot10^{-3}$	-28.74	-18.87
b_1	25.51	$1.43\cdot10^{-2}$	1787.49	$3.56\cdot10^{-4}$	25.33	25.69
b_2	3.71	$33.82\cdot10^{-3}$	109.75	$5.8\cdot10^{-3}$	3.28	4.14
b_3	15.46	$135.27\cdot10^{-3}$	114.31	$5.56\cdot10^{-3}$	13.74	17.18
b_4	$-64.49\cdot10^{-2}$	$9.99\cdot10^{-4}$	645.44	$9.86\cdot10^{-4}$	$-65.76\cdot10^{-2}$	$-63.22\cdot10^{-2}$
b_5	$-350.93\cdot10^{-2}$	$3.99\cdot10^{-3}$	878.11	$7.25\cdot10^{-4}$	$356.01\cdot10^{-2}$	$-345.85\cdot10^{-2}$
b_6	$-44.13\cdot10^{-2}$	$11.25\cdot10^{-3}$	39.22	$16.23\cdot10^{-3}$	$-58.42\cdot10^{-2}$	$-29.83\cdot10^{-2}$

***Table 4** The Regression analysis of experimental results for the optimizing trait Y_2*

R^2 = 0.9988 - the determination coefficient of the regression model of the experimental data						
Regression coefficients	Regression coefficients (value)	Standard error	Student's coefficient	Significance level p, ($p<0.05$)	Average interval - 95%	Average interval - 95%
b_0	-21.584	$21.59\cdot10^{-2}$	99.97	$6.37\cdot10^{-3}$	-24.33	-18.84
b_1	$-62.28\cdot10^{-2}$	$7.93\cdot10^{-3}$	78.56	$8.1\cdot10^{-3}$	$-72.35\cdot10^{-2}$	$-52.20\cdot10^{-2}$
b_2	$282.67\cdot10^{-2}$	$18.79\cdot10^{-3}$	150.46	$4.23\cdot10^{-3}$	$258.8\cdot10^{-2}$	$306.55\cdot10^{-2}$
b_3	$899.01\cdot10^{-2}$	$75.15\cdot10^{-3}$	119.63	$5.32\cdot10^{-3}$	$803.53\cdot10^{-2}$	$994.5\cdot10^{-2}$
b_4	$4.94\cdot10^{-2}$	$5.55\cdot10^{-4}$	89.00	$7.15\cdot10^{-3}$	$4.23\cdot10^{-2}$	$5.65\cdot10^{-2}$
b_5	$11.77\cdot10^{-2}$	$2.22\cdot10^{-3}$	53.00	$12.01\cdot10^{-3}$	$8.95\cdot10^{-2}$	$14.59\cdot10^{-2}$
b_6	$-96.87\cdot10^{-2}$	$6.25\cdot10^{-3}$	155.00	$4.11\cdot10^{-3}$	$-104.82\cdot10^{-2}$	$-88.93\cdot10^{-2}$

For a more accurate reflection of the experimental results, the mathematical regression model has been complicated to the second order. The factors did not interact, if the coefficient of determination was not lower than 0.95. While analyzing data in Tables 3 and 4, it is possible to conclude that all the included factors are statistically significant, as evidenced by the level of their significance. Therefore, the values of the coefficients can be included in the model that describes the process of composition at studied factors. In the general case, the regression equations have the form:

$$\begin{aligned} Y_1 = &-23.80 + 25.51\cdot(X_1)^2 + 3.71\cdot(X_2)^2 + \\ &+15.46\cdot(X_3)^2 + 64.49\cdot10^{-2}\cdot X_1\cdot X_2 - \\ &-350.93\cdot10^{-2}\cdot X_1X_3 - 44.13\cdot10^{-2}\cdot X_2\cdot X_3 \end{aligned} \tag{13}$$

$$\begin{aligned} Y_2 = &-21.584 - 62.28\cdot10^{-2}\cdot(X_1)^2 + 282.67\cdot10^{-2}\cdot \\ &\cdot(X_2)^2 + 899.01\cdot10^{-2}\cdot(X_3)^2 + 4.94\cdot10^{-2}\cdot X_1\cdot X_2 + \\ &+11.77\cdot10^{-2}\cdot X_1\cdot X_3 - 96.87\cdot10^{-2}\cdot X_2\cdot X_3 \end{aligned} \tag{14}$$

***Table 5** The dispersion analysis of the experimental data for the optimizing trait Y_1*

Coefficients	Dispersion	Fisher's criterion	Significance level p, (p<0.05)
b_1	$2.68\cdot10^{3}$	$26.49\cdot10^{6}$	$12.4\cdot10^{-5}$
b_2	$2.56\cdot10^{3}$	$25.34\cdot10^{5}$	$4.0\cdot10^{-4}$
b_3	$5.38\cdot10^{3}$	$53.15\cdot10^{5}$	$2.76\cdot10^{-4}$
b_4	$4.21\cdot10^{2}$	$41.66\cdot10^{4}$	$9.86\cdot10^{-4}$
b_5	$7.81\cdot10^{2}$	$77.10\cdot10^{4}$	$7.25\cdot10^{-4}$
b_6	1.56	$1.53\cdot10^{3}$	$1.62\cdot10^{-2}$

***Table 6** The dispersion analysis of the experimental data for the optimizing trait Y_2*

Coefficients	Dispersion	Fisher's criterion	Significance level p, (p<0.05)
b_1	$11.25\cdot10^{3}$	$1.09\cdot10^{2}$	$1.42\cdot10^{-8}$
b_2	$92.02\cdot10^{3}$	$8.98\cdot10^{2}$	$1.42\cdot10^{-15}$
b_3	$10.44\cdot10^{3}$	$1.01\cdot10^{2}$	$2.41.42\cdot10^{-8}$
b_4	$30.50\cdot10^{3}$	$2.97\cdot10^{2}$	$9.17\cdot10^{-12}$
b_5	$30.75\cdot10^{3}$	$3.00\cdot10^{2}$	$8.62\cdot10^{-12}$
b_6	$71.44\cdot10^{3}$	$6.97\cdot10^{2}$	$1.27\cdot10^{-14}$

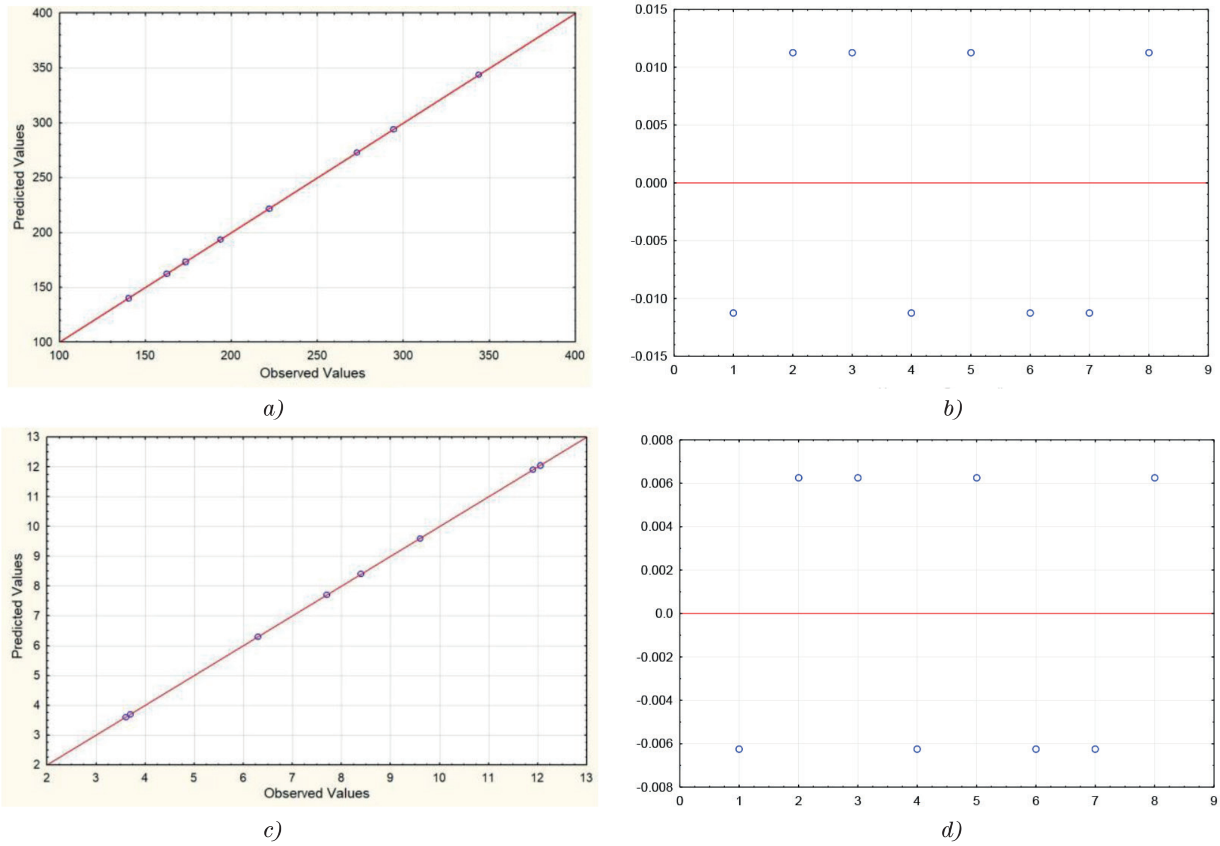
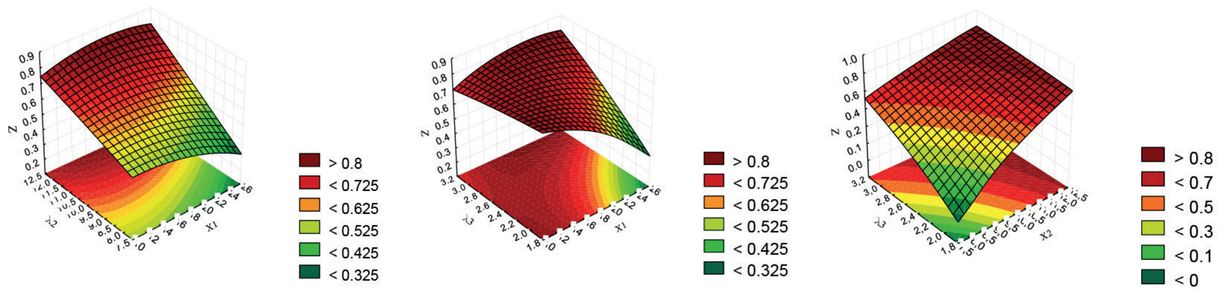


***Figure 1** Graphical display of the projected and observed balances and estimation of their magnitude: a) and b) - for the total cost function; c) and d) - for the output flow intensity*

To assess the adequacy of these models, a variance analysis of the obtained experimental data has been performed and Fisher's criterion has been determined. Realization of the dispersion analysis is reflected in Tables 5 and 6.

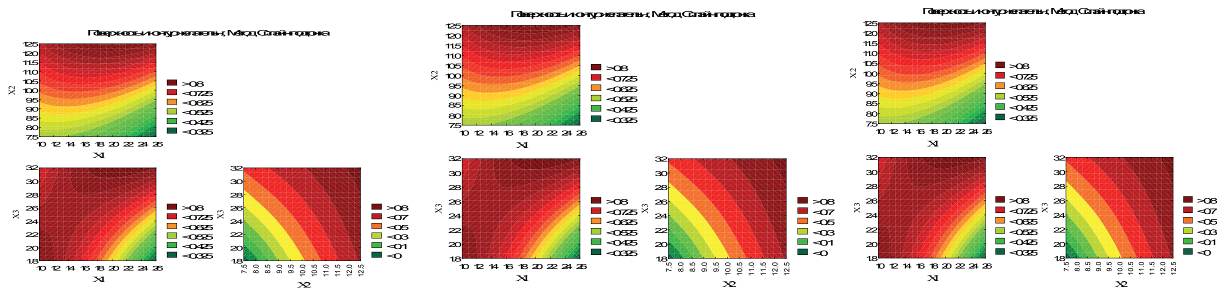
From Tables 5 and 6 it can be seen that the factors included in the mathematical model (13), (14) adequately describe the studied process of the warehouse functioning, so the significance level p, for each factor is below the allowable level of 0.05.

Visually estimate residual dispersion between the obtained and estimated values by regression Equations (13) and (14). It should be noted that significant dispersion of 10% of the maximum predicted values should not be present



a) b) c)

Figure 2 *Graphic representation of surfaces value on the scale of desirability of the studied warehouse work: a) dependence of Z on X1 and X2; b) dependence of Z on X1 and X3; c) dependence of Z on X2 and X3*



a) b) c)

Figure 3 *Graphical representation of value levels on the scale of the investigated tribological supplement: a) dependence of Z on X_1 and X_2; b) dependence of Z on X_1 and X_2; c) dependence of Z on X_2 and X_3*

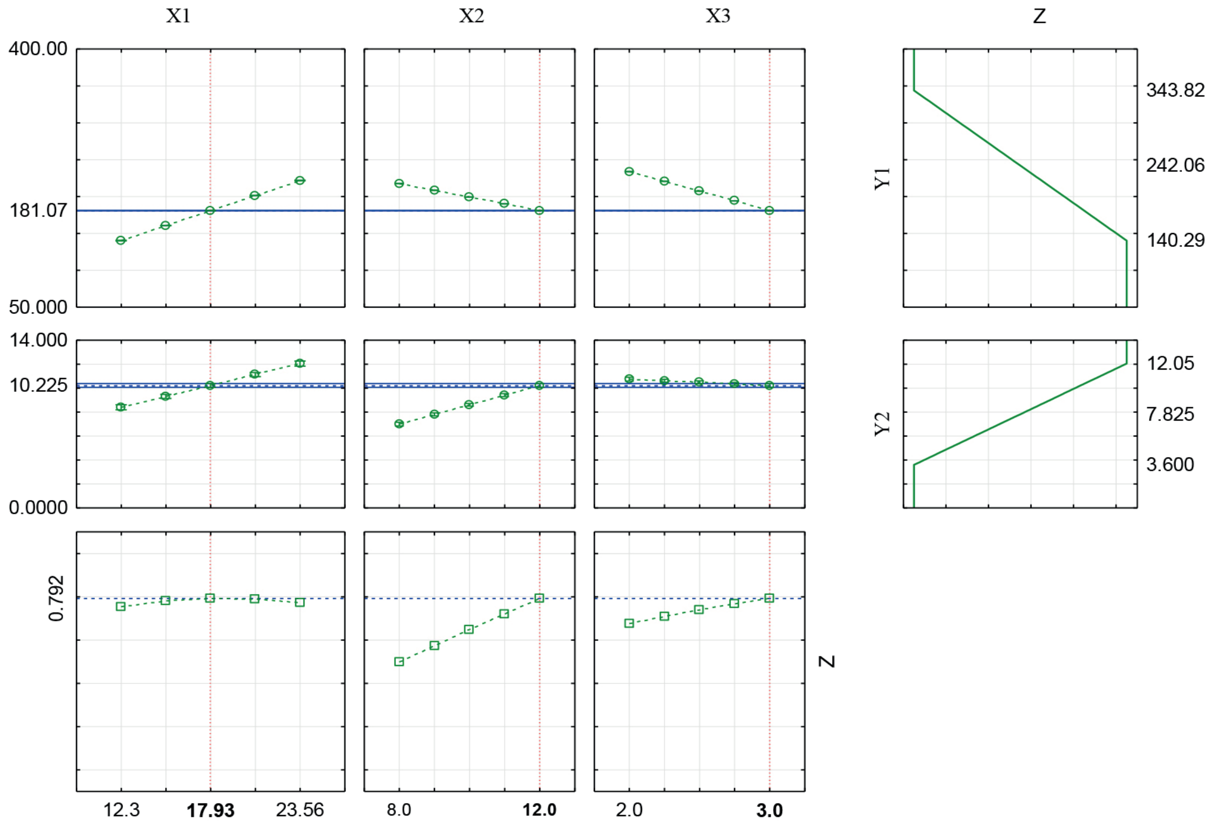


Figure 4 *Graphical representation of the procedure for finding the optimal factors values of the warehouse work of the function profile - Z*

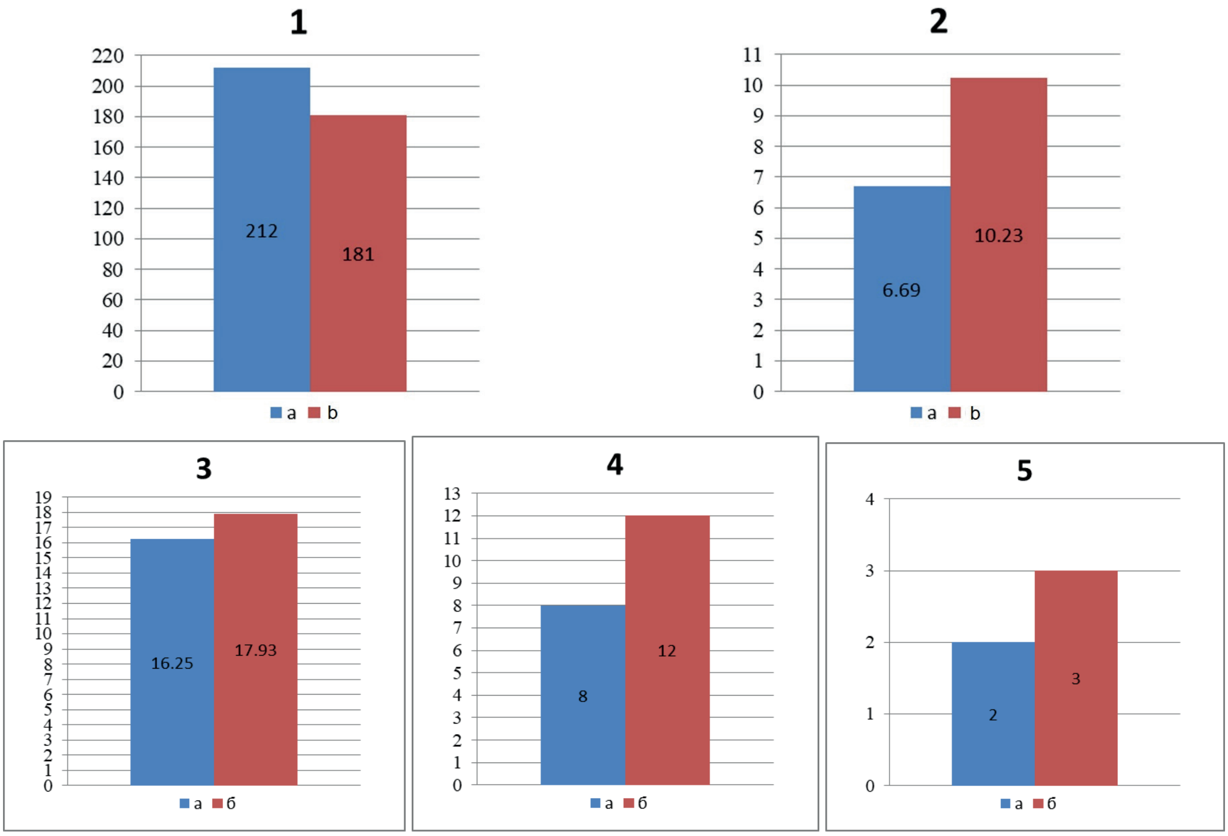


Figure 5 *Average results of the warehouse functioning according to the base variant (a) and optimized (b): 1 - total costs (US$/h); 2 - the input flow intensity (t/h); 3 - the output flow intensity (t/h); 4 - number of employees engaged in non-mechanized labor (empl.); 5 - number of loading and unloading machines (un)*

in the analyzed experiment data. A graphical representation of this is presented in Figure 1.

It can be seen that there are no significant data dispersion, and therefore the mathematical model can be considered as certain.

The surface values of the investigated functions of the warehouse functioning process resultant features with reflections of factors values, on the scale of desirability, are identical in character and are presented in Figure 2. Levels of the function values on the scale of desirability are shown in Figure 3.

Visually analyzing these graphs, it is possible to state unequivocally that the optimal parameters of the warehouse functioning have been presented in the studied ranges of factors values X_1, X_2, X_3. To determine the optimal values of the warehouse work efficiency, set the limits of the investigated values, which will include the entire experimental database that is available for analysis. Under these conditions, it is possible to find the required maximum values for the function. Consider the above for each factor and each function. Realization of the procedure for determining the optimum value of storage conditions is presented in Figure 4.

From Figure 4 can be seen that the optimal variant of the factors values is at the intersection of function maximum value in the defined interval of each factor. With such values of the studied factors, it is possible to state the optimality of the warehouse functioning and the positive solution of the applied problem. The results, which give an opportunity to evaluate the effectiveness of the warehouse functioning, have been shown in Figure 5.

The formed optimal variant (Figure 5) makes it possible to increase the efficiency of the warehouse functioning. There is a decrease in total costs and increase in the intensities of the input flow and the output flow.

5 Discussion

5.1 Research results discussion of the rational technology service orders formation

An increase in efficiency of the warehouse is possible due to the proper organization of its work and providing technological operations with appropriate resources. The transposition of the warehouse into the cross-docking process with subsorting from the warehouse has been considered. The warehouse loading has been performed with an input flow intensity of 12.3...23.56 (t/h). Under those conditions, the number of loading and unloading machines (Electrostacks Reath Track OMG NEOS LAT 3.0) a pcs., in the process of unloading, loading and moving consignments, has been increased. The number of workers employed in non-mechanized forms of work has been gained: cargo reception and stacking in the reception area (moving the respective consignments of cargo to the designated places of the reception area and its arrangement) by changing the number of employees from 1 to 2; cargo reception by quantity and quality: (opening of container, counting by quantity and verification of documentation, culling) by changing the number of employees from 1 to 2; completing and sending from the storage and reception areas (a consignment is formed for the relevant order, the quantity of the cargo and the type of container is determined, packaging and sealing is carried out, documents are being prepared) increase from 1 person to 3 employees. The increase of its efficiency has been shown by conducting the process of the warehouse work optimization on the formed technology and corresponding labor and mechanized resources. After conducting the experiment and the corresponding calculations, the optimal values of the studied parameters have been formed. The cargo output flow intensity is within the variation range (12.3...23.56 (t/h)) the optimum value will be 17.93 (t/h); the number of employees engaged in the non-mechanized labor are within the range (8...12) - optimum values of 12 workers, and loading and unloading machines (2...3) - optimal value 3 (units), which will rationally ensure the technological process of warehouse operation. Under such conditions, the average level of the warehouse operation will be 0.792. The optimal value of the warehouse work costs will be 181.07 US$/h, and cargo output flow intensity will be 10.23 (t/h). Compared to the basic variant, optimized one allows reducing the total costs by 17.2%, and the output flow intensity to increase by 34.6%, while the average values of the input flow intensity can be increased by 10.3%. The given procedure of an increase in the efficiency of the warehouse work functioning on realization of the cross-docking procedure, with subsorting from a warehouse, reflects the positive effect for the enterprise.

6 Conclusions

A. It has been determined that optimum values for warehouse input flow intensity is 17.93 (t/h), the number of employees engaged in the non-mechanized labor - 12 empl., loading and unloading machines 3 pcs, so under such conditions the value of the warehouse work will be 181.07 US$/h, cargo output flow intensity - 10.23 (t/h).

B. During the experiment on the warehouse optimization, an increase in efficiency of the warehouse operation on the implementation of the cross-docking procedure, with warehouse subsorting, has been recorded. It reflects the positive effect for the enterprise, namely reduction of the total costs by 17.2%, increase of the output flow rate by 34.6%, and average input flow intensity values of 10.3%.

C. The experiment of an increase in the warehouse work efficiency, based on the division of labor and mechanized resources, makes it possible to organize and adapt the warehouse work to the requirements of trade networks and customers of transport logistics systems, in more detail.

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SIMULATION OF A QUEUING SYSTEM OF A POST OFFICE IN ANYLOGIC SOFTWARE

This paper displays the design and application of a model that simulates the queuing system of a fictional post office. Starting point for solving more complicated optimization tasks is to create a system model that consists of elements of reality and the relationships between these elements. The key part of the paper includes the model of a queuing system of a post office created in Anylogic simulation software. The model of the post office displays post office with 5 postal counters, a certain input flow and a certain service time with an exponential probability distribution. The model also includes statistics and cost calculation.

Keywords: *post office, simulation, Anylogic, costs, conceptual model*

1 Introduction

Digital technologies and to them related processes of automation and digitalization, are the driving force of the present. They affect the labour market, productivity and efficiency growth and ultimately are one of the key elements of transformation of functioning of society, businesses and economies. Digitalization and automation also affect the transport sector which includes the postal companies [1]. There are many applications in the field of digitalization and automation. From automated sorting systems and intelligent handling equipment in the processing of delivery items to innovative delivery methods through autonomous vehicles and smart mailboxes in the process of mail delivery [2]. In the process of collection of delivery items and within the points of the first contact, the queuing systems are commonly used. It is possible to design such systems through use of the computer simulation. Objectives of computer simulation are: elimination of the shortcomings of analytical methods and capturing of properties and elements of the real system that cannot be expressed in the analytical solution. In the system such as queuing system of a post office there are many random variables that cannot be captured in the analytical solution of optimization problems [3-9]. Therefore it is advisable to use a simulation method to get the system model closer to the real system, as much as possible. Contribution of the simulation method is in the ability of capturing the dynamic side of the system and complicated probabilistic relationships [10-15]. In Slovakia, the quality of postal services is monitored and the quality requirements for the universal postal service are regulated by the regulatory authority of the Slovak Republic [16-21]. Many of those quality requirements affect the Queuing systems of post offices. For example, one of the requirements is that a customer should not wait more than 12 minutes at the queue in the post office. Waiting and service times at post offices are directly related to customer satisfaction [1, 12].

Customer satisfaction, which co-creates a good image of the postal company and can significantly influence customer behaviour and preferences, is one of the factors of the of the postal services quality [22]. It is therefore necessary to shift focus to this area in order to retain customers and meet their needs.

The other factor of the postal services quality is location of the facility (post office). The success of each provider of high-quality services depends on the location of facilities of these businesses in relation to other facilities and its customers. The choice of the facility is primarily based on the availability, with customers choosing the closest (available) facility. Given that the availability provides an overall indicator of how a particular facility is accessible for other sources located in the analysed space, it is also necessary to determine the boundaries of this indicator [23].

2 Theoretical background

2.1 Queuing theory

The queuing theory is a mathematical discipline that analyses and solves processes in which request flows flow through certain devices from which they require service. The pioneer of queuing theory was Danish engineer Agner K. Erlang. At the beginning of the 20th century, he derived unique patterns for probabilities of states of a stabilized Markov system with losses. The queuing

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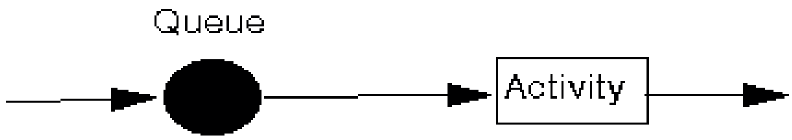

Figure 1 *General queuing system*

systems are systems (physical, social) serving to meet the needs of individuals, customers and requirements entering the system. The queuing service system is everything that is between the arrival of a request in the system and its departure from the system. A queuing system of a post office can be considered as a stochastic system with theoretically unlimited queue, a certain average service time, a customer arrival and a certain number of service lines [1, 7-9].

The queuing theory deals with problems, which involve queuing (or waiting) in the line. Typical examples might be:

- banks/supermarkets -waiting for service,
- computers - waiting for a response,
- public transport - waiting for a train or a bus.

Modelling of queuing systems requires introduction of notions originated by Kendall, which are also used to describe a queuing system [24-25]:

$$A/ B / m / K / n/ D, \quad (1)$$

where: A - distribution function of the inter arrival times,

B - distribution function of the service times, where m is a number of servers,

K - capacity of the system, the maximum number of customers in the system including the one being serviced, where n is the population size, which determines the number of sources of customers,

D - service discipline.

Exponentially distributed random variables are expressed by M, meaning Markovain or memoryless [22-23].

Generally, all the queuing systems can be divided into individual sub-systems consisting of entities, which are queuing for some activity (see Figure 1) [24-25].

2.2 System modelling

Simulation methods are methods that are often used in the queuing theory. Solving complicated optimization tasks using simulation often leads to a creation of model that contains elements of a real system and relationships between them. The dynamic elements of the system are handled by the time-slicing method. This method can model the progress of time when an event occurs. An event represents a change in the state of the system at a time. There are two event types in simpler event-based simulation models arrival of customer and an end of service [10-13].

3 Data and methods

The fundamental methods that are used in this paper are modelling and simulation method. In addition to the simulation model in the Anylogic program, the paper displays a conceptual model of the queuing system of a post office. The conceptual model of the system was created before the simulation model itself.

The model in Anylogic software displays five postal counters servicing customers. Three counters are universal and provide to customers all the postal services from the scope of universal service. There is also a financial counter and a service counter at the post office. For the public the opening hours (every work day) are from 7:00 to 19:00.

The queuing system of a fictional post office is characterized by the two main random variables, namely the average time of service and the average customer input at the post office. For this paper the average customer input is given:

$$\lambda = 2.20 \textit{ minutes}. \quad (2)$$

The given average service time is:

$$\mu = 4.20 \textit{ minutes}. \quad (3)$$

Input data of the model input are fictional. The simulation of a particular system requires a detailed system analysis that includes both an analysis of customer input flow and service time.

According to the Kendall's classification of queuing systems, the queuing system of a post office is classified as a system with an infinite queue, five independent parallel lines, exponential distribution of the arrivals of customers, service times and a waiting discipline FIFO.

3.1 Conceptual model of the post office queuing system

The model starts with an event - the arrival of the customer. The customer checks whether the counters are occupied. If they are not occupied, the customer enters counter. If they are currently occupied, he/she chooses a minimum queue. It is clear that the customer chooses a counter according to the service he/she requires. If the customer is waiting in the queue for more than 6.5 minutes, he/she leaves the post office without being served. This

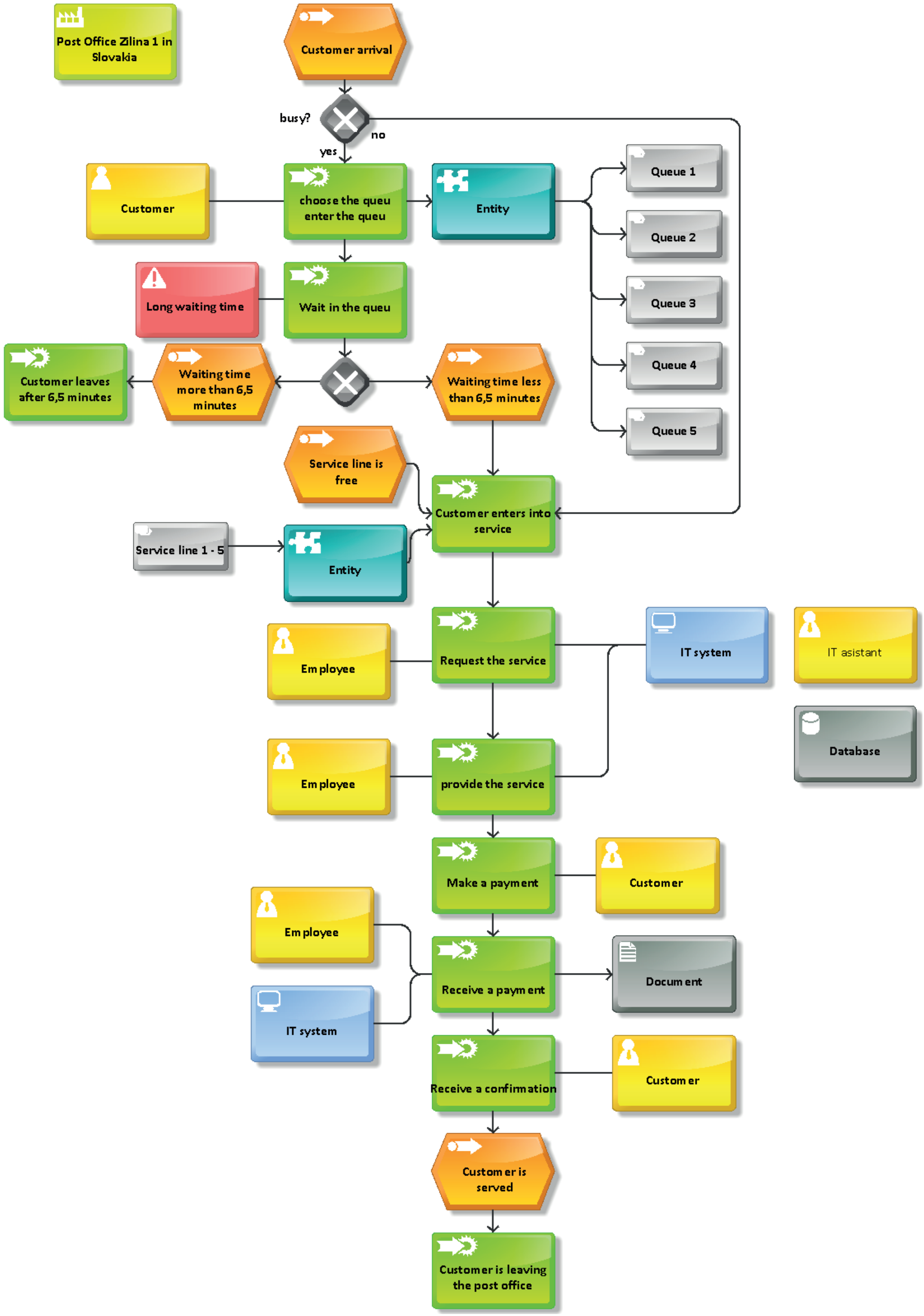

***Figure 2** Conceptual model of the post office queuing system*

condition is based on the results of a survey conducted in 2018 among postal customers. If a given counter is free, the customer enters the counter to be served. A post office employee works with an information system. With this system, employee is able to provide service to the customer. After the customer is served, he or she pays for the service.

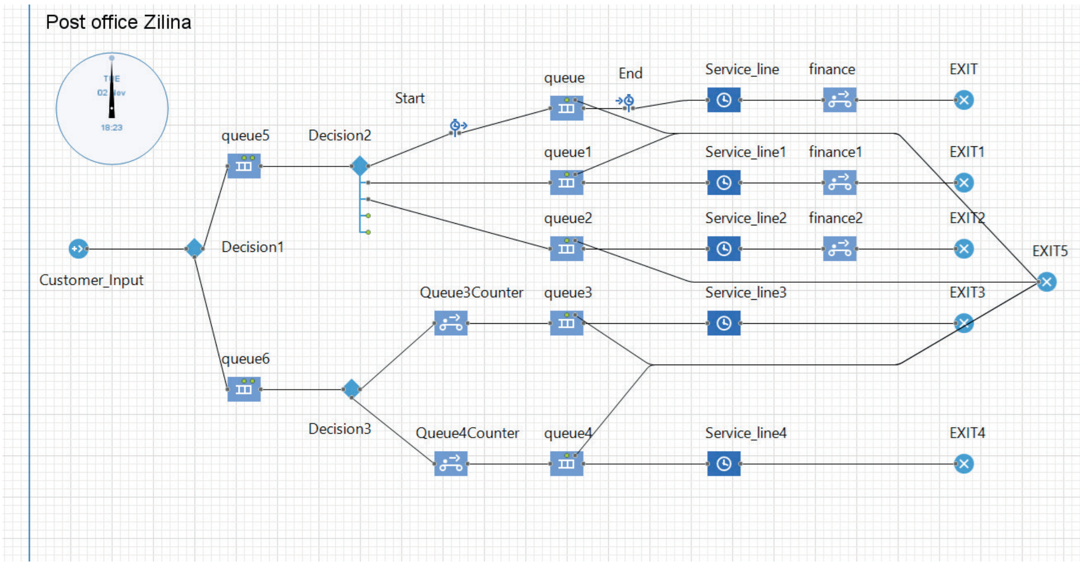

***Figure 3** The queuing model compiled in Anylogic simulation software*

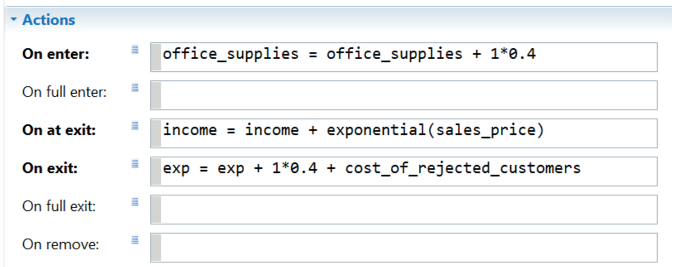

***Figure 4** Calculation of income and expenses in software Anylogic*

The customer is then served and the model ends with customer's activity - customer is leaving the post office. The whole process of functioning of the described model is presented in Figure 2.

4 Objective

The main objective of this paper is to design an application of a model simulating the queuing system of a fictional post office. Using the program, five simulation experiments were conducted. Based on the results of simulation experiments, it is possible to make further decisions about the system. Decisions are derived from the simulation experiments of a simulation model, which includes several variables and graphs.

5 Results

Design of the simulation model and results of five simulation experiments are presented in this section. The structure of the simulation model corresponds to structure of the conceptual model, which was defined in Figure 2.

5.1 Simulation model

The simulation model of a queuing system of a fictional post office, designed in Anylogic is graphically interpreted in Figure 3.

The simulation model (Figure 3) consists of following objects:

Customer_Input - which is defined by interval time. In this case it is exponential distribution with one parameter. The average customer input is λ = 2.20 minutes. Customer comes into the system (queuing model) for service. If they wait in the queue for more than 6.5 minutes, they leave the system without being served (refusal of service). This means the loss for the queuing system of the queuing model.

Decision 1 - customer has to decide if he wants to use service type number 1 provided by Service_line and Service_line2 or service type number 2 provided by Service_line3 and Service_line4. Probability for service type 1 is set up at 0.60. Probability of service type 2 is set up at 0.40.

Queue - after decision 1, customer chooses the queue. The logic is in always choosing the minimum queue. If queues are 0, the customer chooses the service line which is free.

***Table 1** Input data for simulation experiment 1*

	Time/minutes
Simulation Time	3600
Service Time	4.2
Customer Input	2.2

***Table 2** Input data for simulation experiment 2*

	Time/minutes
Simulation Time	3600
Service Time	4.2
Customer Input	4.4

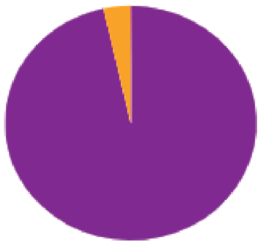

***Figure 5** Simulation 1 -utilization statistics*

Service lines - are defined by the delay time which is in this case the average service time with exponential distribution. In this case the average service time is μ = 4.20 minutes. Customers enter the counter providing the service from the queue (unless they decide to leave because of a long waiting time).

Finance - object Finance 5 is only for calculating expenses and revenue. Figure 4 displays calculation of income and expenses. The input data are fictional.

Model contains **exits 1-4.** There is also exit 5 for customers that decide to leave the queue after 6.5 minutes.

5.2 Simulation results

Several simulation experiments were performed in Anylogic simulation software. The first simulation experiment is based on input data from section 3. The rest of the simulation experiments are based on "what if" questions and are solved in the following parts of paper.

5.2.1 Simulation experiment 1

Simulation experiment 1 reflects current situation in terms of queueing in the service lines in a fictional post office. Table 1 display input data of the simulation experiment 1. Simulation time (3600 minutes) represents five business days. Opening hours in working days are 12 hours a day.

The simulation experiment 1 provided following statistics about the system:

- The final number of customers arriving at the post office within five business days is 7076 customers,
- The first three service lines were able to serve 4283 customers. According to customer numbers and individual service lines one can see that 74% of customers wanted the first type of services, which were served by Service_line and only 3.5% of customers were served by Service_line2,
- The similar situation happened in the case of Service_line3 and Service_line4. Only 2.69% of customers wanted the second type of services, which were served by Service_line4. Figure 5 displays percentage utilization of Service_line3 and Service_line4, respectively queue 3 and queue 4.

5.2.2 Simulation experiment 2

What if the customer input would be doubled? Solution to this problem provides the simulation experiment 2. Table 2 displays input data of the simulation experiment 2. In order to solve the problem the customer input is doubled.

The simulation experiment 2 provided following statistics about the system:

- The final number of customers arriving in the post office within 5 business days is 14 625,
- The first three service lines were able to serve 8744 customers. Only 8.5% customers were served by the Service_line2. It can be said that doubled customer input doesn´t have huge effect on the Service_line2,

Table 3 *Input data for simulation experiment 3*

	Time/minutes
Simulation Time	3600
Service Time	4.2
Customer Input	6.6

Table 4 *Input data for simulation experiment 4*

	Time/minutes
Simulation Time	3600
Service Time	4.2
Customer Input	2.2

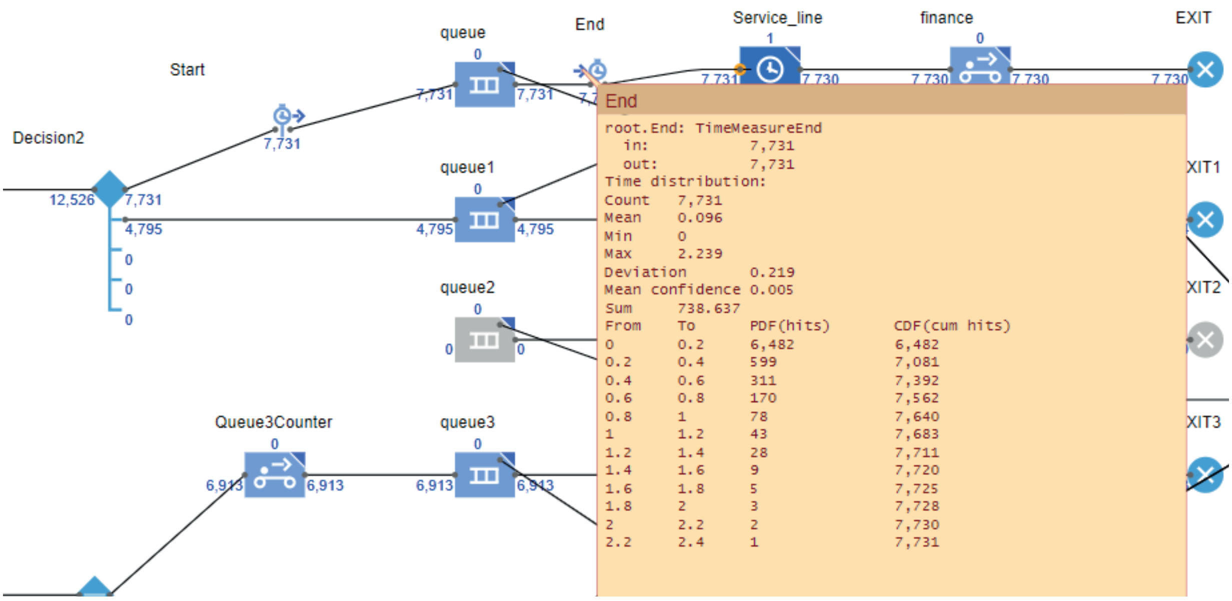

Figure 6 *Average waiting time statistics in simulation experiment 4*

- regarding theService_line4, the percentage change is even less, only 1.6%.

5.2.3 Simulation experiment 3

Simulation experiment 3 solves the following: what if the customer input would be tripled because of Christmas? Table 3 displays input data of the simulation experiment 3. The customer input data is tripled.

The simulation experiment 3 provided following statistics about the system:

- only 14.5% of customers were served by the Service_line2. It can be said that tripled customer input doesn´t have huge effect on the Service_line2,
- utilization of the Service_line2 doesn´t seem efficient; the same case is in the Service_line4, only 18% of customers were serviced by the Service_line4.

5.2.4 Simulation experiment 4

Another problem appears: What if Service_line 2 is closed? The simulation experiment 4 provides the solution to this problem. The Table 4 displays input data of the simulation experiment 4.

The simulation experiment 4 provided following statistics about the system:

- the waiting time for the service type 1 is no longer than 2.23 minutes even when Service_line2 is closed. System was able to serve these customers without any losses. Figure 6 displays statistics related to waiting time, for example the average waiting time or maximum or minimum waiting time in queue.

5.2.5 Simulation experiment 5

Last problem solved in this paper is bound to the question: What if the Service_line4 is closed? The input data of simulation experiment 5 are the same as in simulation experiment 4.

The simulation experiment 5 provided following statistics about the system:

- the waiting time for service type 2 is no longer than 3.10 minutes even when Service_line4 is closed. The system was able to serve these customers without any losses.

6 Conclusion and discussion

The paper examines the queuing system of fictional post office. Anylogic simulation software has proven to be a useful tool for modelling and simulating a queuing system. Using the program, five simulation experiments were conducted. These experiments were based on "what if" questions. "What if" questions were oriented to a change in customer input flow or a change in the number of postal counters. In both cases of a change in the customer input flow, the change does not have a huge effect on the system. The postal counters were able to serve doubled and tripled number of customers without any losses. The service_line2 productivity was low and only 3.5% of customers wanting service type 1 were served by this postal counter. Closing Service_line2 was done without any losses. Same situation can be seen in the case of Service_line4. Closing Service_line4 was done without any losses. The productivity of system can be increased by closing Service_lines2 and 4 and system will be still able to serve customers at a customer friendly waiting time. The major results obtained by the system provide the results that are helpful for making more decisions in the future.

The main objective of this paper was to design the application of the model simulating the queuing system of a fictional post office. The simulation model is functional and provides several statistics. This model also serves as a background for further research oriented to specific post office with specific input data. This kind of research requires a detailed analysis of a specific queuing system, identification of input parameters, their probability distribution, etc. An important phase in modelling the system is to build a model that matches the queuing system and creating it in simulation software. In the future, it is advisable to use Anylogic software for such research. Subject-oriented simulation experiments can result in optimization of the queuing system, new compilation of work schedules for post office employees, change in the number of postal counters or it can increase the system productivity.

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Kamil Krasuski - Stepan Savchuk

ACCURACY ASSESSMENT OF AIRCRAFT POSITIONING USING THE DUAL-FREQUENCY GPS CODE OBSERVATIONS IN AVIATION

This study publishes results of tests with regard to determination of the aircraft positioning accuracy by means of the GPS navigation in aviation. The research exploits the mathematical model of the linear combination "Ionosphere-Free" in order to designate the coordinates of an aircraft. The research uses the actual GPS code observations, recorded by a satellite receiver mounted in the Cessna 172, at the time of the experiment for the EPDE military aerodrome in Dęblin. The computations of the position of the Cessna 172 aircraft for the linear combination "Ionosphere-Free" were made in the APS Toolbox v.1.0.0. programme. Within evaluation of accuracy of the GPS positioning in aviation, the determined coordinates of the aircraft Cessna 172 from the APS programme were compared to an accurate reference position from the solution derived by the PPP measurement technique. In the research, the authors obtained an average positioning accuracy of approximately 5 m in the geocentric XYZ coordinates and approximately 4 m in the ellipsoidal BLh coordinates. In addition, the 3D-error parameter is lower than 7 m for the XYZ geocentric coordinates.

Keywords: *GPS, Ionosphere-Free linear combination, accuracy, PPP method, aviation*

1 Introduction

In the 21st century, the GNSS satellite technology became a common method of aircraft positioning in the field of air navigation and air transport. Development of modern GNSS global navigation systems, such as GPS, GLONASS, BeiDou, Galileo, QZSS Zenith and augmentation systems SBAS (EGNOS, SDCM, WAAS, MSAS, GAGAN, NAVIC) enabled their full operation and implementation in the process of determining the aircraft position. The framework of application, operation and implementation of the GNSS satellite technology in aviation has been clearly defined by the International Civil Aviation Organization (ICAO). The Annex 10 to the Chicago Convention currently allows the use of the GNSS satellite technique in aviation for the needs of performing air operations within the navigation systems of: GPS and GLONASS as GNSS satellite systems which are certified by the ICAO and augmentation systems: ABAS, SBAS, GBAS [1-3].

In the case of the global GNSS navigation systems, only the GPS and GLONASS satellite systems are certified for a general use in civil aviation. It should be emphasized that the GPS and GLONASS systems are fully operational and provide continuous satellite positioning for its users across the globe for 24 hours a day. Certification of the GPS and GLONASS navigation systems in civil aviation includes such parameters as accuracy, availability, reliability and continuity [4]. In accordance with the ICAO recommendation, the accuracy of determining the position of an aircraft with the use of the GPS navigation system must not exceed 17 m for navigation in the horizontal plane, and 37 m for navigation in the vertical plane [5]. Furthermore, the time synchronization error in the GPS system during a flight operation must not be worse than 40 ns (approximately 12 m). In addition, error of the GPS satellite's position in the orbit must not be greater than 30 m, whereas an error of determining the GPS satellite speed and acceleration must not exceed values of 0.006 m/s and 0.002 m/s^2, respectively. In turn, availability of the constellation of the GPS satellites during the flight operations should exceed 99%. The credibility parameter of the GPS system functioning in the civil aviation should exceed 99.79% across the whole globe. The likelihood of the lack of continuity of the navigation solution of an aircraft position by means of the GPS observation must not exceed $2 \cdot 10^{-4}$ per hour [6]. It should be mentioned that the criteria of the parameters of accuracy, availability, reliability and continuity are referenced to the standard SPS positioning service in the GPS navigation system [7]. Within the Standard Positioning Service, it is possible to use L1-C/A observation codes to determine the coordinates of an aircraft in the GPS system. It must be noted that the GPS satellites transmit the signal L1-C/A on the carrier frequency of 1575.42 MHz, using the code-division multiple access technique (CDMA) [8].

The main aim of this article is to determine the positioning accuracy of the aircraft Cessna 172 based on the GPS solution. An analysis of the accuracy of the aircraft positioning was carried out based on the actual navigation data from the GPS satellite system, registered by an airborne receiver Topcon HiperPro, mounted in an aircraft Cessna 172. The position of the Cessna 172 was

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determined based on the linear combination Ionosphere-Free for dual-frequency GPS code observations. The numerical calculations were carried out in individually developed software called Aircraft Positioning Software (APS) Toolbox, developed in the language environment Scilab 6.0.0.

2 Research method

The fundamental observation equation of the linear combination Ionosphere-Free, which facilitates the possibility of determining an aircraft position in the GPS satellite system, can be expressed as [9]:

$$P_3 = \alpha_1 P1 + \alpha_2 P2 = d + c\cdot(dtr - dts) + \\ + Trop + \mathrm{Re}l + M_{P3}, \tag{1}$$

where:
P_3- the "Ionosphere-Free" linear combination for the GPS code observations,
(α_1, α_2) - linear coefficients,
(P_1, P_2) - code observations at the 1st and 2nd frequency in the GPS system,
d - geometric distance between satellite and receiver, $d = \sqrt{(x - X_S)^2 + (y - Y_S)^2 + (z - Z_S)^2}$,
(x,y,z) - coordinates of the aircraft in XYZ geocentric frame,
(X_S,Y_S,Z_S) - satellite coordinates in GPS system,
c - light speed,
dtr - receiver clock bias correction,
dts - satellite clock bias correction,
$Trop$- tropospheric delay,
$\mathrm{Re}l$ - relativistic effect,
M_{P3}- multipath effect for the GPS code observations.

Coordinates of the aircraft from Equation (1) are determined using the least squares method in a stochastic model, as [10]:

$$\begin{cases} \mathbf{A}\cdot\mathbf{Qx} - \mathbf{dl} = \mathbf{v} \\ \mathbf{N} = \mathbf{A}^{\mathbf{T}}\cdot\mathbf{p}\cdot\mathbf{A} \\ \mathbf{L} = \mathbf{A}^{\mathbf{T}}\cdot\mathbf{p}\cdot\mathbf{dl} \\ \mathbf{Qx} = \mathbf{N}^{-1}\cdot\mathbf{L} \end{cases}, \tag{2}$$

where:
$\mathbf{Q_x}$- vector with unknown parameters,
$\mathbf{N = A^T \cdot p \cdot A}$ - matrix of the normal equations frame,
$\mathbf{A}$ - matrix of coefficients, matrix is full rank,
$\mathbf{p}$ - matrix of weights,
$\mathbf{L = A^T \cdot p \cdot dl}$ - vector of absolute terms,
$\mathbf{dl}$ - vector with difference between measurements and modeled parameters,
$\mathbf{v}$ - vector of residuals.

The determined aircraft coordinates from Equations (1) and (2) are physically referenced to the geocentric XYZ frame. Alternatively, there is a possibility to express aircraft coordinates in the ellipsoidal BLh frame. In this case, it is necessary to use a transformation between the geocentric XYZ frame and the ellipsoidal BLh frame in iterative solution, as shown below [11]:

$$B = arc\tan\left(\frac{z}{\rho} + \frac{\delta_1\cdot tgB_{i-1}}{\sqrt{\delta_2\cdot tg^2 B_{i-1}}}\right); \\ L = arc\tan\left(\frac{y}{x}\right);\ h = \frac{\rho}{\cos B} - R, \tag{3}$$

where:
(a,b)- semi-major and semi-minor axes of the ellipsoid frame, respectively,
e - eccentricity, $e = \sqrt{\dfrac{a^2 - b^2}{a^2}}$,
R - radius of curvature of the prime vertical, $R = \dfrac{a}{\sqrt{1 - e^2\cdot\sin^2 B}}$,
$\rho = \sqrt{x^2 + y^2}$,
$\delta_1 = \dfrac{a\cdot e}{\rho\cdot\sqrt{1 - e^2}}$,
$\delta_2 = \dfrac{1}{1 - e^2}$,
$i - 1$ - previous iteration,
(B,L,h) - geodetic coordinates of aircraft's position,
B - Latitude,
L - Longitude,
h - ellipsoidal height.

3 Research experiment

The numerical tests for the presented research method were performed for the actual navigation and GPS observation data, obtained from the airborne Topcon HiperPro receiver, mounted in an aircraft Cessna 172. The test flight by the Cessna 172 was executed over the military airport EPDE, in Dęblin. Duration of the flight was approximately one hour, with the maximum speed of the flight reaching 80 m/s. The geodetic Topcon HiperPro receiver worked in the kinematic mode, gathering the GPS data at a frequency of 1 s. In order to reduce the effect of multipath interference and radio disturbances, the Topcon HiperPro receiver was installed in the cockpit just behind the plexiglass. The GPS code observations, stored in the memory card of the geodetic receiver Topcon HiperPro, were used to reproduce the position of the aircraft Cessna 172 in the post-processing mode. The numerical calculations to determine the position of the Cessna 172 were made in the authors' original software APS (Aircraft Positioning Software) Toolbox v.1.0.0, which was fully developed in the Scilab 6.0.0. environment. For the purpose of the conducted numerical calculations, the configuration of the APS programme was set, as shown in Table 1.

4 Results and discussion

The determined Cessna 172 coordinates in APS programme, in the geocentric XYZ frame and in the ellipsoidal BLh frame, were compared to the actual reference trajectory of the aircraft flight in order to determine the accuracy of the GPS signal in aviation. The precise

Table 1 *Configuration of computations in the APS software*

Parameter	Configuration
GNSS system	GPS system
type of observations	code observations at the 1st and 2nd frequency in GPS system
type of RINEX file	2.10
source of satellite ephemeris data	precise ephemeris from the IGS service
source of satellite clock data	precise ephemeris from the IGS service
method of satellite position computation	9-degrees Lagrange polynomial
method of satellite clock bias computation	9-degrees Lagrange polynomial
effect of Earth rotation and time of pseudorange travelling through atmosphere	applied
relativistic effect	applied
troposphere source	Simple model
receiver clock bias	estimated
multipath and measurement noise	not applied
satellite and receiver phase center offset	based on ANTEX file from IGS service
Sagnac effect	Applied
Cut-off elevation	5^0
a priori standard deviation of pseudorange observations	1 m
positioning mode	kinematic
mathematical model of solution	least square estimation in iterative scheme
adjustment processing	Applied
maximum number of iterations in a single measurement epoch	N=10
number of unknown parameters	k=4, for each measurement epoch
number of observations	n>4, for each measurement epoch
interval of computations	1 s
initial coordinates of aircraft position	based on header of RINEX file
time of the GPS system	GPS Time
reference frame	IGS'08
format of output coordinates	geocentric XYZ and ellipsoidal BLh
local test of residuals	applied
global statistical test	test Chi-square
significance level	$(1-\alpha=0.95)$
DOP coefficients	estimated
coefficients value for HPL and VPL level	$k_{HPL}=6.18$ and $k_{VPL}=5.33$

reference flight trajectory of the Cessna 172 was determined using the PPP precision measurement technique. The PPP measurement technique uses the mathematical model of the linear combination equation - "Ionosphere-Free". The computations of the reference position of the aircraft Cessna 172 for the PPP measurement technique were made in the CSRS-PPP programme [12]. In the framework of the calculations performed in the CSRS-PPP programme, the authors used dual frequency P1/P2 code and L1/L2 phase observations from the airborne receiver Topcon HiperPro. The CSRS-PPP programme uses the IGS precise products such as SP3 precise ephemeris, precise satellite clocks CLK, the characteristics of the antenna phase center of the satellite/receiver ANTEX file format, and DCB hardware delay file format for the computations. The position of the Cessna 172 in the CSRS-PPP programme is expressed in the geocentric XYZ, as well as ellipsoid BLh coordinates, in the global frame IGS'08, whereas the scale of the reference time is the GPS Time. It is worth adding that the program CSRS-PPP allows an accurate determination of kinematic positioning for the aircraft with mean errors of coordinates at a level of approximately 10 cm [13].

Accuracy of the GPS code positioning for the presented research method in the APS programme was defined both in the geocentric XYZ coordinate frame and in the ellipsoidal BLh frame. The accuracy of the GPS positioning in geocentric XYZ coordinates is specified as [14]:

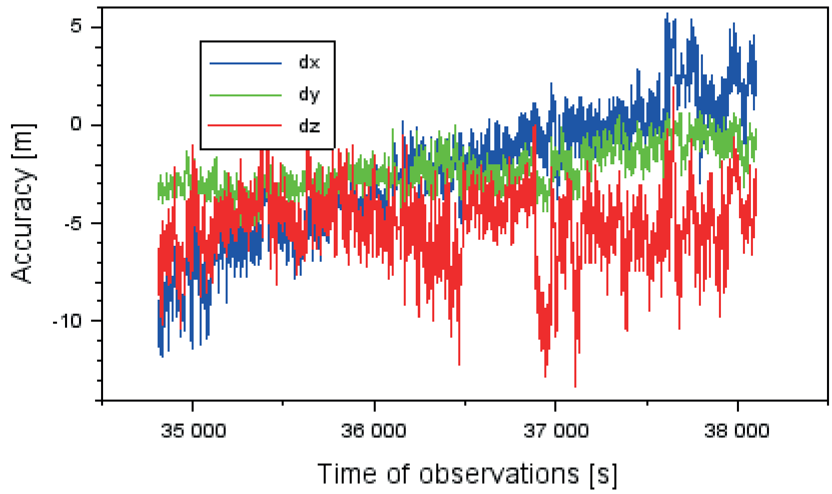

***Figure 1** Accuracy of the Cessna 172 aircraft positioning in the XYZ geocentric coordinates*

$$\begin{cases} dx = x - x_{PPP} \\ dy = y - y_{PPP} \\ dz = z - z_{PPP} \end{cases}, \quad (4)$$

where:
(dx,dy,dz) - accuracy of the GPS positioning in the XYZ geocentric coordinate frame,
x - coordinate of the aircraft along the X axis, determined based on Equation (1),
y - coordinate of the aircraft along the Y axis, determined based on Equation (1),
z - coordinate of the aircraft along the Z axis, determined based on Equation (1),
x_{PPP} - coordinate of the aircraft along the X axis, determined from the PPP measurement technique in the CSRS-PPP programme,
y_{PPP} - coordinate of the aircraft along the Y axis, determined from the PPP measurement technique in the CSRS-PPP programme,
z_{PPP} - coordinate of the aircraft along the Z axis, determined from the PPP measurement technique in the CSRS-PPP programme.

Figure 1 shows results of the GPS positioning accuracy in the geocentric XYZ coordinates for the linear combination "Ionosphere-Free", based on a solution in the APS programme. The positioning accuracy along the X axis in the GPS system for the receiver Topcon HiperPro ranges from - 11.8 m to + 5.7 m. In addition, the value of the average positioning accuracy along the X axis in the GPS system equals - 2.4 m. Moreover, the RMS error along the X axis is equal to 3.4 m. The positioning accuracy along the Y axis for the Topcon HiperPro receiver ranges from - 5.2 m to + 0.9 m. In addition, the value of the average positioning accuracy along the Y axis in the GPS system is - 2.3 m. Additionally, the RMS error along the Y axis is equal to 1.1 m. The positioning accuracy along the axis Z for the Topcon HiperPro receiver ranges from - 13.3 m to + 2.0 m. Moreover, the value of the average positioning accuracy along the Z axis in the GPS system is - 5.1 m. Furthermore, the RMS error along the axis Z is equal to 1.9 m. The span of the GPS positioning accuracy along the X axis is over 17.5 m, along the Y axis it is approximately 6 m, and along the Z axis it is over 15 m. It is worth noting that approximately 75% of the accuracy of GPS positioning results along the X axis are less than 0. On the other hand, approximately 97% results of the GPS positioning accuracy along the axis Y is less than 0. Moreover, approximately 99% results of the GPS positioning accuracy along the axis Z is less than 0. It can therefore be concluded that results obtained with regard to accuracy of the GPS positioning in the APS programme are lower than the readings of the aircraft Cessna 172 position in the PPP solutions in the CSRS-PPP programme.

Figure 2 shows another parameter of accuracy of the GPS positioning in the geocentric XYZ frame, in the form of the 3D-error. The 3D-error parameter specifies a shift in coordinates of the aircraft Cessna 172 between a solution in the APS programme and in the CSRS-PPP programme in the geocentric XYZ frame. The mathematical formula specifying the value of the 3D-error parameter can be determined as [15]:

$$3D - error = \sqrt{dx^2 + dy^2 + dz^2}\,. \quad (5)$$

Based on the obtained results, it is possible to observe that the value of the 3D-error parameter ranges from 1.2 m to 16.1 m. In addition, the average value of the 3D-error parameter equals 6.9 m. It is worth stressing that the value of the 3D-error parameter towards the end of the observation time decreases to a level below 10 m. The drop in the numerical value of the 3D-error parameter is relevant since it directly translates into the location of the aircraft in the three-dimensional space.

Figure 3 shows results of the GPS positioning accuracy in the ellipsoidal BLh coordinates for the linear combination "Ionosphere-Free" based on a solution in the APS programme. Accuracy of the GPS positioning in the ellipsoidal BLh coordinates is specified as [16]:

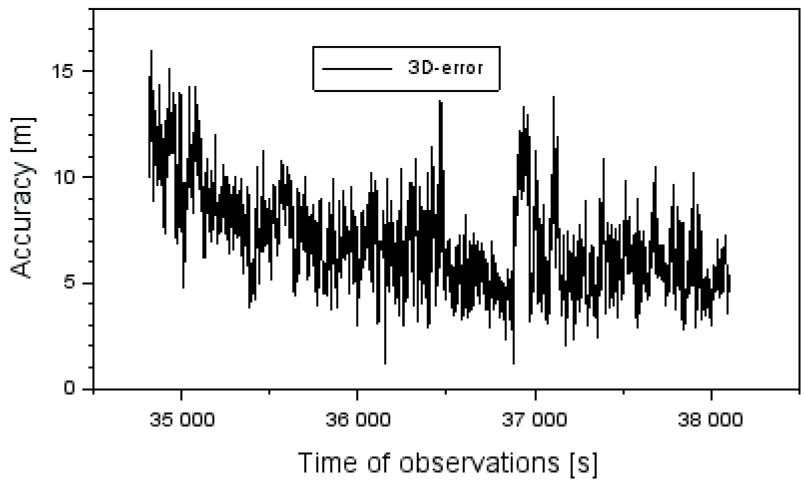

Figure 2 *Results of 3D-error parameter*

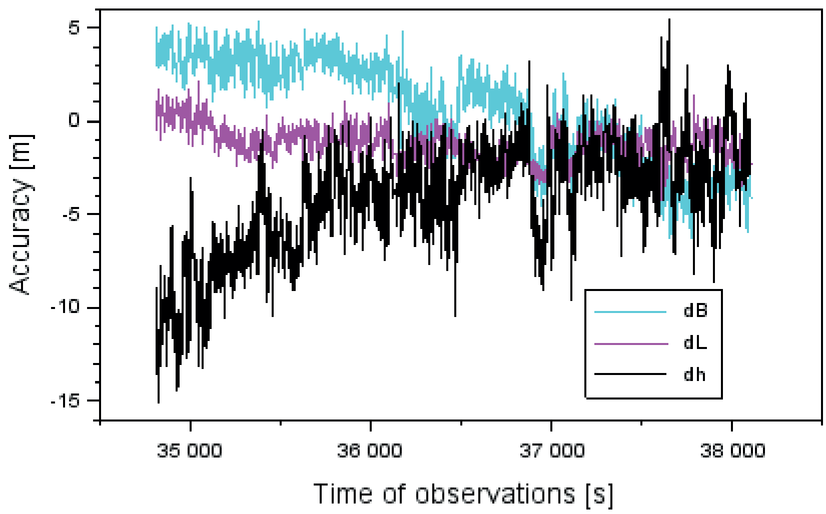

Figure 3 *Accuracy of the Cessna 172 aircraft positioning in the BLh ellipsoidal coordinates*

$$\begin{cases} dB = B - B_{PPP} \\ dL = L - L_{PPP} \\ dh = h - h_{PPP} \end{cases}, \qquad (6)$$

where:

(dB, dL, dh) - accuracy of the GPS positioning in the ellipsoidal BLh frame,

B - coordinate of the aircraft for the B component, determined based on Equation (3),

L - coordinate of the aircraft for the L component, determined based on Equation (3),

h - coordinate of the aircraft for the h component, determined based on Equation (3),

B_{PPP} - coordinate of the aircraft along the B axis, determined by the PPP measurement technique in the CSRS-PPP programme,

L_{PPP} - coordinate of the aircraft along the L axis, determined by the PPP measurement technique in the CSRS-PPP programme,

h_{PPP} - coordinate of the aircraft along the h axis, determined by the PPP measurement technique in the CSRS-PPP programme.

The positioning accuracy for the B component in the GPS system for the receiver Topcon HiperPro ranges from - 6.8 m to + 5.4 m. In addition, the average value of the positioning accuracy along the axis B in the GPS navigation system is + 0.6 m. Moreover, the RMS error along the axis B is equal to 2.7 m. The positioning accuracy for the component L, for the receiver Topcon HiperPro, ranges from - 4.2 m to + 2.2 m. Furthermore, the average value of the positioning accuracy along the axis L in the GPS navigation system equals - 1.2 m. In addition, the RMS error along the axis L is equal to 0.9 m. The positioning accuracy, for the component h for the receiver Topcon HiperPro, ranges from - 15.1 m to + 5.5 m. In addition, the average value of positioning accuracy along the axis h in the GPS navigation system is - 4.1 m. Besides, the RMS error, along the axis h, is equal to 3.1 m. It is worth stressing that only 38% of the GPS positioning accuracy findings, along the axis B, are below 0. Therefore, readings of the coordinate B in the APS programme are inflated in relation to results in the programme CSRS-PPP. On the other hand, approximately 90% results of the GPS positioning accuracy along the axis L are less than 0. Moreover, approximately 95% results of the GPS positioning accuracy along the h axis are less than 0. It can therefore be concluded that the obtained findings with regard to accuracy of the GPS positioning for the L and h components in the APS programme are too low in relation to the measurements of the aircraft Cessna 172 in the PPP solution, in the CSRS-PPP programme.

Based on the conducted investigations, it appears that the largest RMS error in the geocentric XYZ coordinates is along the X axis. On the other hand, the lowest RMS error in the geocentric XYZ coordinates is along the Y axis. In the coordinate ellipsoidal BLh frame, the largest RMS error can be observed for the coordinate h, while the lowest one is along the axis L. The value of the RMS parameter results directly from the obtained results in the accuracy of GPS positioning, in the geocentric XYZ frame or in the ellipsoidal BLh frame, respectively. In the case of air operations, it is essential to monitor changes of coordinates of an aircraft flight trajectory, on a continuous basis. Regardless of the selected method (or technique) of the GPS positioning in aviation, the key issue is credibility of the determined aircraft coordinates. Thus, in aviation research conducting an objective control of the navigation parameters recorded by sensors, during the execution of the flight operations, plays a tremendous role. Mounting a GPS receiver on board an aircraft allows monitoring changes in the navigation position, in real time and post factum. For this reason, it is important to develop navigation applications for control calculations of an aircraft position, such as the APS programme, from the beginning.

The presented research method was applied in papers by one of this paper co-authors. For example, in paper [17], the Iono-Free linear combination was utilized for recovery of the aircraft position based on dual-frequency GPS code observation in the APS software. In that paper the parameters such as: aircraft trajectory, receiver clock bias, DOP coefficients, mean errors of aircraft ellipsoidal coordinates, Chi-square statistical test, HPL and VPL integrity terms were presented and described. In the next paper [18], the Iono-Free linear combination was utilized for recovery of the aircraft position based on the dual-frequency GPS code observation in gLAB software package. In that paper, the parameters such as: aircraft trajectory, DOP coefficients, mean errors of aircraft ellipsoidal coordinates, MRSE term, HPL and VPL integrity terms were analyzed and shown. In another article [19], the Iono-Free linear combination for the BSSD module in the APS software package was applied for determination of the aircraft position based on the GPS data. In that paper the parameters such as: DOP coefficients, mean errors of aircraft ellipsoidal and geocentric coordinates, MRSE term, HPL and VPL integrity terms, Chi-square statistical test were estimated and presented.

5 Conclusions

The article presents and describes results of the scientific research on use of the dual-frequency GPS code observations in aircraft positioning. In particular, the study focuses on determination of accuracy of the GPS positioning in air transport. During the research, the authors used a linear combination “Ionosphere-Free” as a mathematical model to determine aircraft coordinates. The source materials for the scientific research used the raw P1/P2 code observations in the GPS system from the Topcon HiperPro receiver. The Topcon HiperPro geodetic receiver was installed on board the Cessna 172, which performed a test flight over the EPDE military airport in Dęblin. The collected code P1/P2 observations in the GPS system allowed performing numerical calculations in order to establish coordinates of the Cessna 172. The numerical calculations of the Cessna 172 position were made in the APS v.1.0.0 software programme. For the purpose of determining the GPS positioning accuracy in aviation, the authors made a comparison of the determined coordinates from the APS reference position of the Cessna 172. The precise flight trajectory of the Cessna 172 was determined based on the PPP measurement technique in the CSRS-PPP programme. Based on computations, it was found that the accuracy of the GPS positioning in aviation is:

- between - 13.3 m and + 5.7 m in the geocentric XYZ coordinates,
- between - 15.1 m and + 5.5 m in the ellipsoidal BLh coordinates.

In addition, the accuracy measurements of determining the position in the form of the RMS parameter are as follows:

- less than 3.4 m in the geocentric XYZ coordinates,
- less than 3.1 m in the ellipsoidal BLh coordinates.

The obtained research findings indicate a problem with the low GPS positioning accuracy in aviation. The problem is closely related to the choice of a positioning method presented in this work. The dual-frequency GPS code observations have high measurement noise at the carrier frequency L1 and L2. Moreover, in the case of an application of the dual-frequency GPS code observations in navigation computations, there appears an issue of eliminating an ionospheric delay, which directly affects determination of the horizontal coordinates of an aircraft. The authors plans to conduct research into monitoring the ionospheric status during the air operations in the airspace of Poland. Moreover, in the future additional research is planned aimed at exploiting the GLONASS code observations in aircraft positioning in aviation.

Acknowledgement

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Annex - Nomenclature

The abbreviation	The full name
GLONASS	Globalnaja Nawigacionnaja Sputnikowaja Sistiema / Global Navigation Satellite System
GPS	Global Positioning System
BSSD	Between Satellite Single Difference
ICAO	International Civil Aviation Organization
GNSS	Global Navigation Satellite System
ABAS	Aircraft Based Augmentation System
SBAS	Satellite Based Augmentation System
GBAS	Ground Based Augmentation System
EPDE	ICAO airport code
APS	Aircraft Positioning Software
IGS	International GNSS Service
ANTEX	Antenna Exchange Format
RINEX	Receiver Independent Exchange System
HPL	Horizontal Protection Level
VPL	Vertical Protection Level
DOP	Dilution of Precision
MRSE	Mean Radial Spherical Error
PPP	Precise Point Positioning
XYZ	Geocentric coordinates
BLh	Latitude, Longitude, ellipsoidal height
BeiDou	Chinese satellite navigation system
Galileo	European satellite navigation system
QZSS Zenith	Japanese regional satellite navigation system
EGNOS	*European Geostationary Navigation Overlay Service*
SDCM	The System for Differential Corrections and Monitoring
WAAS	The Wide Area Augmentation System
MSAS	The Multi-functional Satellite Augmentation System
GAGAN	The GPS Aided Geo Augmented Navigation
NAVIC	Indian Regional Navigational Satellite System
SPS	Standard Positioning Service
C/A	Coarse Acquisition
CDMA	Code-Division Multiple Acces
CSRS-PPP	Canadian Spatial Reference System - Precise Point Positioning
DCB	Differential Code Biases
RMS	Root Mean Square

Miroslava Mikusova - Jamshid Abdunazarov - Joanna Zukowska - Alisher Usmankulov

DESIGNING OF PARKING SPACES TAKING INTO ACCOUNT THE PARAMETERS OF DESIGN VEHICLES IN RUSSIA

Nowadays, in all the cities, there is an acute problem of a lack of parking spaces. The number of vehicles are becoming more and more larger, not only in megacities, but in small cities of the country, as well and there are no more parking places - the pace of solving the problem is several times slower than the rate of the transport growth among the citizens. The article is dedicated to the determination of the optimum sizes parking place for designing vehicles on a parking space, which is an element of the roads. The optimum amount parking places are determined on examples of the passenger cars and trucks. The results of research on dimensioning of parking spaces and recommendations to use the results for design of objects of transportation infrastructure are presented. According to the research, authors included the term "design vehicle" and gave its definition. The authors developed a template for 7 types of design vehicles and their sizes and also recommended sizes for longitudinal parking for each of their design vehicles. The optimum parking plot angles are determined, as well.

Keywords: *trajectory, parking space, design vehicle, software Auto TURN, turning radius of vehicles*

1 Introduction

Trends in the size of cars in traffic flow and an acute shortage of parking space require a more careful attitude towards design of the size of a parking place and parking space. Unfortunately, design of parking does not take into account the composition of the traffic flow that takes shape on a specific road, transport infrastructure object (requirements are obvious here, in the USA where the size of cars is larger than in Europe, the size of parking space is larger), duration of parking is not taken into account; short-term parking near shops, banks, etc., requires more space for manoeuvring upon arrival and departure from the parking space than during the long-term parking). The most acute problem manifested itself when a ban was imposed on the transit movement of vehicles weighing more than 12 tons during the daytime along the Moscow Ring Road (Resolution of the Mayor of Moscow, dated November 15, 2012 No. 650-PP “On Amendments to Legal Acts of the Government of Moscow” [1]). According to the Moscow mayor’s office, more than 150 thousand trucks with a maximum weight of more than 3.5 tons are moving through the city streets during the daytime. About 40 thousand trucks are arriving daily from other regions.

At the Moscow Ring Road, large trucks make up 30% of the flow, half of which are transit and do not serve the needs of the capital [2]. At that time, there was no experience in designing parking place for cars arriving in Moscow or following in transit.

In the domestic regulatory and procedural documents, the dimensions of parking spaces for the road infrastructure facilities are defined in the Methodological Recommendations of the SRC MDRS MIA [3], IRM 218.4.005-20101 и SS Р 52289-20042. The dimensions in these documents were copied from the Handbook for Automobile Transportation and Traffic Management [4] published in the USSR in 1981, which, in turn, was a translation of the American Road Traffic Management Handbook of 1965 and the recommendations given in the third edition of the Transportation and Traffic Engineering Handbook [5].

Requirements for parking geometry in regulatory documents contain ambiguous, sometimes contradictory information that may adversely affect the level of the road safety. Thus, in the “Methodological recommendations on the design and equipment of highways to ensure traffic safety” [6], the turning radius of a passenger car is 8 m and for a truck is 9-12 m. When approximate calculation of the total area of coverage in parking place, including the area of manoeuvring and parking is done, it is recommended to proceed from the average area per one passenger car of 25 m^2 and on a truck 40 m^2. At the same time, in the album of typical projects “Cross-sectional profiles of highways passing through settlements” (TP503-0-47.86) [7], the average parking area for a truck should be 92.4 m^2, not 40 m^2, as stated in the methodological recommendations. The dimensions of the parking space, given in the Regulations for the placement of multifunctional zones of road service on roads [8-10], take into account the size of modern cars,

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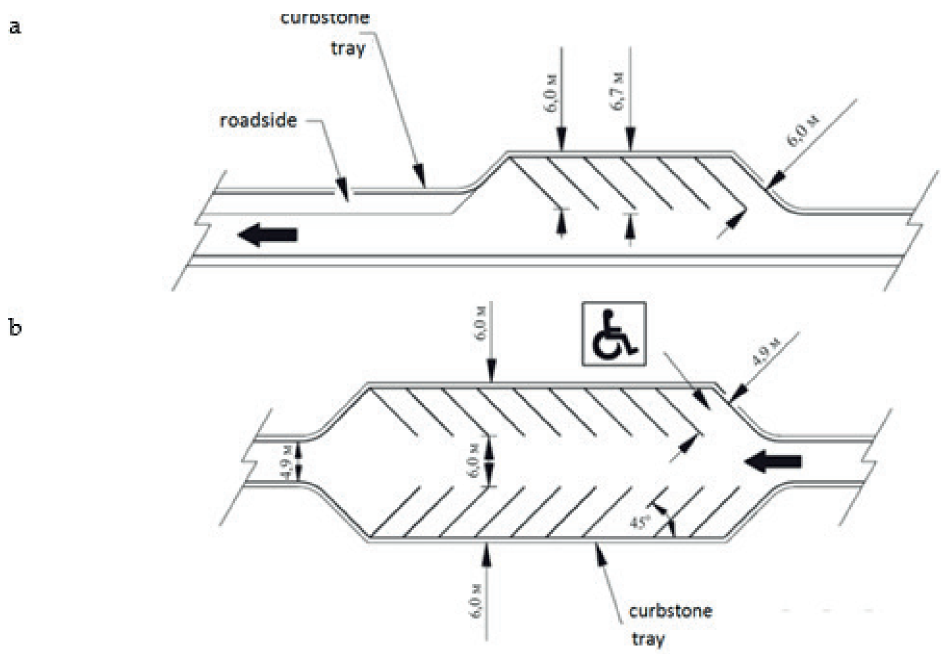


Figure 1 *Schemes of planning of parking spaces for passenger cars with one-sided (a) and two-sided (b) placement*

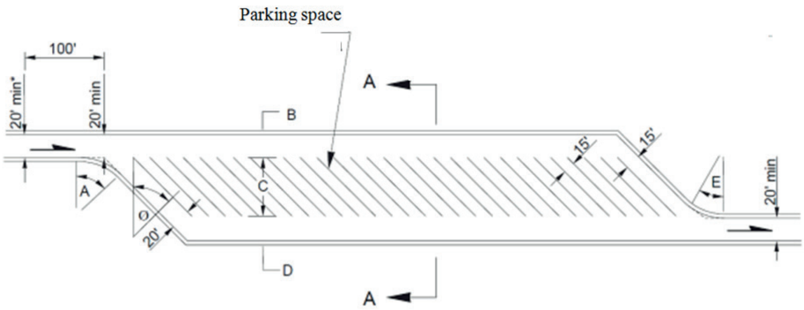


Figure 2 *The fundamental planning of placement of the parking spaces for trucks, recommended in the US:*
ϕ - 30-45°; A - 25.9-3.0.5 m; B- 9.1-13.7m; C - 15.2-18.8 m; D - 9.1-13.7 m; E - 3.0.5-3.5.0 m.

but this is not enough to develop a complete planning solution, since the parking manoeuvres are not taken into account, and only the dimensions of the parking space are given.

The situation in the regulatory documents of Uzbekistan is similar. Since Uzbekistan was part of the USSR, it uses the same technical document that Russia used before, [3]. At the moment, technical documents, recommending the size of design vehicles, taking into account the current flow in the republic, have not been adopted. For example, the parameters (sizes) of trucks that were produced in the 70s of the last century are still being used. The situation is similar in terms of the size of the parking spaces. At the moment, the republic uses the regulatory document, which requires updating based on time. The passenger car and truck placement schemes, used in the United States and the dimensions of parking spaces shown in Figure 1, provide more complete information. The planning solution for placing the parking spaces for trucks, which provides the simplest conditions for entering and leaving a parking space, recommended in the USA, is shown in Figure 2. The sizes on the scheme, presented in Figure 3, correspond to a parking angle of 45°, while it is indicated that at angles of 30°, the width of the passages can be reduced to 6.0 m and the width of each parking space - by 30 cm. For large trucks, the length of the longitudinal parking space must be at least 41 m and width 5.2 m. The same values are specified in the regulations of the United Arab Emirates for large trucks on parking spaces.

At the Department of Survey and design of roads MADI a research to justify the size of parking spaces for vehicles, taking into account the characteristics for modern traffic on the roads of the Russian Federation, has been conducted. The studies were conducted on category 1b roads, as well as on city parking lots.

This research work included: monitoring parking manoeuvres, studying the real situation when setting up parking spaces and modelling parking manoeuvres of passenger cars and trucks, using the Auto TURN software, which allows simulating the movement and manoeuvring of vehicles at speeds up to 60 km/h, and also to model the three-dimensional movement on a 3D surface, localize modelling for various groups of vehicles; graphically represent the dynamic dimensions indicating the dynamic dimensions of the vehicles (external and internal wheels, characteristic points of the body); create vehicle reversal

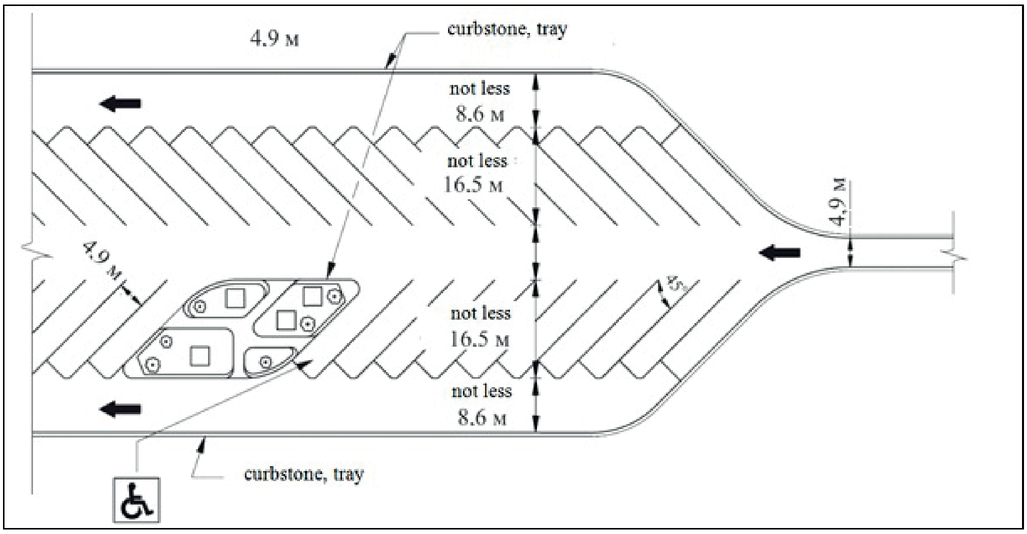


Figure 3 *Scheme of parking spaces for trucks*

patterns [11]. The AutoTURN is a CAD software released for the AutoCAD, MicroStation, BricsCAD platforms, developed and marketed by Transoft Solutions Inc. Among many things, it analyzes and models the maneuvering of a vehicle along a path.

The parking space for vehicles includes parking space for a vehicle and a manoeuvring area, designed for the entrance to parking spaces, exit and setting cars. The dimensions of the parking space must ensure unhindered entry, opening the doors of vehicles, unloading or loading luggage, and then unimpeded exit without hitting other vehicles.

The dimensions of the car parking space determine its type and size (length, width, turning radius of the inner rear wheel, overhang, base and gauge). To be able to bypass and open the doors of the car, the parking dimensions should be 0.5 m larger than the corresponding dimensions of the designing vehicles [12].

The "Methodological guidelines for design and equipment of highways to ensure traffic safety" [13], indicated that parking at large recreation areas, at roadside catering establishments, motels and campgrounds should be placed between the highway and buildings with vehicle separation by types and sizes. Parking areas for trucks and passenger cars should be demarcated and a separate entrance to the appropriate temporary parking area should be provided for each type of vehicle.

In this case, passenger cars and buses are recommended to be on the left-hand side and trucks on the right in the direction of travel.

It is recommended to place the parking of trucks parallel to the axis of movement, while parking of passenger cars mainly should be arranged according to an oblique angle at an angle of 45-60°. For long stays in the parking place, as well as in cramped conditions, when the parking place has one exit, it is recommended to install vehicles perpendicular to the direction of the axis of movement. Recommendations are given for the designation of the average area of coverage for one vehicle, taking into account the area of the exit and entry zones and the area of the parking space itself.

Due to increase in the dynamic characteristics of vehicles, the requirements for the construction and design of roads are being improved. During the roads designing, it becomes necessary to introduce the concept of a "design vehicle". This term is defined differently. "A design vehicle is a vehicle used to determine the geometrical parameters of roads (minimum turning radii of the intersection at one level, turning radii, roundabout) affecting safety, capacity and cost of the intersection. This is a conditional transport unit, the parameters of which are used in the calculations of the pavement and its elements. A design vehicle is such a car, the mass, dimensions and dynamic qualities of which are used when designing a road. Parameters of the design vehicle, such as dimensions and the minimum turning radius, should be the same for majority of vehicles of the same class, which are supposed to be used for the movement of the designed road".

During the roads and parking spaces designing, it becomes necessary to determine the width of the path of overhang, the size of the manoeuvres space, and geometric parameters. This in each case requires the construction of the dynamic dimension of the design vehicles, which is a time-consuming process (especially for the road trains) and not it is sufficiently mastered by designers.

The lack of systematic reference material on these issues is often the cause of unreasonable design decisions, which either lead to an overestimation of the estimated costs of facilities or do not provide normal operating conditions for vehicles.

2 Materials and methods

To determine the width of the manoeuvring of parking spaces, the authors took into account the minimum turning radius of the design vehicle and its dynamic clearance. To do this, studies have been conducted that allowed to

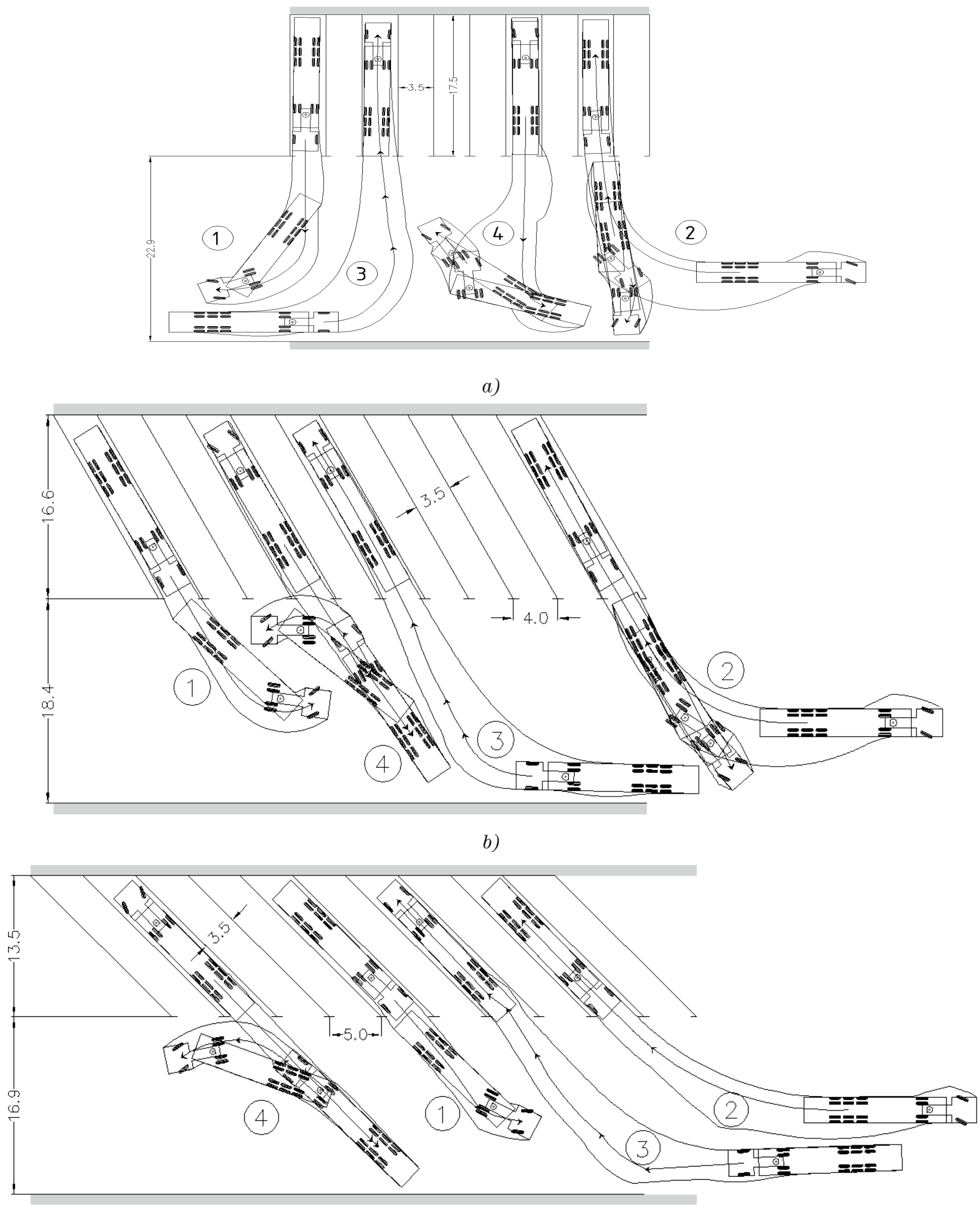
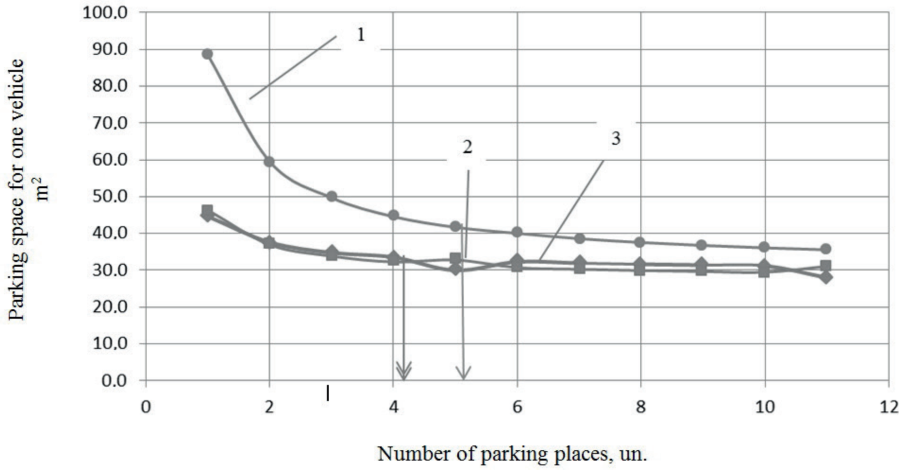


Figure 4 *Manoeuvring schemes for a train (16.5 m²) in a parking: a) the location of the parking space at an angle of 90°; b) the location of the parking space at an angle of 45°; c) the location of the parking space at an angle of 60° (1-way forward; 2- backing; 3- forward ride; 4 - reversing)*

determine these characteristics [14-16]. In the study, the width of the passage was determined as follows. When designing the parking space and the entrance of vehicles at parking spaces, the following schemes and provisions were applied in the calculations:

1 - The road train leaves the parking space in the forward direction;
2 - Auto train drives backward in a parking space;
3 - Road train drives forward;
4 - The road train leaves the parking space in reverse.

It was found that for reversing a large manoeuvring lane is needed than in other variants. This manoeuvre is a common parking method for the road train drivers. With this in mind, the width of the manoeuvring strip was determined.



a)

b)

Figure 5 *The dependence of the area of parking space on the number of parking spaces for passenger cars: a) and for a train 16.5 m long; b) when set at the corners: 1 - 90°; 2 - 60°; 3 - 45°*

The design vehicle made a manoeuvre at the location of a parking space at an angle of 90°, 60° and 45° (see Figure 4). After each manoeuvre, the parking length, manoeuvring lane, and parking width were determined.

Studies have shown that for one passenger car, taking into account manoeuvring, 28.7 m^2 of parking space is needed. For a road train length of 16.5 m, this value is 143.1 m^2 of area.

From Figure 5 it follows that with more than five parking spaces the area of parking space for one vehicle does not increase (depending on the angle). When the parking space is located at an angle of 90° and if there are less than 5 parking spaces in the parking, the parking space is reduced by one car. At the location of parking spaces at angles of 60° and 45°, the indicator is 4 parking spaces. Similar values are obtained for cars and for trucks. Proceeding from this, it can be concluded that, when parking places at an angle of 90°, designing less than five parking spaces is ineffective for any type of car and if placed at angles of 60° or 45°, up to four parking spaces are considered ineffective.

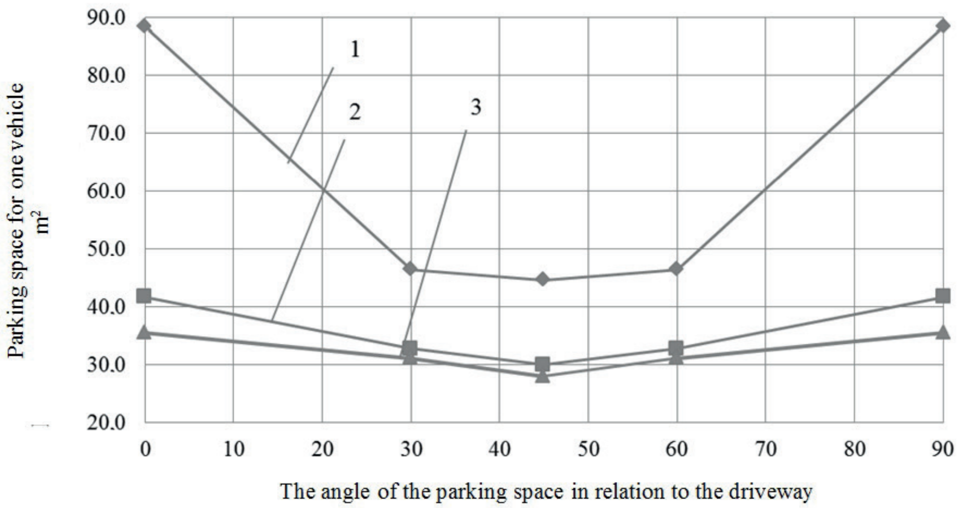
From Figure 6 it follows that at the location of parking spaces at an angle of 45° less parking space is required than at an angle of 60° or 90°. These values do not affect the number of parking spaces; moreover, these values are the most effective indicator when manoeuvring cars on the parking site.

3 Results and discussion

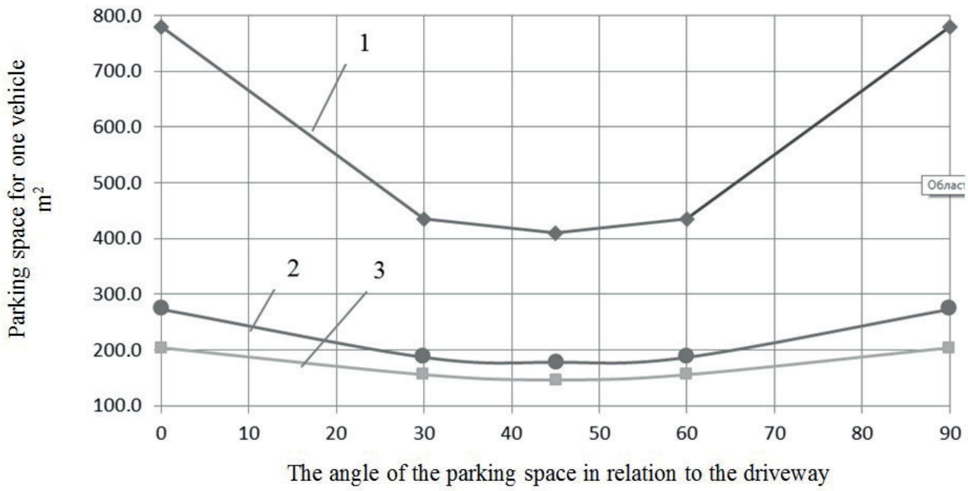
Based on the above data, one can draw the following conclusions:

1. Less than 5 parking places at an angle of 90° are economically inefficient for any type of vehicles;
2. When located at angles of 60° or 45°, up to 4 parking places are considered to be economically inefficient.

The following types of design vehicles were recommended as the most frequently encountered on the roads for Russian Federation: passenger car (P); city bus (CB); bus (B); articulated bus (AB); truck (T); road train consisting of truck tractor and semi-trailer (A16); road train consisting of a truck and a trailer (A20). The main dimensions of the specified design vehicle are given in the Table 1 with a template for the design of curves in the plan with the minimum radius of the design vehicle: Figure 7



a)



b)

Figure 6 *The required parking area at different angles of installation of vehicles and parking capacity: 1 - one vehicle; 2 - 5 vehicles; 3 - 11 vehicles [a) for passenger cars; b) for road trains with a length of 16.5 m]*

Table 1 *Recommended size of the design vehicles*

Type of design vehicles	Designation		Wheelbase, m	Dimension, m			
				general		overhang	
	RD1)	TR2)		length	width	front	rear
Passenger car	P	L	2.90	4.90	1.90	0.90	1.10
City bus	CB	M_2	6.20	12.0	2.50	2.75	3.05
Bus	B	M_3	6.90/1.30	15.0	2.50	2.60	4.20
Articulated bus	AB	M_3	5.96/6.05	18.4	2.55	2.68	3.71
Truck	T	N_3	6.80	12.0	2.50	1.50	3.70
Road train	A16	N_2+O_4	3.80/7.02	16.50	2.50	1.43	2.98
Road train	A20	N_3+O_4	6.80/4.30	19.80	2.50	1.50	0.70

Note:
RD1) - vehicle designation adopted in the article.
TR2) - designation of cars in accordance with the Technical Regulations "On the safety of wheeled vehicles" (approved by the decision of the Commission of the Customs Union of 9 December 2011 No. 877)

Table 2 *Minimum turning radius of the design vehicle*

Type of design vehicles	Minimum turning radius, m	Minimum outer radius, m	Minimum inner radius, m
Passenger car (P)	6.55	6.85	4.42
City bus (C)	9.20	10.54	5.40
Bus (B)	10.32	11.52	6.40
Articulated bus (A)	13.12	14.21	10.10
Truck (T)	11.07	11.82	6.15
Road train (A16)	9.69	10.19	6.20
Road train (A20)	12.06	12.63	8.50

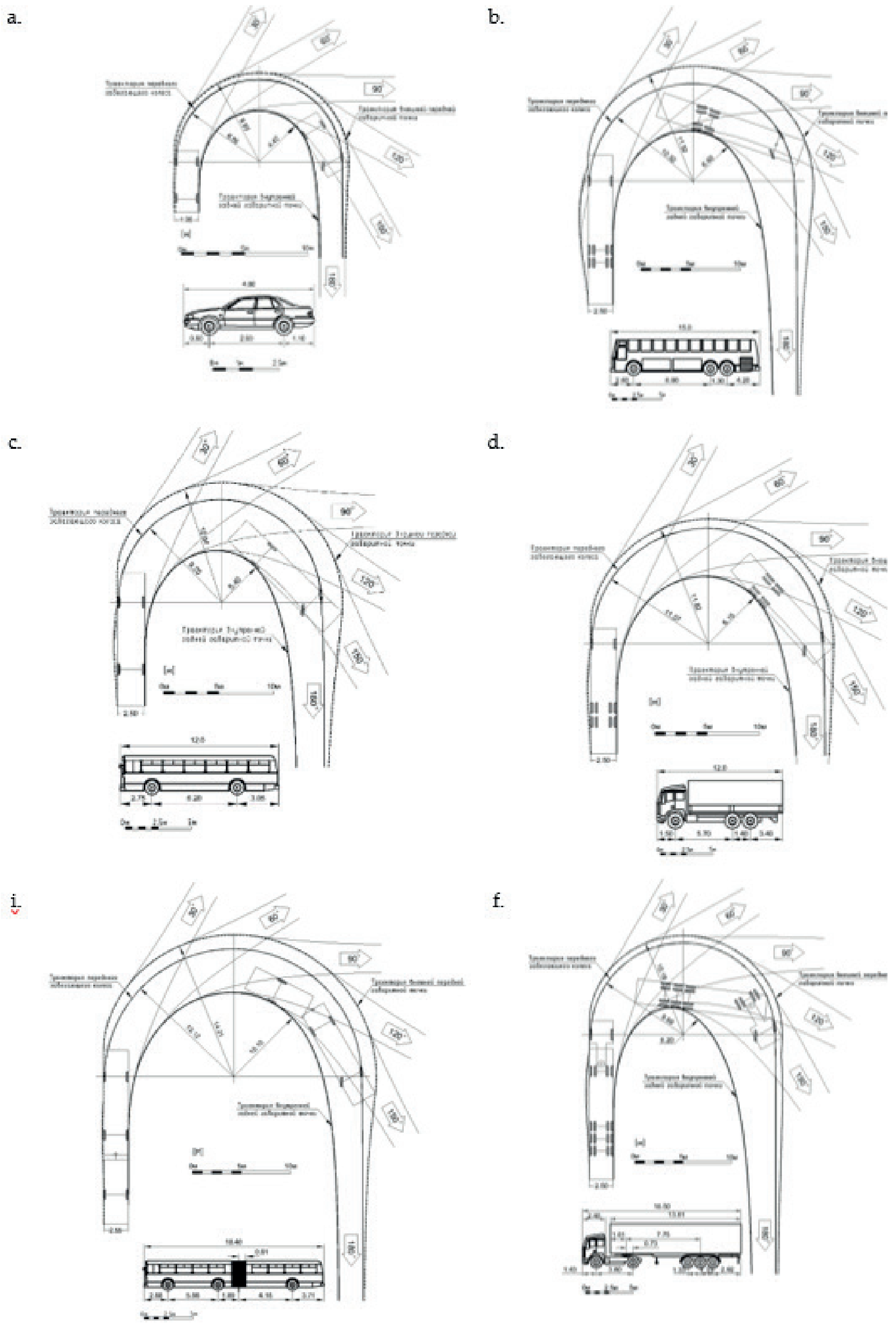


Figure 7 *Template for the design of curves in the plan with the minimum radius of the design vehicle: a) passenger car (P); b) city bus (CB); c) bus (B); d) truck (T) i) articulated bus (AB); f) road train (A16)*

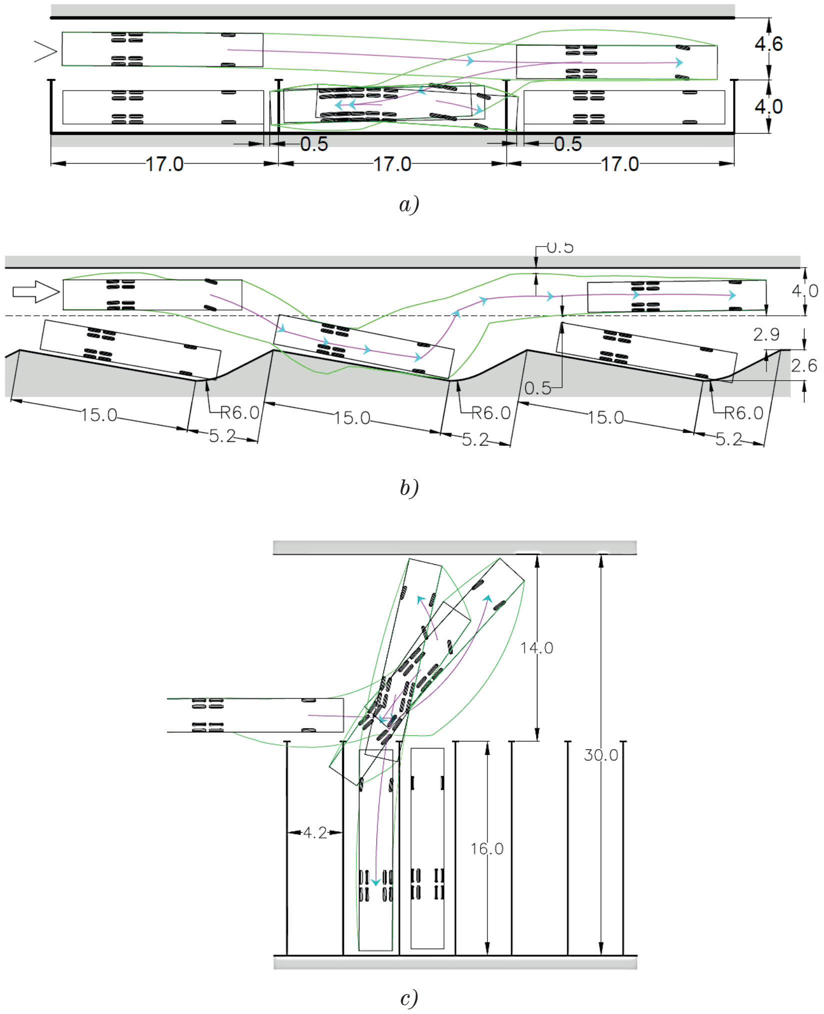


Figure 8 *Scheme and dimensions of parking spaces for bus: a) when parallel; b) saw tooth; c) perpendicular placement in relation to the driveway or manoeuvring zone. A similar scheme is proposed for other type of buses*

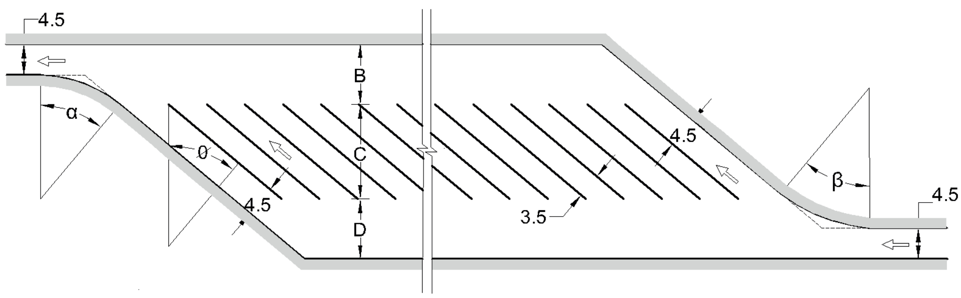


Figure 9 *Elements of breakdown of parking space for trucks α - β - parking angle; Ø - vehicle installation angle; B - D - manoeuvring strip; C - parking module length*

[17], the minimum turning radius - in the Table 2. Scheme and dimensions of parking spaces for bus are given in Figure 8.

The resulting sizes of parking spaces and the scheme of their breakdown are given in Table 3. Recommended lengths of parking spaces for longitudinal placement of design vehicles are presented in Table 4. Considering the foreign experience of organizing parking spaces for large-sized vehicles, which provides for entry and exit to parking without reversing (Figure 9), as a result of research, it is recommended to take the dimensions of parking spaces in accordance with values in Table 5.

Table 3 *Dimensions and average areas of one parking space*

Vehicle installation angle, degree	Sizes of elements, m									Average area for 1 vehicle, m^2	
	a	b	c	d	e	f	g	h	i	without maneuvering	with maneuvering
1	2	3	4	5	6	7	8	9	10	11	12
One-way car parking (P)											
90	5.0	7.0	17.0	11.5	0.5	6.0	2.5	2.5	0.5	12.5	28.7
60	5.2	4.2	14.6	8.9	0.5	3.2	2.5	2.9	0.5	15.1	25.8
45	4.8	4.0	13.6	8.3	0.5	3.0	2.5	3.5	0.5	16.8	29.0
Two-way car parking (P)											
90	5.0	8.0	18.0	12.5	0.5	7.0	2.5	2.5	0.5	12.5	22.5
60	5.2	5.2	15.6	9.9	0.5	4.2	2.5	2.9	0.5	15.1	22.6
45	4.8	5.0	14.6	9.3	0.5	4.0	2.5	3.5	0.5	16.8	25.5
Truck Parking (T)											
90	13.0	16.1	42.1	28.6	0.5	15.1	3.5	3.5	0.5	45.5	100.1
60	11.8	12.4	36.0	23.7	0.5	11.4	3.5	4.0	0.5	47.2	94.8
45	10.5	8.7	29.7	18.7	0.5	7.7	3.5	5.0	0.5	52.5	93.5
City bus parking (CB)											
90	13.0	16.1	42.1	28.6	0.5	15.1	3.5	3.5	0.5	45.5	100.1
60	11.8	12.4	36.0	23.7	0.5	11.4	3.5	4.0	0.5	47.2	94.8
45	10.5	8.7	29.7	18.7	0.5	7.7	3.5	5.0	0.5	52.5	93.5
Bus parking (B)											
90	16.0	19.0	51.0	34.5	0.5	18.0	3.5	3.5	0.5	56.0	120.7
60	14.3	16.1	44.7	29.9	0.5	15.1	3.5	4.0	0.5	57.2	119.6
45	12.4	11.7	36.5	23.6	0.5	10.7	3.5	5.0	0.5	62.0	118.0
Articulated bus parking (AB)											
90	19.5	25.1	64.1	44.1	0.5	24.1	3.5	3.5	0.5	68.3	154.3
60	17.3	20.3	54.9	37.1	0.5	19.3	3.5	4.0	0.5	69.2	148.4
45	14.9	18.5	48.3	32.9	0.5	17.5	3.5	5.0	0.5	74.5	164.5
Road train parking (A16)											
90	17.5	23.9	58.9	40.9	0.5	22.9	3.5	3.5	0.5	61.3	143.1
60	16.6	18.9	52.1	35.0	0.5	17.9	3.5	4.0	0.5	66.4	140.0
45	13.5	17.4	44.4	30.4	0.5	16.4	3.5	5.0	0.5	67.5	152.0
Road train parking (A20)											
90	21.0	33.0	75.0	53.5	0.5	32.0	3.5	3.5	0.5	73.5	187.2
60	18.6	23.8	61.0	41.9	0.5	22.8	3.5	4.0	0.5	74.4	167.6
45	16.0	21.1	53.1	36.6	0.5	20.1	3.5	5.0	0.5	80.0	183.0

Table 4 *The length of parking spaces for longitudinal design vehicles*

Design vehicle	Passenger car (P)	Truck (*T*)	Buses			Road Train	
			(CB)	(B)	(AB)	(A16)	(A20)
Parking space length, m	6.0	14.0	14.0	17.0	22.5	20.0	24.0

Table 5 *Sizes of parking spaces at different corners of the parking of trucks*

Set angle, degree			Sizes of parking spaces, m (see Figure 9)		
Ø	α	β	B	C	D
			A16		
30	30	30	7.5	12.0	7.5
35	35	35	8.5	13.0	8.5
40	40	40	8.7	13.5	8.7
45	45	45	9.5	15.5	9.5
			A20		
30	30	30	8.0	13.0	8.0
35	35	35	9.0	15.5	9.0
40	40	40	9.2	16.5	9.2
45	45	45	10.0	17.7	10.0

For highways, where trucks and road trains predominate as part of the traffic flow, it is recommended to the plan parking spaces with a transverse arrangement so that trucks do not need the turning manoeuvre or movement with minimum radii. Design of diagonal parking may vary depending on the angle at which the vehicles are located. To determine the size of the diagonal parking spaces for trucks, the authors created a design vehicle model and modelled the movement path of the design vehicle and determined the dynamic size, as well. With this in mind, the main dimensions of the parking lot were determined (Figure 9). Using the above approach, the diagonal parking sizes were determined at an angle from 30° to 45°. The planning of the parking space includes the following actions: alternative placement of parking spaces within the parking lot, modelling using the dynamic dimensions of the design vehicle of entrances to the parking space and exits. A necessary element of the traffic organization in the parking lot and design of the parking space, is organization of unimpeded passage of vehicles pass parking spaces with a width of 4.5 meters. The minimum radius for entering the parking lot should be at least 26 m and at the exit - at least 30 m. Dimensions of the parking spaces at different parking angles are presented in Table 5.

4 Conclusions

During the studying of the parking lots sizes the authors found that the previously adopted regulatory documents recommended dimensions for the existing traffic flow in the twentieth century. Regulatory documents contained ambiguous, sometimes contradictory information, which is contrary to objectives of the road safety and its convenience. Dimensions of the parking space, recommended by the author, differ from the current regulatory documents in the direction of reducing the area for a parking space. This is due to the fact that in modern vehicles dynamic indicators are optimized and require less space for manoeuvring.

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Irwanda Wisnu Wardhana - Dhani Setyawan - Khairunnisah

DETERMINANTS OF LABOR MARKET IN JAKARTA METROPOLITAN AREA: A SURVIVAL ANALYSIS OF COMMUTERS

This study aims to assess the determinants of the labor market in the Greater Jakarta Area (Jabodetabek) with a population of 27.9 million (2010 census) and growth rate of 3.6 percent per annum over the period 2000-2010. With a total area of 4,384 square kilometers (1,693 sq mi), the city has a very high population density of 14,464 people per square kilometer (37,460/ sq mi), while the metro area has a density of 4,383 people/sq km (11,353/sq mi). The paper employs the survival regression analysis by incorporating attributes of commuter, namely gender, age, distance, travel time, wages, stress, education level, double income households and home ownership. The area consists of Jakarta as the receiving labor market and eight municipalities and regencies as labor suppliers. The study utilizes a cross-section data from a commuter survey with more than 4,000 respondents participated using different modes of land transport. The results reveal that some determinants have influenced commuters' resiliency and their willingness to participate in the receiving labor market. This study found that gender, distance, wages and home ownership do not affect the respondent's decision whether to stay or quit as commuters. On the other hand, the fittest model exhibits that age, education level, stress, travel time and double income households have significant effects on individual's decision to stay or quit as a commuter. It is found that gender, distance, wages and home ownership do not matter for respondent's decision on whether to stay or to quit as commuters. The model exhibits that age, education level, stress, travel time and double-income household have significant effects on an individual's decision to stay or quit as a commuter. Education level has a positive effect; on the other hand, age, stress, double-income household and travel time have a negative effect. The policy implications for improving the labor supply provision and some contested policy options are suggested, such as the provision of affordable housing in Jakarta, the improvement of commuting enjoyment, the establishment of child care facilities in the office buildings and the creation of more sophisticated jobs within the Jakarta's surrounding municipalities and regencies.

Keywords: commuter, labor supply, survival analysis, transportation

1 Introduction

Jakarta, as Indonesia's capital city, has been a magnet to every immigrant to work. Aside from being the center of every governance activity, Jakarta economic activities also attract more labors, especially from the outside of Jakarta. Although Jakarta's economic growth tend to fluctuate, from 5.97% to 5.93% in the first quarter of 2018, Jakarta has contributed 17% to Indonesia's economy [1]. Higher pay and more abundant opportunities are some factors influencing individual decision to move to Jakarta. Some of them are willing to travel for 10 or more hours in order to relocate to Jakarta.

Not only attracting those who lived 10 hours away from Jakarta, labor from districts and cities that circled Jakarta also attracted to gamble in this city, to have a better life through higher pay and a more suitable job that match their qualifications. Those who live in the outskirt of Jakarta are willing to travel back and forth from their home to their workplace in Jakarta. These people are known as commuter labors. There are 2.43 million commuters who are traveling within, into and out of the city in a day. Of these people, 1.38 million are those who live in the outskirt of Jakarta, such as Depok, Tangerang, Bogor, Bekasi, and Banten [2].

This study would like to assess the determinants of commuter labor on their decision making to be a commuter and fulfill Jakarta's market labor. By employing a survival regression analysis, this study will shed light on how commuter labors decide to stay or quit as a commuter in the future.

2 Literature review

In the last two decades is recorded a very high growth of population in developing countries [3]. In line with the growing population, the needs of mobility are also increasing. Accessibility of a sound public transport system has become more important in order to design and to evaluate sustainability of a transit system. Besides the transport system, access for public transport has been

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considered to have an impact to life satisfaction [4-5]. If the high demands of public transports were not able to meet a certain level of supply of transport infrastructure that may lead to congestions and increasing of waiting times in the streets and public transport hubs [6]. Improvements in the public transport systems lead to betterment in other services sectors [7]. Thus, developing and formulating an efficient public transport system have become one of the primary objectives for planners and policy makers in many metropolitan cities across countries [8].

Many studies have investigated several correlation and impact of accessibility of public transport to the life satisfaction and environment that could cause a certain impact on quality of life and public health [4]. Improvement in the sustainability of public transport, public health, economic conditions of residents and environments can be achieved by reducing the use of private transport and shifting to the mass transport system and environmentally friendly transport such as cycling and walking [9].

The relation between job opportunities and accessibility for public transport has become an interesting topic to be investigated in many studies. One of the purposes of enhancing urban public transport systems is to improve commuting and also to facilitate individual performance on the employment market [4]. According to [10], a positive correlation between labor force attachment and transportation accessibility might not be caused by the public transport role, but is a result of spatial urban factors. Enhancing job accessibility might increase earnings and individual employment rates by various mechanisms [4].

Furthermore, according to [11], the correlation between employment and transport accessibility has mostly become an area of dispute in formulating transport infrastructure and geographic conditions. It seems that the job locations and the workforce's residential locations could be overcome by providing a sound transit system. Labors might not consider various relevant job opportunities due to long commuting time [12]. In this sense, the characteristics of a sound public transportation system can become one of productive strategy to challenge unemployment [13].

The relation between employment and access of transit system has been revealed by [13] which employed geographical information system to investigate the various labors characteristics within different transport systems. This study found that the transport accessibility has become one of the key factors in determining employment participation. Further, by evaluating the correlation between labor participation levels and transport access and employing the two-stage least squares regression model, [13] proved that a stronger relationship between labor participation and public transit accessibilities. Further, a study of [11] justified the previous study of [13]. In [11] was investigated the available network of public transport system influence on the employment rate variation at a local level and a statistically significant relationship between the shorter commuting time and higher employment levels was found.

In a recent study, [14] were analyzed the factors affecting women's decisions in choosing the transport mode in order to determine individual travel requirements that are affected by socio economic condition, life stages and gender. Their study employed 6000 household's data and investigated mobility behavior data provided by Zilina self-governing region from 2013 to 2016. Authors found that the relation of daily travel mode, characteristics of activity participation, and socio-demographics of male and female commuters were more gender sensitive.

2.1 Influence of commuters on labor market supply

An individual decision on doing the commuting can be caused by wages creating the process in the labor market that differs between areas. The amount of wages received by commuters is assumed to be the basis for them to choose transportation modes [15]. In this study, Jakarta's commuters that fill the labor market in 2014 have been attracted to the minimum wage policy that fixated on IDR 2,44 million. It was the highest minimum wage to be set compared to the other eight cities/regencies outside Jakarta. Other than Jakarta's minimum wages, transportation cost and housing price have accounted on household's decision making on whether they should be a commuter or not. Social demographic characteristics, such as education level, age, gender and race also influenced an individual decision on commuting [16].

Labor supply limitation due to migration will keep minimum wage high in the receiving labor market [17]. Meanwhile, commuters that are eager to increase their utilization to get the most satisfying pay and the job will travel back and forth in one day. This event will imply the unlimited labor availability in the city, additionally with a regional minimum wage policy set above other areas than Jakarta. Commuters flow will improve labor supply for the job in the commuters' receiving labor market. Hence, it will lower the cost of opening new job opportunities. Okun's Law has stated that decrease in labor demand on receiving labor market will affect in the rise of product and services demand, assuming that commuters utilize and spend their money in the district where they work, not where they originated from [16].

2.2 Staying duration on current living area

Sociodemographic characteristics affect an individual decision on doing the commuting. How long they have stayed in their current living area is one of the satisfaction indicators on migration process they perform, because it can describe the adaptation process of the immigrant to their environment [18]. Recent migration has limited staying duration up to five years compared to their current living area. For this reason, this study was aimed to find how the personal satisfaction to keep or stop being a commuter, regarding their duration of stay in their current living area. Staying duration will describe individual resilience on shortening their traveling distance to the workplace. The longer the staying duration, it will describe different individual decision on comfortability factors that cannot be offered by other areas.

2.3 Commuting duration, distance and double-income household migration strategy

Every individual has own resilience stability to perform commuting in a day for one hour [19]. If the commuting takes place more than an hour, it will affect individual decision making to stay as a commuter or to stop the act of commuting. Male commuter and female commuter have different resilience in commuting; where male are described as more resilient on long-distance commuting, this is not what happens with female commuters. Female commuters' resilience can be affected by the household conditions. Household where husband and wife are both working outside their original labor market will discuss whether they will stay as commuters or quit the job. A tendency to quit a job more likely happens to wives due to household conditions, the school-age child they have would make a female more likely to stop commuting and choose a job much closer to her home [20-21].

Additionally, the experience of having a long-distance commuting with a longer duration will affect an individual decision on staying or quitting as a commuter [22]. A study by [19] on measuring commuting resilience duration with survival analysis, while [22] divide subsamples of the research based on how long they have been commuting with multinomial analysis. In this study, the research team has used the survival analysis on the duration of staying in their current living area with individual decision to stay or stop being a commuter.

3 Methodology

This research uses Jabodetabek commuters in 2014 survey data that has been conducted by Statistics Indonesia. This survey has been conducted in five districts in Jakarta, namely South Jakarta, East Jakarta, Central Jakarta, West Jakarta, North Jakarta and eight surrounding cities and regencies, namely Bogor Regency, Bogor City, Bekasi Regency, Bekasi City, Depok, Tangerang Regency, Tangerang City and South Tangerang City. This research used 1,712 households whose household members perform commuting to Jakarta in one day back and forth to fulfill Jakarta's labor market. The total commuter individuals, who headed to Jakarta, were 3,522. To analyze the commuting resilience of the individual, 2,485 units sample, who has been living in their current living area up to 10 years, were gathered. Ten years of living decided as the limitation because many cases of quitting as a commuter happened in this period, although it is still an indifferent duration for commuters to stay or quit.

Survival analysis, in particular, the survivor function and hazard ratio will measure the commuters' resiliency. This research uses parametric survival regression with log logistic distribution. Survivor function S(t) is a function that stated individual chances to stay longer in their current living area and become a commuter to Jakarta up until the certain point of time, which can be defined as:

$$S(t) = P(T \geq t). \tag{1}$$

The random variable T defined staying duration in the current living area and keep being a commuter. The probability density function $f(t)$ is:

$$f(t) = -\frac{dS(t)}{dt}, \tag{2}$$

proof:

$$s(t) = \int_t^{\infty} f(x)dx, \tag{3}$$

$$\int_{-\infty}^{t} f(x)dx + \int_t^{\infty} f(x)dx = 1, \tag{4}$$

$$\int_{-\infty}^{t} f(x)dx = 1 - S(t), \tag{5}$$

$$\frac{d\left[\int_{-\infty}^{t} f(x)dx\right]}{dt} = \frac{d[1 - S(t)]}{dt}, \tag{6}$$

$$f(t) = -\frac{dS(t)}{dt}. \tag{7}$$

On the other hand, the Hazard function is used to define the probability of someone to keep staying in their current living area and stop being a commuter in time t subject to the provision of someone quitting as a commuter up until the time they are willing to quit. This study used 5.9 years as the limitation based on survival time mean. Given is the function:

$$h(t) = \lim_{\delta t \to 0} \frac{P(t \leq T < t + \delta t | T \geq t)}{\delta t}. \tag{8}$$

3.1 Relation between Survivor function and Hazard function

$$P(t \leq T < t + \delta t | T \geq t) = \frac{P(t \leq T < t + \delta t)}{P(T \geq t)} \tag{9}$$

$$= \frac{F(t + \delta t) - F(t)}{S(t)}, \tag{10}$$

$$h(t) = \lim_{\delta t \to 0} \left\{ \frac{P(t \leq T < t + \delta t | T \geq t)}{\delta t} \right\} \cdot \frac{1}{S(t)}, \tag{11}$$

$$h(t) = \frac{f(t)}{S(t)} \tag{12}$$

because $(t) = -\frac{dS(t)}{dt}$, (13)

therefore $h(t) = -\frac{d}{dt}\{\log S(t)\}$, (14)

$$\log\ \log S(t) = \int h(t)dt = H(t), \tag{15}$$

$$\log S(t)\exp(-H(t)). \tag{16}$$

The parametric method, applied in this study, is using analysis method with log logistic distribution assumption, after distribution test conducted with Matlab software. Thus, Survivor function and log-logistic distribution used in this study are defined as:

$$S(t) = 1 - F(t) = 1 - \frac{e^{\theta}t^{k}}{1+e^{\theta}t^{k}} = = \frac{1+e^{\theta}t^{k} - e^{\theta}t^{k}}{1+e^{\theta}t^{k}} = \frac{1}{1+e^{\theta}t^{k}}. \tag{17}$$

Meanwhile, Hazard function with log-logistic distribution will be:

$$h(t) = \frac{f(t)}{S(t)} = \frac{ke^{\theta}t^{k-1}}{(1+e^{\theta}t^{k})^{2}}\frac{1+e^{\theta}t^{k}}{1} = . \tag{18}$$

The Accelerated Failure Time (AFT) log-logistic model was used to analyze the survival probability.

3.2 Accelerated Failure Time (AFT) log-logistic model

This model describes when the commuter stops happening faster than the survival time (accelerated failure time).

3.3 Hazard function with the AFT model

$$h_i(t) = e^{\eta_i}h_0(e^{-\eta_i}t), \tag{19}$$

$$h_0(t) = \textit{Initial Hazard Function}, \tag{20}$$

$$h_i(t) = \textit{Initial Hazard Function on} - i, \tag{21}$$

$$\eta_i = \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_p x_{pi}, \tag{22}$$

where i=1,2,…,n.

3.4 Survivor function with AFT model

$$S_i(t) = \frac{fi(t)}{hi(t)}, \tag{23}$$

$$S_i(t) = \textit{Initial Survivor function on} - i, \tag{24}$$

$$h_i(t) = \textit{Hazard function on} - i. \tag{25}$$

How long commuter will stay in his current living area and keep being a commuter is estimated by $(\theta + k\eta_i, k)$ parameter.

3.5 The log-linear format from Accelerated Failure Time log-logistic model

Log linear is a group of a variable in surviving time T_i:

$$\log T_i = \mu + \alpha_i x_{1i} + \cdots + \alpha_p x_{pi} + \sigma\varepsilon_i. \tag{26}$$

Using the Survivor function definition, thus:

$$S(t) = P(T \geq t) = P(\log T_i \geq \log t) = P\left(\varepsilon_i \geq \frac{\log t - \mu - \cdots - \sigma_\rho x_{\rho i}}{\sigma}\right). \tag{27}$$

Assuming that ε distributes logistics, the density of opportunity function probability and Survivor function from ε are:

$$f(\varepsilon) = \frac{e^{\varepsilon}}{(1+e^{\varepsilon})^{2}}, \tag{28}$$

$$S(\varepsilon) = \frac{1}{1+e^{\varepsilon}}. \tag{29}$$

Therefore, the Survivor function from T_i is:

$$S_i(t) = \left[1 + \exp\left\{\frac{\log t - \mu - \cdots - \sigma_\rho x_{\rho i}}{}\right\}\right]^{-1}. \tag{30}$$

The Survivor function, with i-individual distributes the log-logistic with $(\theta + k\eta_i, k)$ parameter estimation, where η_i is:

$$\eta_i = \beta_1 x_{1_i} + \beta_2 x_{2_i} + \cdots + \beta_p x_{p_i}. \tag{31}$$

The Survivor function given from T is:

$$S_i(t) = \frac{1}{1+e^{\theta + k\eta_i}t^{k}}. \tag{32}$$

Compared to T Survivor function that:

$$\theta = -\frac{\mu}{\sigma}, \tag{33}$$

$$k = \frac{1}{\sigma}. \tag{34}$$

The Hazard ratio from the Proportional Odds Log-logistic model is:

$$\frac{h_i(t)}{h_0(t)} = [1 + (e^{\eta_i} - 1)S_0(t)]^{-1}. \tag{35}$$

4 Results and discussion

When forming its labor market, Jakarta as Indonesia's capital city cannot separate the local labor (stayers' labor) and labor who are mobile (movers' labor) with daily duration (commuting labor) or more than one-day duration (circular labor) in six months period. The increasing percentage of Jakarta, Banten and West Java's commuter labors indicated a spatial interaction to fulfill the labor market for each area. The Spatial interaction happened

Table 1 *Data descriptions*

Variable	Log Logistic Survival 1 = Quit 0 = Stay
Total Sample	n=2485
Gender	
Male	1
Female	2
Age	
Education	
Up to Elementary/Islamic Elementary or equivalent	1
Junior High School/Islamic Junior High School or equivalent	2
Senior High School/Islamic Senior High School or equivalent	2
Diploma I/II/III	4
Diploma IV/Bachelor/Master/Doctoral	5
Homeownership status	
Self-owned	1
Rent/Contract	2
Other	3
Feeling stress when headed to/from receiving labor market	
Yes	1
No	2
Commuting Duration	
Mileage	
Average income from the primary job	
Double-income household	
Yes	1
No	2

in the form of labor mobilization that moves across their city or district border. This interaction implies the increase of income per capita on receiving labor market and an increase in welfare on the labor's origin area, especially for a household with commuter labor. This phenomenon can describe two sides of commuter labor as an input on production factor in the receiving labor market to produce output and as a resident of the area of origin with better income level compared to when they do not move. In [15] is explained that the commuter labor is most likely to work outside their current living area than in their origin area, assuming reservation wage for every labor is treated as equal.

This study has analyzed how the commuter labor's characteristics from the surrounding area of Jakarta, such as Banten district and West Java, are fulfilling Jakarta's labor market, based on Jabodetabek commuter survey in 2014 by Statistics Indonesia. Jakarta, as a megapolitan, has grown through the suburbanization process that happens in the surrounding area of Jakarta. This phenomenon, described by [23], happened where suburbanization takes place with spatial distribution pattern that spread more widely, along with the growth of metropolitan cities. Table 1 below describes the characteristics of respondents in this study.

Labor mobility that happens with a daily duration from the surrounding of Jakarta is an implication caused by suburbanization around Jakarta. 12.44% of labors from Depok fulfilled Jakarta's labor market and became the most significant percentage compared to the other 13 districts/cities/regencies that directly bordered with Jakarta. 32.45% of the commuter labor from 13 districts/cities/regencies around Jakarta, headed to South Jakarta and Central Jakarta every day. That describes how Jakarta's biggest economy happened in the Central and South Jakarta, supported by commuter labors from 13 districts/cities/regencies. The Central and South Jakarta are the biggest Jakarta's most significant GDP contributors, with 24.34% contribution come from Central Jakarta and 22.35% from South Jakarta. Moreover, commuter labors that headed to Jakarta fulfill governance and public service sector (21.78%), trade sector (19.85%), insurance and finance (12.21%) and

Table 2 *Data analysis*

Variable	Total Samples (n = 2485)		Full Model	Fitted Model
	Willing to Quit		Coefficient	Coefficient
	Yes	No		
Samples	173	2312		
Gender				
Male	126	1619		
Female	47	693	0.0185968 (0.1262742)	
Age	173	2312	0.0139384 ** (0.0065005)	0.0161032 ** (0.0063751)
Education Level				
Elementary/Islamic Elementary or equivalent	14	100		
Junior High School/Islamic Junior High School or equivalent	11	169	0.6434834 ** (0.2849675)	0.6277425 ** (0.2879138)
Senior High School/Islamic Senior High School or equivalent	94	1122	0.5567855 *** (0.2094445)	0.5765493 *** (0.2113748)
Diploma I/II/III	11	214	0.8876308 *** (0.2759957)	0.9076511 *** (0.2778538)
Diploma IV/Bachelor/Master/Doctoral	43	707	0.7377673 ** (0.2291076)	0.7590284 *** (0.2267885)
Home ownership status				
Self-owned	123	1723		
Rent/Contract	32	380	-0.1110324 (0.1402029)	
Other	18	208	-0.1814356 (0.1768024)	
Feeling stress when heading toward/ from the activity area				
Yes	111	1058		
No	62	1254	0.3410174 *** (0.1089175)	0.3290216 *** (0.1091749)
Commuting Duration	173	2312	-0.003817 ** (0.0016782)	-0.0023322 * (0.0013896)
Mileage (Distance)	173	2312	0.0067719 (0.004922)	
The average income per month from the primary job			-1.58e-08 (7.72e-09)	
Double-Income Household				
Yes	65	833	-0.1936276 * (0.1121168)	-0.1963347 * (0.1101553
No	108	1479		
Constants			1.953655*** (0.3370987)	1.886609 *** (0.3215616)
1/ln_gamma			-0.8366013 *** (0.0916982)	-0.826973 *** (0.0918275)
gamma			0.4331803 (0.0397219)	0.4373712 (0.0401627)

* p<0.10, ** p<0.05, *** p<0.01

Table 3 Surviving probability and Hazard ratio on quitting as a commuter

Variable	Survivor Function		Hazard Function		Hazard Ratio
	Stay as a Commuter		Quit as a Commuter		
	0	i	0	i	i
Global	0.466		-0.109		
Age		0.471		-0.108	0.992
Education Level					
Elementary/Islamic Elementary or equivalent					
Junior High School/Islamic Junior High School or equivalent		0.799		-0.041	0.376
Senior High School/Islamic Senior High School or equivalent		0.876		-0.025	0.232
Diploma I/II/III		0.986		-0.003	0.026
Diploma IV/Bachelor/Master/Doctoral		0.989		-0.002	0.022
Feeling stress when heading toward/from the activity area					
Yes					
No		0.659		-0.070	0.639
Commuting Duration		0.466		-0.110	1.002
Double-Income Household					
Yes		0.488		-0.105	0.960
No					

manufacturing industry (11.73%). These four sectors are the most significant contributor to Jakarta's gross domestic, local product and become the main characteristic of a big city such as Jakarta. In 2014, the trading sector contributed 16.64% to Jakarta's GDP, followed by governance and public service sector (15.18%), manufacturing (12.94%) and financial services (10.21%).

The technology development, marked by better transportation system, which connects Jakarta and its surroundings, has affected the commuter labors to mobilize and head toward to Jakarta without any significant time constraint. According to [19], a stable individual will travel to his receiving labor market in 60 minutes duration. Additionally, 40.60% commuter labor who headed to Jakarta, are more likely to travel in 31-60 minutes duration and 16.7% travel for 11-20 km from their home to their workplace. Travel duration can be an indicator to describe the commuter labor supply from the surrounding area that fills the Jakarta's labor market.

Jakarta, where most of the economic activities happened, has attracted labors from outside of Jakarta to take a role in the labor market. Most of Jakarta's commuters come from the surrounding area of Jakarta and become a recent immigrant, not a resident. Experience on becoming an immigrant, where they have long experience to live in their current area that differs from where they lived five years ago, is an indicator of immigration satisfaction [18]. 8.92% of commuters have lived in their current area for five years or different home compared to five years ago. While 57.04% have experienced living in the area other than their current districts/cities/regencies, 19.39% of the commuters live in their current place following where their husband/wife/parents/kids live. 11.19% of them said it is because of housing and followed by working reason 8.21%. Therefore, it contributed to individual decision to stay in their current home or choose to seek a home near their workplace and decide to quit as a commuter.

Commuting duration and previous experience as an immigrant are the reason why individual decided to maximize their utilization to stay in their current area. 30.72% commuters explained that they decided to commute because of the security and convenience in their current living area, while 13.49% commuters are willing to sacrifice their two hours to go to work for their current living area. On the other hand, Jakarta's labor market has become the reason for 34.64% commuters to get the job that matches their skills and competence. Table 2 below describes the results of the data analysis.

6.39% stated that they want to make a better living through higher income, compared to their current living area. That can be an indicator what happens in the labor mobility where the opportunity of getting higher income in receiving labor market is more significant than in their current living area [24].

Rational individual choice is more likely to lean to the decision to avoid long commuting time [22, 25]. Thus, every individual will maximize their utilization when facing two choices between stay or quit as a commuter. This research used willingness to quit as a commuter for the next one-year approach to limit the event on analyzing commuter resilience on fulfilling Jakarta's labor market. According to Jabodetabek commuter survey in 2014, 70.56%

commuter decided to stay in their current living area for less than or up to 10 years. Therefore, this study takes that sub-population to see their commuting resilience to their decision on quitting as commuter labor. Table 3 below indicates results of the commuter decision.

Nearly one-third of the commuter labors fulfilled Jakarta's labor market and contributed to Jakarta's economy. Commuter labors resilience can be drawn by examining their commuting duration. According to [19], 60 minutes that every labor takes every day to commute is a description of labor's duration stability. It describes how the individual resilience on commuting in one day. Therefore, if commuting is done repeatedly more than one hour a day, it will deflate the individual's utilization. Thus, according to [25], the individual will tend to find a home closer to their workplace.

Staying duration in the current living area can describe the adaptation process every recent migrant is going through, where they had a different living area with what they have today. Staying duration is also closely related to immigrant's psychological wellness [26]. When the adaptation process is not going well and the burden of commuting duration is more significant than before, commuters may be affected by a psychological disorder, which in this study can be described with stress and plan to quit on being a commuter in the next year. Meanwhile, a household with double income where husband or wife work, and both are commuters will be more likely to face a tendency to decide which one will quit as a commuter. In majority of cases, women tend to quit as a commuter [22].

A study by [22] described that the duration of being a commuter could be affected by education level and gender. While age does not describe someone's willingness to quit as a commuter or have a shorter duration on commuting, it is still an aspect that needs to be considered regarding the ability to perform commuting. Related to a commuting distance where housing location is formed in the surrounding area of Jakarta, home ownership status becomes an essential consideration for someone on deciding to have a home closer to their workplace and quit being a commuter.

This research used survival analysis in seeing commuter resilience on commuting with current living area approach as a stimulus to migrate, shortening their commuting duration from home to workplace based on their commuting adaptability to their environment.

Based on Table 2, it describes that gender, distance, income and home ownership do not affect the respondent's decision whether to stay or quit as commuters. The fittest model exhibits that age, education level, the psychological condition, commuting duration and availability of spouse who is also a commuter can affect individual's decision to stay or quit as a commuter.

This research used parametric survival regression where gamma value was defined as a shape from data distribution that describes the hazard value. The Survival model on the duration of staying in Jakarta's commuter has shown a declining hazard value. Thus, it can describe how individual choose to stay as a commuter.

In the end, Jakarta's government can apply a policy that will comfort commuters and help them to stay as a commuter.

In Table 3 is shown that commuter probability of staying a commuter is more significant than the hazard of quitting as a commuter. Based on the education level, Jakarta has offered much more job opportunity for those who earn education higher than senior high school level compared to the local area. Therefore, the higher the education level, the more commuters will stay as a commuter rather than quit. In order to keep their labor working in their origin area, commuter's area of origin must develop economic activities that will expand jobs opportunity for labor with higher education level qualification. Additionally, a regional minimum wage that Jakarta has established already matches the commuter's utility. It can be seen through commuter's probability to stay rather than to quit as a commuter.

Based on age, the hazard ratio was found to be higher than the opportunity to stay as a commuter. The older is the commuter, the more likely they want to work in their origin area and fulfill their local area labor market, rather than being a commuter in the future. This is also the case of a double-income household where the probability of one of the household members is more likely to quit as a commuter is more significant due to the internal decision in the household, regarding the family condition and where the school-aged kid is in the household or not. Thus, the female commuter is more likely to fill the local's labor market rather than being a commuter [22]. For the commuting duration, the longer the commuting takes time, the higher the chance of someone to quit as a commuter. However, this is not the case where commuter does not feel any stress on commuting. The more commuter resistance to stress, the probability of quitting or staying is almost the same.

Jakarta offers significant job opportunities with tight competition. It has attracted commuter labor to participate in Jakarta's labor market. Productive age with higher level education commuter is more likely to contribute to Jakarta's labor market. On the other hand, to maintain the large numbers of commuters to Jakarta's economy, the public transportation system must be able to make commuters feel at ease on their commuting time so that long commuting time will not be a constraint for a commuter to keep on commuting.

5 Conclusions

With the growing economy activities in Jakarta, the surrounding area of Jakarta will eventually get spillover from this event. One of the aspects that is most likely to be affected is the labor market. With the development towards a better transportation system, housing price and opportunities available in the megapolitan city, it surely will attract more labors from outside of Jakarta to participate in Jakarta's labor market. However, several factors are playing a role in commuter labor decision making, whether they want to stay or quit as a commuter.

The policy implications for improving the labor supply provision and some contested policy options are suggested such as the provision of affordable housing in Jakarta, the creation of jobs within the Jakarta's surrounding cities and improvement of the commuting enjoyment.

Labors with a higher educational level are those who are willing to stay as a commuter in order to pursue their most wanted and most suitable job for their qualification. Jakarta has offered much more opportunities compared to its surrounding areas such as Depok, Bogor, Tangerang and Banten. However, as labor grow older, they are more likely to stay in their area of origin and plan to quit as a commuter, especially if the commuting time is longer than one hour and trigger stress on the labor. This is also the case of women commuter, especially if they already have a spouse and a school-aged kid, where they are more likely to quit as a commuter due to household decision making.

Jakarta surroundings already has its advantage of the lower house pricing compared to Jakarta. Thus, the provision of affordable housing in Jakarta will help retaining labor supply. However, the lower housing prices and rents would be a trigger to labors to be commuters. Furthermore, most people are still reluctant to work in the surrounding area of Jakarta due to the small number of job opportunities given by the local labor market. If Jakarta's surrounding area wants to retain their residents to work in their area, jobs opening, especially for labor with a higher level of education, must be attractive enough to the employee candidates. It can be started by giving better incentives and more job opportunities that match their qualifications and interests.

If Jakarta wants to retain their numerous commuter labors, it must improve the transportation system. Not only the inner-city transportation that must be developed but the intercity transportation, as well. Therefore, it will make commuters more likely to head to Jakarta because there will be no more significant constraint to head to work, especially the time constraint. Tariff reduction on public transportation can also play a role to retain and attract more labor from the surrounding area. In addition, the enjoyment during the traveling time must be taken into consideration. A seamless experience for commuters, when changing their transportation modes would be very much welcomed. Additionally, entertainment during the commuting is also useful to reduce boredom such as access to free internet.

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METHODS OF PREDICTING THE HEADING, PITCH AND ROLL ANGLES FOR AN UNMANNED AERIAL VEHICLE

The article discusses handicaps in predicting values of rotation angles with regard to Heading, Pitch and Roll for an Unmanned Aerial Vehicle. Within the simulation of the rotation angle values, the linear, polynomial and logarithmic methods were used. The programme source code was written in the numerical editor Scilab 5.4.1. The source data for investigation were recorded by a measuring device Trimble UX-5. The article provides results of comparing the real values of Heading, Pitch and Roll rotation angles to findings obtained from the prediction methods. Based on the conducted research, it was found that the largest value of standard deviation parameter in prediction of the rotation angles is for the angle of Heading, as it equals approximately 5°, whereas the smallest ones are for the Roll and Pitch angles, equalling less than 1.4o.

Keywords: *UAV, prediction, heading, pitch, roll*

1 Introduction

A fundamental navigation aspect in the Unmanned Aerial Vehicle (UAV) technology is determination of coordinates and orientation angles in airspace. In the case of determining the UAV coordinates, the preferred method of positioning is the GNSS satellite technology [1], using code observations on the L1 frequency [2]. However, the UAV orientation during a flight mostly relies on readings from the IMU device, being part of the INS sensor. The IMU device has in-built accelerometers (to determine the aircraft acceleration along the three axes of the reference system) and gyroscopes (to determine three angles of rotation). Ultimately, the INS system provides six degrees of freedom within the navigational designation of the user's position with an integration based on GPS/INS data [3]. The Heading, Pitch, Roll (HPR) rotation angles refer to the internal aircraft system, representing the UAV turn, bank and rotation [4]. An important element in determining the HPR angles of rotation is also a simulation of predicting the UAV in-flight space orientation. This issue is crucial as it allows specifying the HPR angular values for an UAV in the following cases:

- an entire loss of data from an UAV,
- loss of UAV control due to mechanical damage or forces of Nature,
- failure of a data link from an UAV to the flight operator,
- loss of visual contact with an UAV.

The fundamental task of the user, when taking an advantage of the mechanisms of an UAV orientation prediction, is to restore, as closely as possible, the missing flight stage of an aircraft, exploiting available numerical tools and mathematical algorithms.

The primary objective of this article is a possibility for presenting the methods of prediction of the HPR angles, as well as a verification of their results in comparison to the actual data, registered by an UAV. For this purpose, real readings of the HPR angles from the Trimble 5 platform were taken. In the simulation calculations, three methods of predicting the HPR values were used, i.e. the method of linear regression, the polynomial method and the logarithmic method.

2 Methods of research

In the framework of simulation of predicting the rotation angles, i.e. Heading, Pitch and Roll, three test methods were exploited, i.e.:

- the linear regression method,
- the polynomial method,
- the logarithmic method.

The model of linear regression is described by dependence [5]:

$$Y = a \cdot X + b\,, \tag{1}$$

where:

Y - stands for the value of the Heading, Pitch or Roll rotation angle,

a - is a determined linear coefficient,

X - indicates the number of the next measurement epoch,

b - is a determined linear coefficient.

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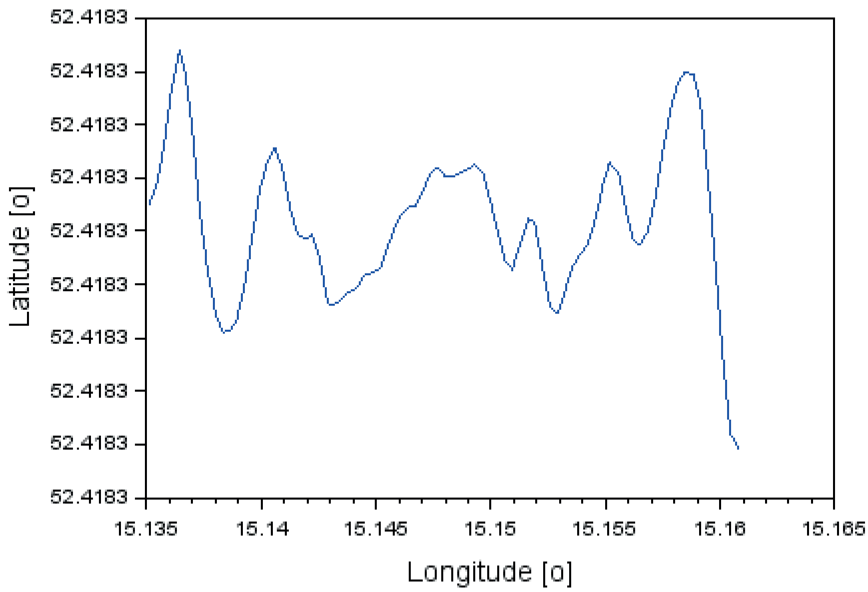

Figure 1 *Horizontal trajectory of the UAV flight*

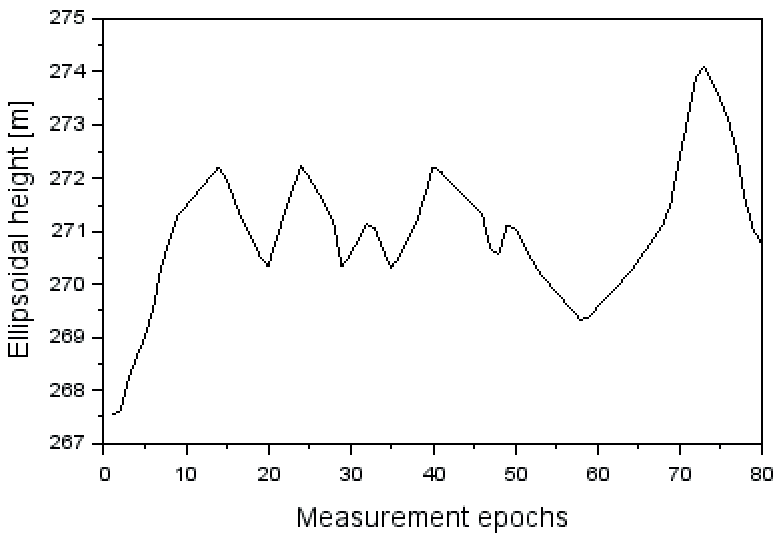

Figure 2 *Vertical trajectory of the UAV flight*

The polynomial model is expressed by equation [6]:

$$Y = c \cdot X^2 + d \cdot X + e\,, \tag{2}$$

where:
Y- stands for the value of the Heading, Pitch or Roll rotation angle,
c - is a determined linear coefficient,
X - indicates the number of the next measurement epoch,
d and e are determined linear coefficients.

The logarithmic model is expressed by formula [7]:

$$Y = f \cdot \log X + g\,, \tag{3}$$

where:
Y- stands for the value of the Heading, Pitch or Roll rotation angle,
f - is a determined linear coefficient,
X - indicates the number of the next measurement epoch,
g - is a determined linear coefficient.

The mathematical Equations (1), (2) and (3) are solved using the least squares method, as below [8]:

$$\begin{aligned} & A \cdot \delta q - l = v \\ & N = A^T \cdot A \\ & L = A^T \cdot l \\ & \delta q = N^{-1} \cdot L \\ & m_0 = \sqrt{\frac{[vv]}{n-k}} \end{aligned}\,, \tag{4}$$

where:
A - matrix of partial derivatives,
δq- designated parameters,
l - vector of observation,
v - residuals vector,

Table 1 Coefficients for the Heading angle

Research method	Value of the linear coefficients	Value of m_0 parameter
Linear regression	b= 270.70° a = -0.01°	m_0= 1.09°
2nd degree polynomial	e= 272.16° d = -0.22° c= 0.01°	m_0= 0,91°
Logarithmic trend	g= 271.60° f= -0.92°	m_0= 1.04°

Table 2 Coefficients for the Pitch angle

Research method	Value of the linear coefficients	Value of m_0 parameter
Linear regression	b= 4.02° a = 0.03°	m_0= 0.98°
2nd degree polynomial	e= 4.00° d = 0.03° c= -0.01°	m_0= 0.98°
Logarithmic trend	g= 3.45° f= 1.03°	m_0= 0.97°

Table 3 Coefficients for the Roll angle

Research method	Value of linear coefficients	Value of m_0 parameter
Linear regression	b= -0.01° a = -0.01°	m_0= 1.43°
2nd degree polynomial	e= 0.38° d = -0.01° c= 0.01°	m_0= 1.42°
Logarithmic trend	g= 0.62° f= -0.57°	m_0= 1.41°

N - matrix of a set of normal equations,
L - vector of free terms,
m_0 - standard deviation of residuals,
n - number of measurements,
k - number of designated parameters.

The mathematical model from Equation (4) is used for numerical calculations separately for each test method and independently of each HPR angle.

3 Research test and results

The scientific experiment was carried out for real data obtained from the Trimble 5-UX device. For the experiment, the authors selected 80 exemplary measurement periods, for which the sensor Trimble UX-5-determined the position, flight altitude and the HPR values. Figures 1 and 2 illustrate the horizontal coordinates and the UAV flight altitude, respectively. The UAV coordinates were determined by using the C/A code observations on the L1 frequency in the GPS system and were updated every 10 Hz. The UAV coordinates are referenced to the geodetic BLh frame and recorded by the sensor Trimble UX-5 in a universal text format "log" [9].

The first stage of the experiment was to determine linear coefficients from Equations (1) to (3) for each HPR angle. The sought parameters from Equations (1) to (3) were determined based on the readings from 40 measurement epochs (epochs 1 to 40). The values of linear coefficients from Equations (1) to (3) are shown in Tables 1, 2 and 3. Furthermore, those Tables present the value of standard deviation of m_0 for each HPR angle and each test method. In all the cases, values of the m_0 parameter do not exceed 2^0, which constitutes a boundary value of accuracy for the HPR angles from the metric of the Trimble UX-5 instrument. The largest values of the m_0 parameter occur for the Roll angle, being equal to approximately 1.5^0 and the lowest for the Pitch angle, being equal to approximately 1^0.

4 Discussion

Within the discussion, the authors focused on the problem of extrapolation of the HPR angles' values. To

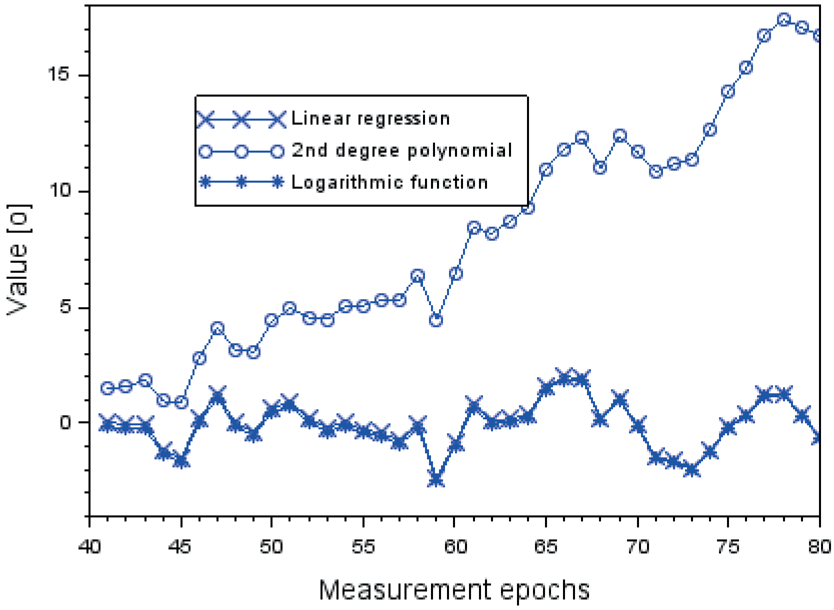

Figure 3 *Comparison of predicted and real values of the Heading angle in each measurement epoch*

this end, prediction of values of the HPR angles for the measurement epochs 41-80 was made. New values of the HPR angles for the prediction phase were specified based on the functional relationships.

- the linear regression method,

$$Y_{pred} = a \cdot X_{pred} + b\,, \tag{5}$$

where:
Y- stands for the extrapolated value of the angle of rotation Heading, Pitch or Roll for epochs 41 – 80,
a - linear coefficient determined for epochs 1- 40,
X_{pred} - number of measurement epoch from 41 to 80,
b - linear coefficient determined for epochs 1- 40;
the 2nd degree polynomial:

$$Y_{pred} = c \cdot X_{pred}^2 + d \cdot X_{pred} + e\,, \tag{6}$$

where:
Y- stands for the extrapolated value of the angle of rotation Heading, Pitch or Roll value for epochs 41 – 80,
c - linear coefficient determined for epochs 1- 40,
X_{pred} - number of measurement epoch from 41 to 80,
d and *e* - linear coefficients determined for epochs 1- 40;

- logarithmic trend model:

$$Y_{pred} = f \cdot \log X_{pred} + g\,, \tag{7}$$

where:
Y- stands for the extrapolated value of the angle of rotation Heading, Pitch or Roll value for epochs 41 – 80,
f - linear coefficient determined for epochs 1- 40,
X_{pred} - number of measurement epoch from 41 to 80,
g - linear coefficient determined for epochs 1- 40.

The predicted values of the HPR angles are compared to the real readings of the orientation angles from the sensor Trimble UX-5 on the basis of the following dependence [9]:

$$\begin{aligned} dH &= H_{pred} - H_{real} \\ m_H &= \sqrt{\frac{[dH^2]}{nr-1}} \\ dP &= P_{pred} - P_{real} \\ m_p &= \sqrt{\frac{[dP^2]}{nr-1}} \\ dR &= R_{pred} - R_{real} \\ m_R &= \sqrt{\frac{[dR^2]}{nr-1}} \end{aligned}\,, \tag{8}$$

where:
dH - difference between the extrapolated value from a given test method and the real value of the Heading angle from the Trimble UX-5 sensor,
R_{pred} - extrapolated value of the Heading angle based on Equations (5), (6) and (7),
P_{real} - recorded value of the Heading angle from the UAV device,
nr - number of measurements, nr = 40,
m_H - the error associated with the extrapolation of results signifies the matching error of predicted results of the Heading angle with respect to the actual values from the sensor Trimble UX-5.
dP - difference between the extrapolated value from a given test method and a real value of the Pitch angle from the Trimble UX-5 sensor,
R_{pred} - extrapolated value of the Pitch angle based on Equations (5), (6) and (7),
P_{real} - recorded value of the Pitch angle from the UAV device,
m_p - the error associated with the extrapolation of results signifies the matching error of predicted results of the Pitch angle with respect to the actual values from the sensor Trimble UX-5,

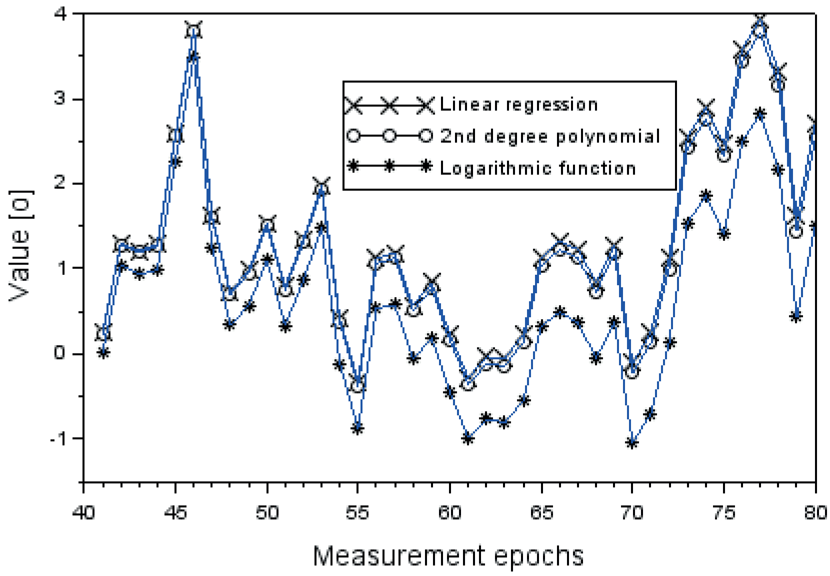

Figure 4 *The comparison of predicted and real values of the Pitch angle in each measurement epoch*

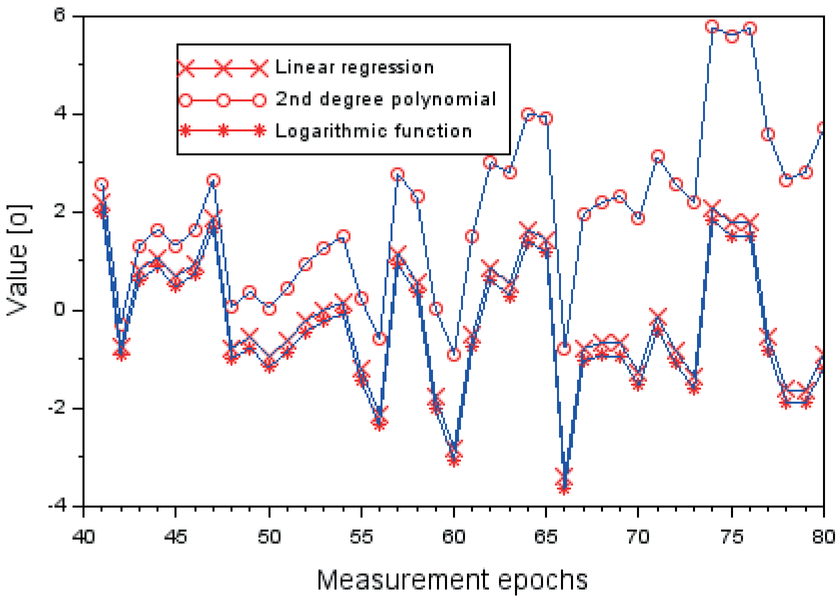

Figure 5 *Comparison of predicted and real values of the Roll angle in each measurement epoch*

dR - difference between the extrapolated value from a given test method and the real value of the Heading angle from the Trimble UX-5 sensor,

R_{pred} - extrapolated value of the Roll angle based on Equations (5), (6) and (7),

P_{real} - recorded value of the Roll angle from the UAV device,

m_R - the error associated with the extrapolation of results signifies the matching error of predicted results of the Roll angle with respect to the actual values from the sensor Trimble UX-5.

Figure 3 shows the dH parameter values for the Heading angle based on Equation (8). Values of the dH parameter were determined for the linear regression method, the polynomial method and the logarithmic trend. In the linear regression model, the average value of the dH parameter is under 0.01°, with the scatter of results ranging from -2.37° to 1.99°. Moreover, the median value for parameter dH is 0.02° and the error of extrapolation is equal to 1.01°. In the polynomial model, the average value of the dH parameter equals approximately 8.11°, with the scatter of results ranging from 0.87° to 17.38°. Besides, the median value for parameter dH in this model equals 7.28° and the error of extrapolation is equal to 4.96°. The average value of the parameter dH in the logarithmic method is equal to -0.13° for the scatter of results ranging from -2.51° do 1.88°. The median value for the parameter dH in this model is equal to -0.14°, while the extrapolation error for m_H is equal to 1.01°. Based on obtained results, it can be concluded that results of the parameter dH for the linear regression model and the logarithmic trend definitely differ from the other ones.

Figure 4 shows the dP parameter values for the Pitch angle based on Equation (8). Values of the dP parameter were determined for the linear regression method, the polynomial method and the logarithmic trend. In the linear regression model, the average value of the dP parameter equals 1.34°, with the scatter of results ranging from -0.32° to 3.99°. Moreover, the median value for the parameter dP is 1.20° and the error of extrapolation is equal to 1.13°. In the polynomial model, the average value of the dP parameter equals approximately 1.25°, with the scatter of results ranging from -0.38° to 3.80°. Besides, the median value for the dP parameter in this model equals 1.12° and the error of extrapolation is equal to 1.11°. The average value of the parameter dP in the logarithmic method is equal to 0.64° for the scatter of results ranging from -1.04° do 3.48°. The median value for the dP parameter in this model is equal to 0.47°, while the extrapolation error for m_P is equal to 1.08°. Based on obtained results, it can be concluded that results of the dP parameter for the linear regression model and the polynomial model are similar. The largest scatter of the dP results and the error of extrapolation are noticeable in the logarithmic model.

Figure 5 shows the dR parameter values for the Roll angle based on Equation (8). Values of the dR parameter were determined for the linear regression method, the polynomial method and the logarithmic trend. In the linear regression model, the average value of the dR parameter equals -0.17°, with the scatter of results ranging from -3.40° to 2.18°. Moreover, the median value for the dR parameter is -0.54° and the error of extrapolation are equal to 1.36°. In the polynomial model, the average value of the dR parameter equals approximately 1.99°, with the scatter of results ranging from -0.90° to 5.77°. Besides, the median value for the dR parameter in this model equals 2.07° and the error of extrapolation is equal to 1.69°. The average value of the dR parameter in the logarithmic method is equal to -0,41° for the scatter of results ranging from -3.66° do 1.99°. The median value for the dR parameter in this model is equal to -0.77°, while the extrapolation error for m_R is equal to 1.37°. Based on obtained results, it can be concluded that the results of the dR parameter for the linear regression model and the logarithmic trend remain on a similar level. The largest scatter of dR results and the error of extrapolation is noticeable in the polynomial model.

In References there are many different algorithms for solving the problem of predication of the HPR angles values. For example, in paper [10] the author proposed to prediction of HPR angles in the two mathematical functions: polynomial and trigonometric. The maximum range between the real and predicted data of the HPR angles is close to ±23°. In another paper [11], the authors present the Newton Euler's mathematical model for controlled the UAV position. The maximum difference between the real and model data of the HPR angles reaches up ±2-3°. In the next paper [12], the authors described the MPC (Model Predictive Control) algorithm for quadrotor Unmanned Aerial Vehicle motion. In the research test, the Roll and Pitch angles were estimated in computer simulation. Based on comparison to reference results, the accuracy of Roll angle equals to 2° and for Pitch angle more than 8°, respectively. In addition, in paper [13], the MPC method was used in Ariel UAV model in Matlab Simulink environment. The algorithm is focused on differential equation for controlling the UAV dynamics. The paper presents good convergence between predicted and real time data, with difference less than 0.5° for the HPR angles. In next article [14], the authors presented results of research for determination of the HPR angles in the prediction model. In that case, the Extended Kalman Filters based on GPS/INS fusion data was applied for prediction the HPR angles for UAV. The accuracy of presented method is about ±2°. In paper [15], the authors presented different scenarios for simulating the HPR angles, especially, the data from gyroscope model, accelerometer model, as well as magnetometers were utilized in simulation of the HPR angles. The maximum orientation error of the Heading angle has reached up to ±30°, whereas for Pitch and Roll it was close to ±10°.

The obtained results of comparison of HPR predicted values are better than results in papers [10] and [15]. In addition, the simulated values of the HPR angles (e.g. especially for the Roll and Pitch angles) are close to results included in papers [11] and [14]. Moreover, the obtained values of standard deviation of the HPR angles are lower than values in paper [12]. Only results from the MPC method from paper [13] are better than presented values of the HPR angles in this article. Finally, the presented method of estimation of the HPR angles is a good and correct solution for prediction model of the UAV orientation.

5 Conclusions

In paper, the scientific problem of comparison between simulated and real data of the HPR angles of a UAV was presented. Especially the scientific problem should be developed when the UAV object or navigational data from the UAV from flight mission would be lost. For that reason three scientific methods for recovery of the UAV orientation were applied in this paper, i.e. the method of linear regression, the model of the 2nd degree polynomial and the logarithmic trend.

For each test method, the values of the HPR angles were determined at the prediction stage and compared to the actual readings of the rotation angles from the device Trimble UX-5. The experimental test was performed for exemplary results of the HPR rotation angles from 80 measurement epochs. Based on the obtained findings, the following conclusions were formulated for accuracy of each research method:

1) the standard deviation term of linear regression method for the HPR angles is less than 1.4°;
2) the standard deviation of the 2^{nd} degree polynomial method for the HPR angles is less than 5°;
3) the standard deviation of logarithmic method for the HPR angles is less than 1.4°.

Finally, the presented research methods can be developed and applied in technology of UAV in aerial navigation. The obtained results of the HPR angles' prediction are acceptable and suitable for the UAV technology. The typical accuracy of measurement of the HPR angles equals to $m_{HPR}=2^o$ [10]. Moreover, the obtained results of accuracy of the HPR angles' prediction are less than boundary error of the UAV orientation error, i.e. $3 \cdot m_{HPR}=6^o$. based on that, the presented research methods can be implemented in the UAV technology.

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Annex - Nomenclature of used abbreviations

Abbreviation	Full name
GNSS	Global Navigation Satellite System
UAV	Unmanned Aerial Vehicle
INS	Inertial Navigation System
HPR	Heading, Pitch and Roll
IMU	Inertial Measurement Unit
GPS	Global Positioning System
C/A	Code Acquisition
BLh	Latitude, Longitude, Ellipsoidal Height
MPC	Model Predictive Control

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ANALYSIS OF ROAD SAFETY IN POLAND AFTER ACCESSION TO THE EUROPEAN UNION

The article presents an assessment of the state of safety on Polish roads in the period 2004-2018 in terms of changes that occurred after Poland's accession to the EU. The number of vehicles in the period in question was analyzed and the annual growth of the number of vehicles of the main types was assessed. Analysis of changes in the length of the most important road types was carried out. The number of accidents and fatalities was analyzed and the changes in this area were assessed. The statistical decrease in the number of accidents and fatalities, as well as a very strong correlation between them, were confirmed. It was indicated in which groups of accidents the fatality risk is the highest. The paper presents a summary of the types of roads on which traffic accidents and fatal traffic accidents occurred. Shares of these roads were determined, indicating that the most dangerous roads in Poland are the two-way, two-lane roads.

Keywords: *road safety, accident, accident statistics*

1 Introduction

The use of cars has become commonplace in everyday life. Unfortunately, the road traffic is a source of traffic events hazardous to the health and life of road users. Every year, there are tens of thousands of accidents in Poland, with several thousand fatalities. Tens of thousands of people are injured in these accidents, which is of no less importance. Traffic accidents have significant social and economic consequences [1-2]. In 2004, the unit cost of a fatality in Poland, estimated according to the PANDORA 2014 method, was approximately PLN 2.05 million and that of severely injured person was PLN 2.32 million. In Poland, the costs of accidents in the year 2004 amounted to about PLN 30 billion [2].

Due to the significance of the traffic accidents problem, a number of publications [3-5] have undertaken analysis of the state of safety on roads of a multitude countries, including Poland [6-8]. This is despite the fact that the roads in the EU are considered to be among the safest in the world. Among those involved in the matters of the road safety, one question is still being raised: what solutions should be implemented to reduce accident rates and their negative consequences? In order to consider these issues, an in-depth analysis of the causes and consequences of traffic accidents is necessary, taking into account various factors [9]. Factors that may determine the possibility of traffic accidents include: the state of road infrastructure in a given country [10], technical factors [11], cultural factors, e.g. inclination to respect the provisions of the Road Code, alcohol consumption, psychological factors [12], road factors [13-14], etc. Problems related to road safety were analyzed in a number of publications [15-17].

In 2004, Poland was included into the European Union. Since then, significant changes have taken place in many aspects of life in Poland. The possibility of free movement in Europe within the Schengen Area, liberalization of many regulations caused changes in the structure of exploited vehicles caused by a large influx of used vehicles. At the same time, along with numerous investments in infrastructure, significant changes have taken place in the broadly understood road surroundings.

The article analyzes selected factors that impact the safety on Polish roads.

2 Vehicles in Poland

The number of vehicles registered in Poland in the analyzed period has significantly changed. In nearly 15 years, it has increased from approximately 16.7 million to nearly 30 million. If we take the 2004 (as 100%) as a baseline value, the recorded increase in this respect reached 77% [18].

At the same time, the number of passenger cars has increased from nearly 12 million to over 22.5. In turn, this translates into an increase of nearly 90%. The number of trucks (44%) and motorcycles (71%) also increased. A summary of the numbers of motor vehicles and passenger cars is presented in Figure 1. When analyzing the number of registered vehicles and population [19], it can be observed that the number of passenger cars per 1000 residents in

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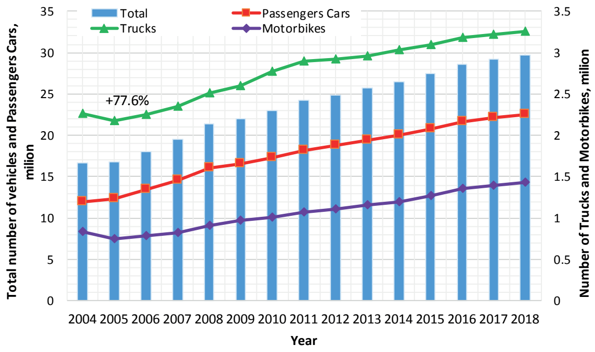

***Figure 1** Numbers of vehicles by type in Poland between 2004 and 2018*

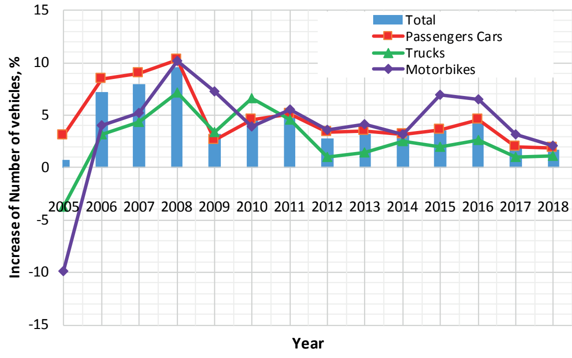

***Figure 3** Relative change in numbers of vehicles*

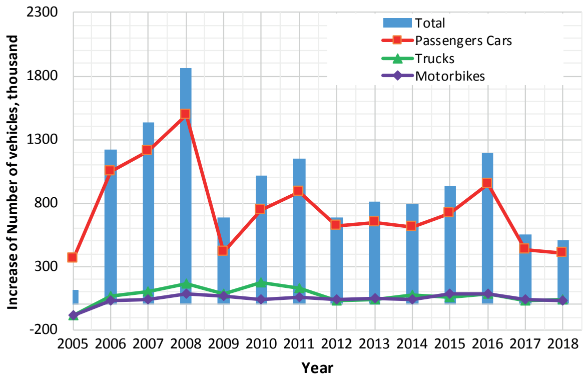

***Figure 2** Change in the numbers vehicles by type*

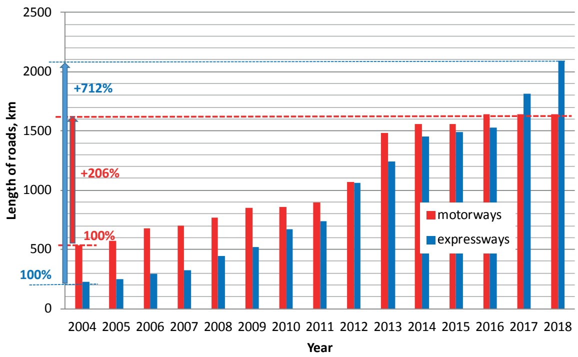

***Figure 4** Change in the length of the most important roads in Poland in the years 2004-2018*

Poland increased form 314 in 2004, and to 586 cars in 2018. In this respect, Poland is currently one of the leading European countries.

After the borders were opened and procedures such as customs formalities were simplified, the annual increases in the number of cars were significant, as shown in Figure 2.

One of the main factors influencing the increase in the total number of vehicles was the change in the number of passenger cars. In the record-breaking year of 2008, the growth of all registered vehicles reached 1.85 million vehicles, 1.5 million of which were passenger cars. If the relative changes in the number of vehicles (Figure 3) in particular groups of vehicles are analyzed, it is clear that the only decrease was recorded in 2005 (compared to 2004) with regard to the number of trucks and motorcycles.

In 2008, the highest relative increase in the number of passenger cars, motorcycles and trucks was recorded -7-10% [18].

3 Changes to roads in Poland

There are over 420 thousand public roads in Poland [8, 20]. In recent years, especially after Poland's accession to the EU, the road network has undergone certain changes. The length of public roads has increased relatively little, by slightly more than 10%. However, the changes are particularly visible in the case of national roads [21], as well as expressways and motorways [22].

The change in the length of the most important roads in Poland is presented in Figure 4 [22]. At the end of 2018, the total length of expressways and motorways in Poland amounted to 2092 km and 1638 km, respectively. In total, these roads in relation to all the public roads in Poland constitute only just over 0.8% of all roads.

In Europe, Spain has the most developed motorway network, having more than 17 thousand km of motorways on an area of 500 thousand km^2 [6]. In Germany (total area of 357 thousand km^2) there are 15.3 thousand km of such roads, while in France (551 thousand km^2) -just over 11.6 thousand km of such roads [18, 23]. The length of such roads per total area of a country is an indicator that determines the degree of development of the road network and the density of the best roads. In Poland, it is only 0.005 km/1 km^2, while in Belgium it is 0.058 km/1 km^2, Holland 0.074 km/1 km^2, Spain 0.0344 km/1 km^2.

Apart from expressways and motorways [22], Poland has nearly 20 thousand km of national roads [24]. All of them include the most important road routes managed by the Polish General Directorate for National Roads and Motorways (GDDKiA). In Poland, these constitute nearly 5% of all available roads.

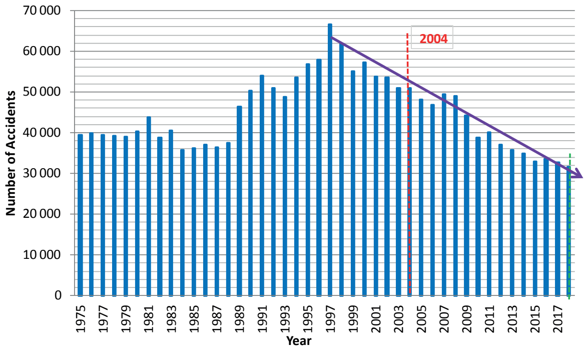

Figure 5 *Number of traffic accidents in Poland*

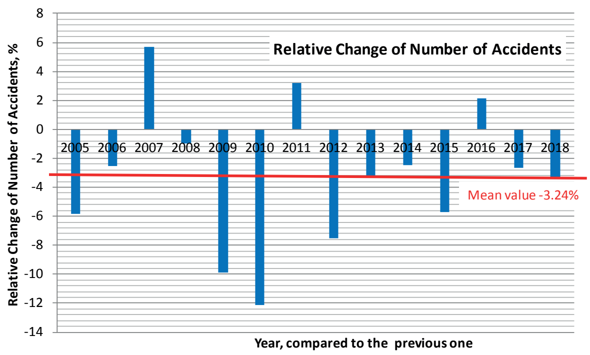

Figure 7 *Relative change in the number of accidents*

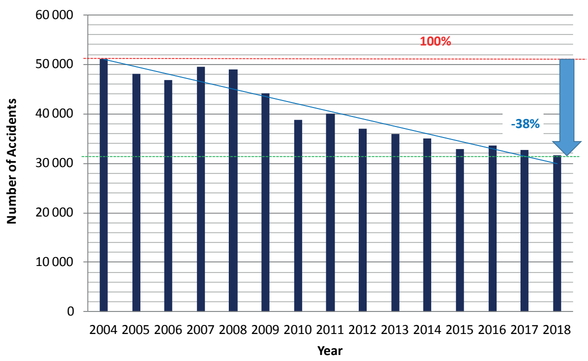

Figure 6 *Decrease of number of traffic accidents in Poland in 2004-2018*

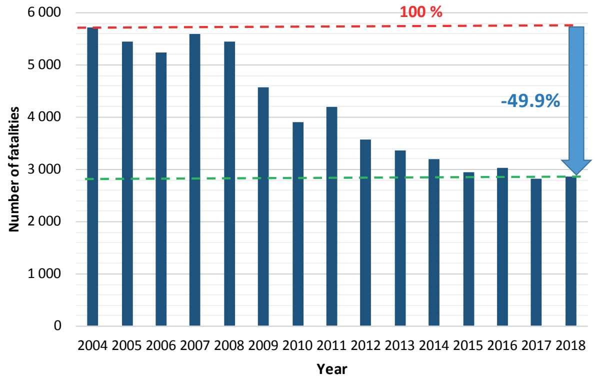

Figure 8 *Number of fatalities on Polish roads in 2004-2018*

If 2004 is assumed as the baseline for the state of roads, in nearly fifteen years the length of motorways has increased by more than 206%, while the length of expressways has increased by 712%.

4 Traffic accidents, their causes and consequences

The road traffic generates the danger of collisions and accidents. Unfortunately, these incidents are still an integral part of the road traffic. Despite many actions taken both in Poland [25-27] and by EU authorities [28-30], the still unattainable and still time-shifted goal is to halve the number of deaths. Such an ambitious goal was set earlier for the year 2020 (in relation to 2010) [28, 30].

In Poland, in the analyzed years, considering the significant density of traffic, the statistically assessed road safety improved, although it was subject to significant fluctuations [7, 16, 31]. To make the state of safety in Poland easier to assess, Figure 5 shows the number of accidents in the last 40 years.

From such a perspective, it is clear that the culmination point of the number of accidents on Polish roads (which occurred many years before Poland's accession to the EU) was in 1997. A record number of over 66 thousand accidents was recorded in Poland in that year. In order to indicate the importance of the problem, it is worth mentioning that according to EC (CARE) data [23, 32-33] there were more than 1.36 million accidents in Europe total. In terms of the number of accidents, this placed Poland among the top European countries. In this respect Poland was surpassed by such countries as: Germany with 339 thousand accidents, Italy -243 thousand, Great Britain -213 thousand or, the similar in terms of area and population, Spain -94 thousand. It should be noted, however, that the way in which accidents are counted and defined varies from country to country, making it very difficult to compare these data in full. During a meeting of EU transport ministers in Valetta, attention was also drawn to the fact that EU Member States should report traffic accidents using a common definition of "accidents", using comparable and reliable data [28, 34].

Since 1997, there has been a clear decrease in the number of accidents in Poland. When the analysis is narrowed down to the period 2004-2018 (see Figure 6) it can be seen that the number of accidents since Poland's accession to the EU has decreased by 38%. It is worth noting, however, that at the same time in the analyzed period the number of vehicles increased by nearly 80%.

The value of the relative change in the number of accidents is shown in Figure 7, the average value (marked with a red line) in the analyzed years amounted to -3.24%. This indicates an annual statistical decrease in the number of accidents. The largest decrease, i.e. approx. 10% and over, was recorded in the years 2009-2010. However, the downward trend was not recorded annually, as in 2007 the highest increase in the number of accidents was recorded, reaching 6%.

In 2004, a total of 47,900 people died in EU countries. In Poland, this value was 5,712. Calculated per million citizens,

Table 1 *Coefficient of determination R^2 for the accident data in different European countries*

Country	Coefficient of determination R^2	Country	Coefficient of determination R^2
Austria	0.450	Italy	0.912
Belgium	0.754	Latvia	0.893
Bulgaria	0.733	Lithuania	0.969
Croatia	0.934	Luxembourg	0.870
Czech Republic	0.828	Malta	0.043
Cyprus	0.830	Netherlands	0.714
Denmark	0.827	Poland	0.994
Estonia	0.981	Portugal	0.819
France	0.941	Romania	0.006
Finland	0.754	Slovakia	0.667
Germany	0.922	Slovenia	0.919
Greece	0.928	Spain	0.230
Hungary	0.982	Sweden	0.960
Ireland	0.249	UK	0.960
		EU	0.988

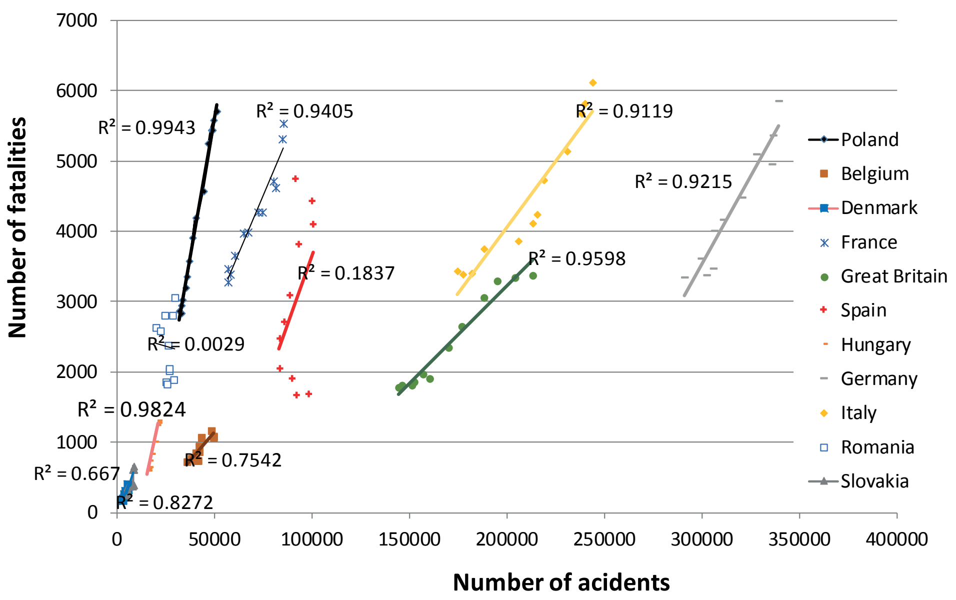

Figure 9 *Number of road accidents versus the number of fatalities for several member states of the EU*

this means that, in 2004, there were almost 150 fatalities in traffic accidents per million citizens. In the period 2004-2018 the number of fatalities on Polish roads decreased by nearly 50% (Figure 8).

In 2018, 3,862 fatalities were recorded, which means that statistically 76 people per 1 million citizens died on the roads in Poland. Taking into account the fact that the EU average in 2018 in this respect was 49, Poland ranked fifth in this unfavorable ranking. Poland was ahead of Romania (96), Bulgaria (88), Latvia (78) and Croatia (77) in this respect. United Kingdom (28), Denmark (29), Ireland and Netherlands (31) and Sweden (32) have been identified as the safest countries in this respect [33]. According to incomplete data, in 2018 there were around 25,300 fatalities and 135,000 injured on the EU roads [30].

Analysing the available information presented by CARE [23, 33], one wonders whether there is any relationship between the number of road accidents and the number of fatalities. From the data presented in [34] it is clear that the number of accidents in Poland is largely dependent on the number of people killed. If one compares the results provided in Figure 9, it can be seen that the coefficient of determination R^2 for Poland is very high, reaching approximately 0.99. High values are also reported for such countries as Hungary (R^2= 0.982), Estonia (R^2= 0.981), Lithuania (R^2= 0.982) and the UK (R^2= 0.96). The values indicate that if the number of road accidents is reduced, the number of fatalities will decrease, too. However, reducing the number of killed to zero in this way is not possible in practice. The mean coefficient of determination obtained

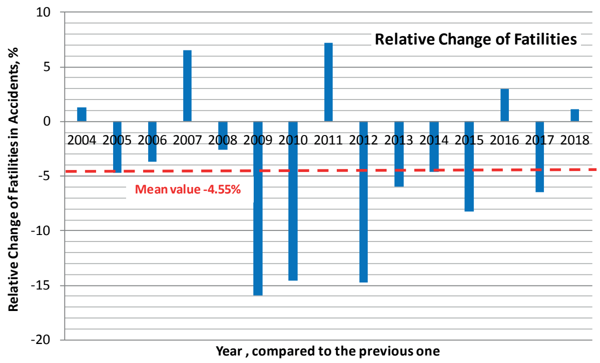

Figure 10 Relative decrease in the number of fatalities

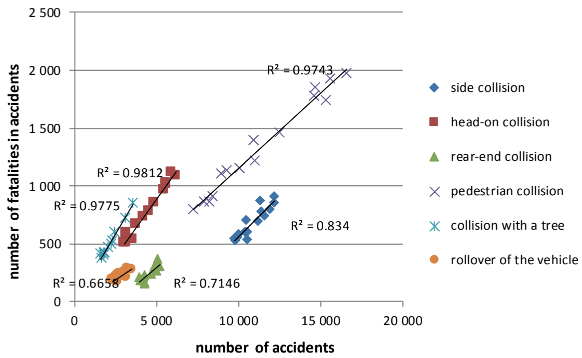

Figure 13 Dependency of number of fatalities on number of accidents

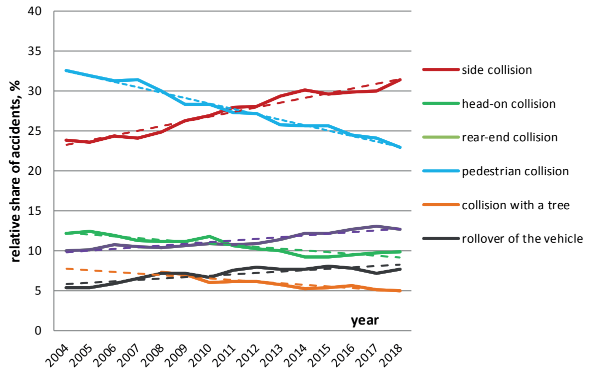

Figure 11 Specificity of traffic accidents in Poland

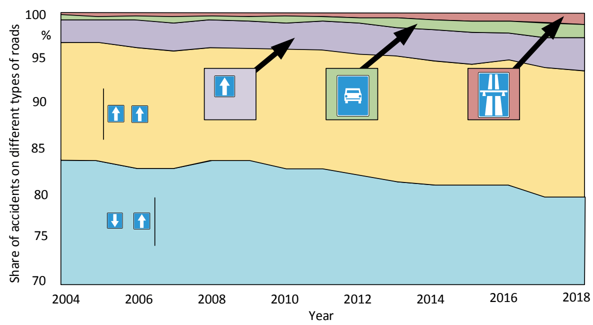

Figure 14 Share of accidents on different types of roads in Poland

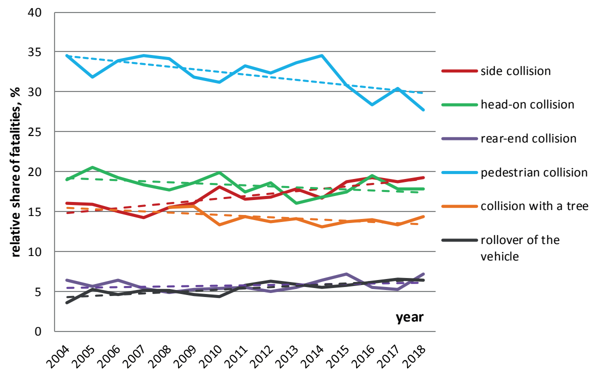

Figure 12 Specificity of fatalities in the main types of traffic accidents in Poland

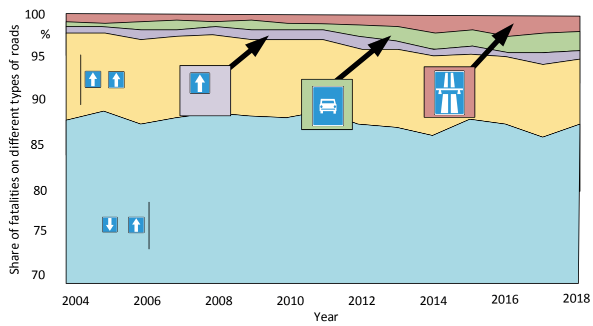

Figure 15 Graphic representation of the shares of fatalities on particular types of roads in Poland

for the total number of accidents and the total number of fatalities in the EU member states is R^2=0.988. The lowest values of R^2 are observed for Romania (R^2= 0.006), Malta (R^2= 0.043) and Luxembourg (R^2= 0.087), which suggests that there is no such relationship for these countries.

Table 1 shows the values of the coefficient of determination R^2, being the ratio of the number of road accidents to the number of fatalities, obtained for selected EU member states in the analysed period.

Figure 10 presents the results of analysis of the relative annual changes in the number of traffic accident fatalities.

In certain years (especially in 2009, 2010 and 2012) quite a significant reduction of their value -by about 15%, was recorded. Only in four years of the analyzed period, an increase was recorded, with the highest in 2011 (by 7%). The average decrease in the relative number of road fatalities in the analyzed period was 4.55%.

When analyzing the state of the road safety in the period in question, accidents where divided in the main types as presented in Figure 11.

Analyzing the specificity of accidents, it is worth noting that in the years 2004-2019, the share of side collisions caused by e.g. not yielding when appropriate, as well as rear-end collisions and rollovers, significantly increased. It is worth emphasizing that, in the analyzed period, the share of pedestrian collisions significantly decreased from 33% to about 24% [18, 35]. Despite the number of accidents involving pedestrians still being high, this decrease can be deemed positive, as almost every accident with participation of the so-called unprotected road users results in a fatality or serious injury [25].

Figure 12 presents the share of fatalities in this type of accidents. The largest, although decreasing (over 30%) share in the number of fatalities are accidents related to pedestrians being run over. This is followed by the head-on collisions (20%), although it can be seen that the side collisions have been equally dangerous in recent years.

Figure 13 presents the results of the correlation analysis between the number of accidents and the number of fatalities in different types of accidents.

When analyzing the graph in Figure 13, it can be seen that the high value of the coefficient of determination confirms the close dependency between the number of accidents and fatalities. The lowest coefficient of determination occurs in case of rollovers and amounts to R^2=0.665. The highest coefficients were recorded for head-on collisions (R^2=0.981), collisions with trees (R^2=0.977) or pedestrian collisions (R^2=0.971), which means that these types of accidents have the greatest impact on the number of fatalities.

Figure 14 presents a summary of accidents occurring on different types of roads. The following types of roads were considered:

a) “A” -two-way, two-lane roads,
b) “B” -one-way, two-lane roads,
c) “C” -one-way, single-lane roads,
d) “E” -expressways,
e) “M” -motorways.

The dominant type of roads (and at the same time the most common in Poland) with regards to number of accidents recorded were type “A” roads. Despite a number of investments, the share of accidents on these roads was over 80%. On type “B” roads the percentage of accidents was approx. 13%, on type “C” roads it was around 3-4%, while on roads type “M” and “E” it was approx. 1.5% [18].

Since the share of accidents on roads type “C”, “E” and “M” is relatively small, the range of values on the ordinate axis in the graph presented in Figure 14 was narrowed down to 70%-100% in order to improve its legibility [18].

Figure 15 presents a summary of the types of roads on which fatal accidents are recorded. The dominant type of roads in this respect were type “A” roads, i.e. two-way, two-lane roads. The share of fatalities on these roads was nearly 86-88%.

Comparing Figures 14 and 15, there are certain clear trends in the analyzed period. The share of accidents on type “A” roads, i.e. two-way, two-lane roads is decreasing (a decrease of about 4% was recorded), but it did not result in a significant decrease in the share of fatalities on these roads (about -0.6%). A minor increase (by about 1%) in the number of accidents on other types of roads resulted in a decrease in the share of fatalities on roads type “B” by 2.3% and the increase on motorways (type “M”) and expressways (type “E”) by slightly more than 1%.

5 Conclusions

In 2004, Poland has joined the European Union. Since then, a visible qualitative change is taking place in many areas in Poland. In the area of transport and road safety, certain changes and regularities could also be observed over the past 15 years. It is easily noticeable that the number of registered cars in Poland in 2018 grew to nearly 30 million with over 22.5 million passenger cars. When analyzing these data in relation to the base year 2004, one can speak of increases of 77.6% and 88%, respectively. The annual increase of the number of vehicles in certain years was as high as 10%. These vehicles make use of the available road network. The total length of all public roads in Poland increased by about 10%, in the case of the most significant roads and best in terms of their technical characteristics, the increase was more pronounced. The changes in the linear infrastructure were accompanied by changes in the statistics of traffic incidents. In the analyzed period, the number of accidents dropped by 38% and the number of fatalities by nearly 50%.

The high values of the coefficient of determination R^2 reported for several European countries, including Poland, confirm that one of the ways to reduce the number of fatalities is reducing the number of accidents.

Analyzing the number of accidents and fatalities, a very strong correlation (R^2>0.97) between the number of accidents and the number of fatalities was confirmed, in case of certain types of accidents: head-on collisions, collisions with trees or pedestrians. Analyzing the structure of the road network, a summary was made of the types of roads on which accidents and fatal accidents took place. The most dangerous roads in Poland are two-way, two-lane roads.

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Jan Steininger - Stefan Medvecky - Robert Kohar - Tomas Capak

OPTIMIZATION PROCEDURE OF ROLLER ELEMENTS GEOMETRY WITH REGARD TO DURABILITY OF SPHERICAL ROLLER BEARINGS

The article deals with an optimization procedure of roller elements geometry with regard to durability of spherical roller bearings. The aim of the article is to examine the impact of change of the roller elements inner geometry on durability and reliability of spherical roller bearings; the contact strain along a spherical roller by means of the Finite Element Method at contact points of components of a spherical roller bearing by means of designed 3D parametric models. The most appropriate shape of roller elements inner geometry of a bearing from the standpoint of calculated durability was determined based on results of the contact analyses.

Keywords: *rolling element, contact strain, spherical roller bearing*

1 Introduction

Roller bearings are an inseparable part of most machines and devices in which there takes place a rotation movement or a linear motion. There are different requirements on roller bearings. Production machines need bearings, which are able to work in high revolution, in power engineering bearings have to carry heavy loads, etc.

Development, or rather rolling bearing optimization, is conditioned by an increase of technical parameters in machines and devices. This fact refers especially to an increase of input parameters such as power and revolution, weight and volume reduction, noise level reduction, etc. However, the most important parameters requiring optimization are the bearing lifetime and reliability.

Development of new technologies introduces also new construction materials, new production techniques of semi-finished products and bearing components or new installation methods. It is important not to overlook the bearing construction. Here it is possible to perform geometry adjustment optimization. This adjustment applies especially to geometry adjustment of raceways and rolling elements in the spherical roller bearings.

2 Spherical roller bearings durability

The double-row angular spherical roller bearing has a raceway spherically ground on the outer ring. The bearing is able to accommodate very high radial loads, as well as heavy axial loads in both directions. The high radial load capacity is caused by the great number of rolling elements, the so-called spherical rollers and their close contact on the inner ring raceways [1].

Roller bearings durability depends on a revolution number, which the bearing can perform until fatigue of any of their components takes place. A peeled material is a sign of the component fatigue. Fatigue is a basic and natural way of bearing damage. It is demonstrated by the presence of small cracks under the bearing raceway surface. The depth of these cracks is usually about 0.05-0.3 mm depending on the surface curve radii of rolling elements and the bearing ringsraceways. The crack depth allows the material changes, which are caused by the slide pulsating strain. This process leads to a gradual crack formation under the surface. It can take quite a long time until it is visible on the surface in a form of the peeled off material, the so-called pitting [2-3].

3 Contact strain along spherical roller in a spherical roller bearing

It is possible to calculate the intensity of the contact pressure and the size of the contact surface - effective length l_{ef} and width 2b from the contact pressure distribution at the most strained point in the bearing inner ring. Figure 1 shows the course projection (the curve) of the contact pressure along the contact surface l_{ef} of the contact ellipse on the bearing inner ring. The contact strain curve has been calculated using the finite element method [4].

4 Optimization of geometry of spherical roller bearing

The bearing model was simplified by axial symmetry. the bonds between the individual parts of the bearing were

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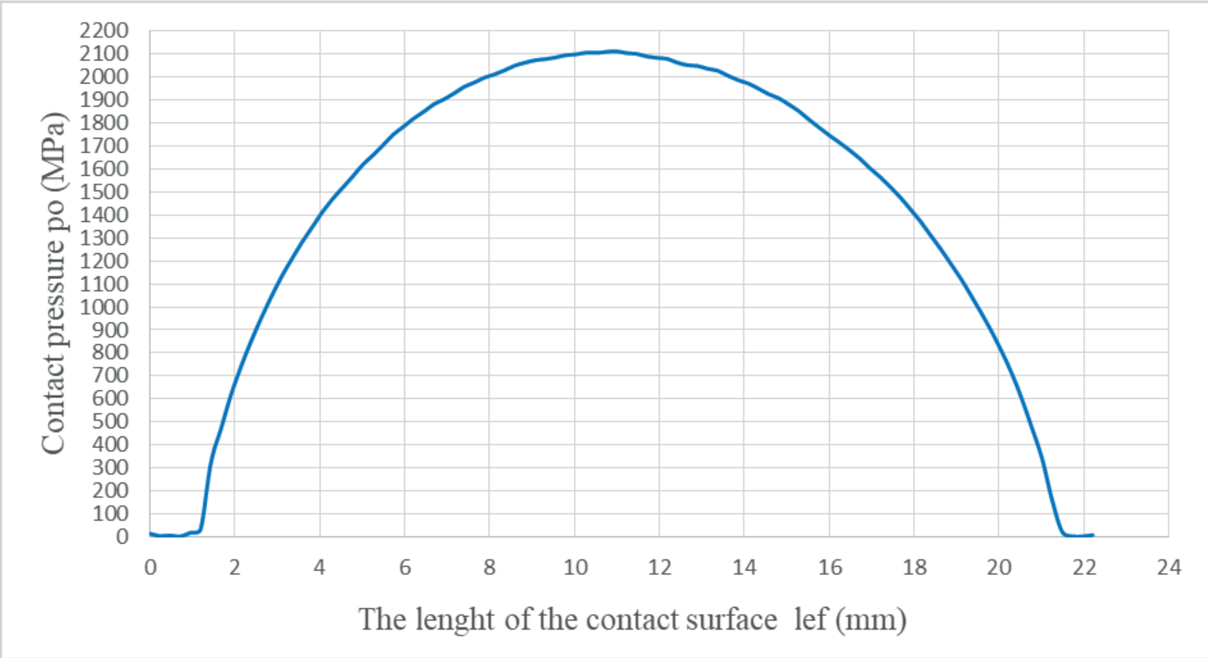

Figure 1 *The contact pressure course on the inner bearing ring raceway*

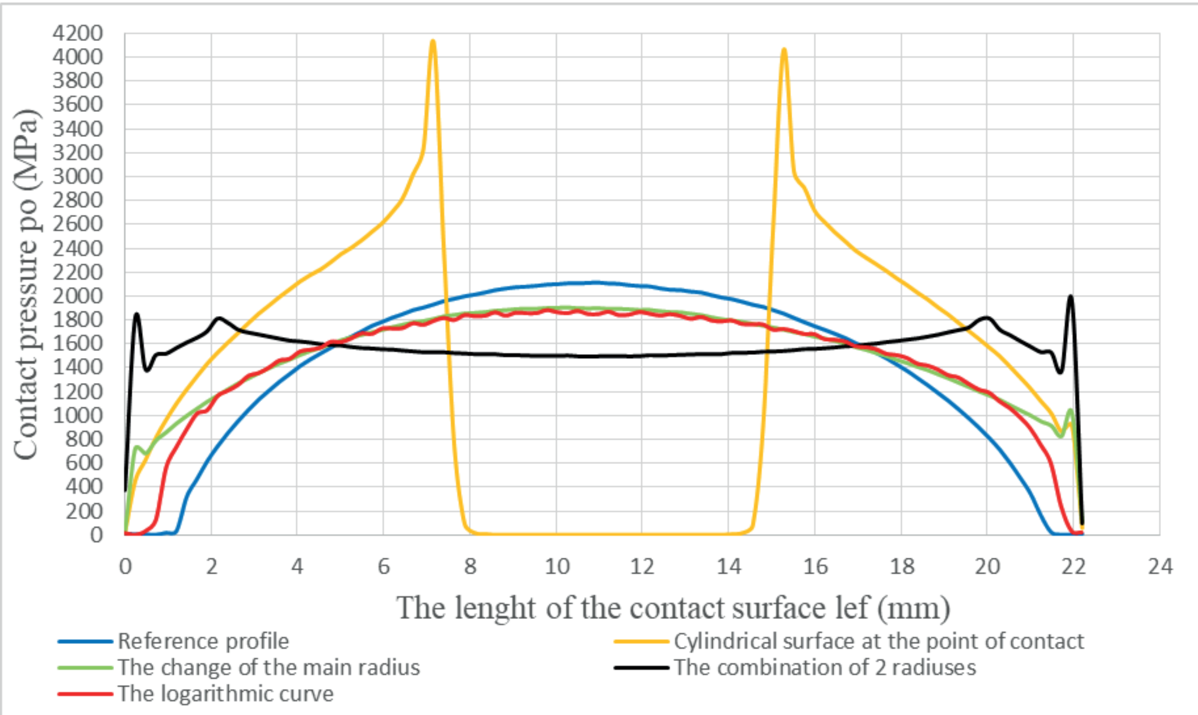

Figure 2 *Comparison of the contact pressure courses in the bearing raceway of the spherical roller bearing inner ring for the rolling element analyzed geometries*

replaced by contacts. Degrees of freedom were taken from the outer ring of the bearing. The rolling element load calculation is based on the Hertz theory and the reference bearing calculation data. It is possible to distribute the bearing load to individual rolling elements. The load on the selected part of the bearing was calculated to be 9 kN. The contact volumes were meshed with 0.08 mm hexahedrons. The other parts were meshed with 0.56 mm tetrahedrons. The transition edges were meshed at 0.24 mm [5-6].

The aim of optimization was a decrease of contact pressure that acts at the point of contact of the rolling element with the outer and the inner ring. The profile of a rolling element was optimized and the contact strain between the rolling elements and bearing rings was calculated, as well [7].

The three new geometries of the rolling element for spherical roller bearings were designed that were consequently compared with the reference profile. Selection of the most appropriate design of the new geometry of the

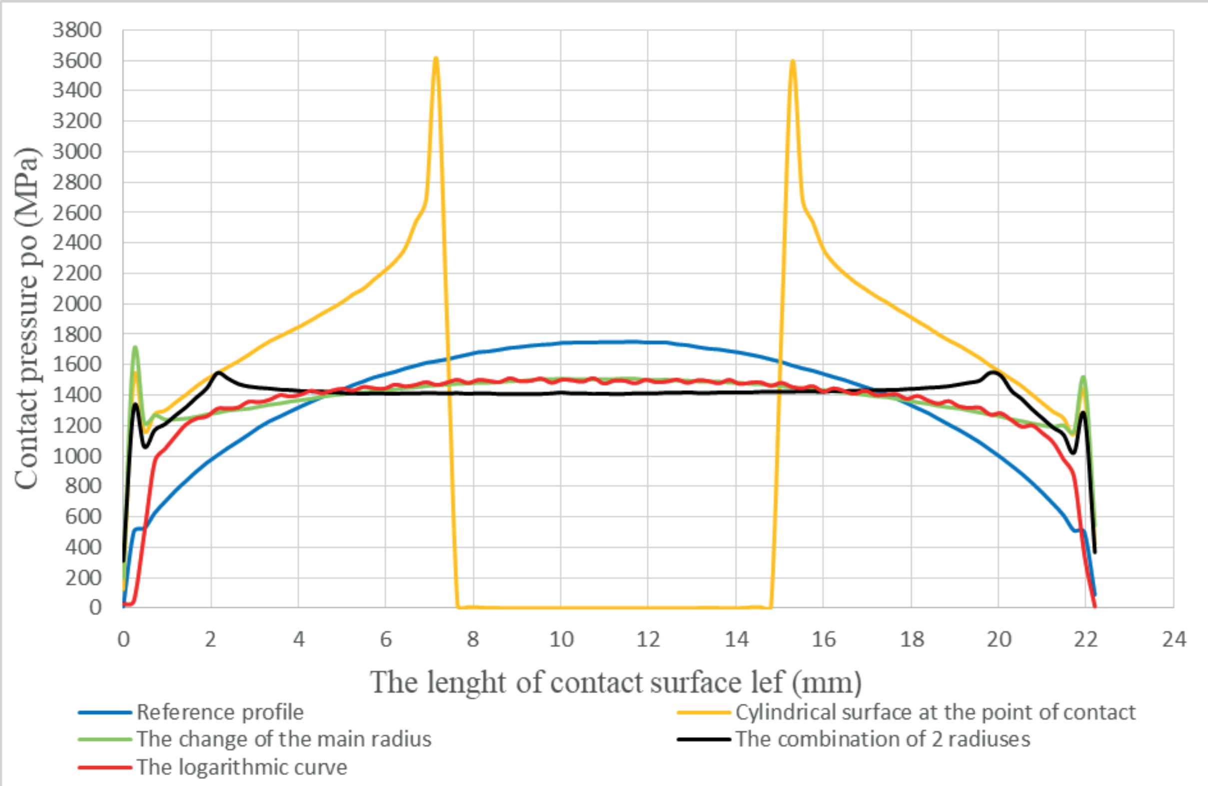

Figure 3 *Comparison of the contact pressure courses in the bearing raceway of the spherical roller bearing outer ring for the rolling element analyzed geometries*

Table 1 *Evaluation of results of analyses in the spherical roller bearing inner ring*

Design nr.	Title	l_{ef} (mm)	b_{ef} (mm)	p_o (MPa)	σ_{max} (MPa)
Reference bearing	Profile	21	0.96	2106.1	1426
1	Cylindrical surface at the point of contact	22.14	1.21	4022.1	3019.1
2	The change of the main radius	22.13	0.96	1921.5	1319.9
3	The combination of 2 radii	22.14	0.64	2106.1	1315.3
4	Logarithmic curve	21.9	0.63	1948.3	1302.6

Table 2 *Evaluation of results of analyses in the spherical roller bearing outer ring*

Design nr.	Title	l_{ef} (mm)	b_{ef} (mm)	p_o (MPa)	σ_{max} (MPa)
Reference bearing	Profile	21.8	0.8	1758.4	1426
1	Cylindrical surface at the point of contact	22.13	0.99	3658.6	3019
2	The change of the main radius	22.14	1.21	2048.7	1319.9
3	The combination of 2 radii	22.14	1.18	1719.7	1315.3
4	Logarithmic curve	22	0.64	1576.9	1302.6

rolling element was based on comparison of the contact pressures on bearing raceways of the inner and outer bearing rings.

The comparison of curves of the rolling elements contact pressures depends on the length of the contact surface l_{ef}. Figure 2 (inner ring) and Figure 3 (outer ring) show the curves' shape. A decrease of contact pressure on bearing raceways of bearing rings was obtained in all the designs of a new geometry of the rolling element [7-8].

As shown in Figures 2 and 3, the lowest contact pressure acts between the two bearing rings and the rolling element with new geometry 4. At the same time, the contact pressure that acts between the bearing rings and the rolling element does not produce maximum strain

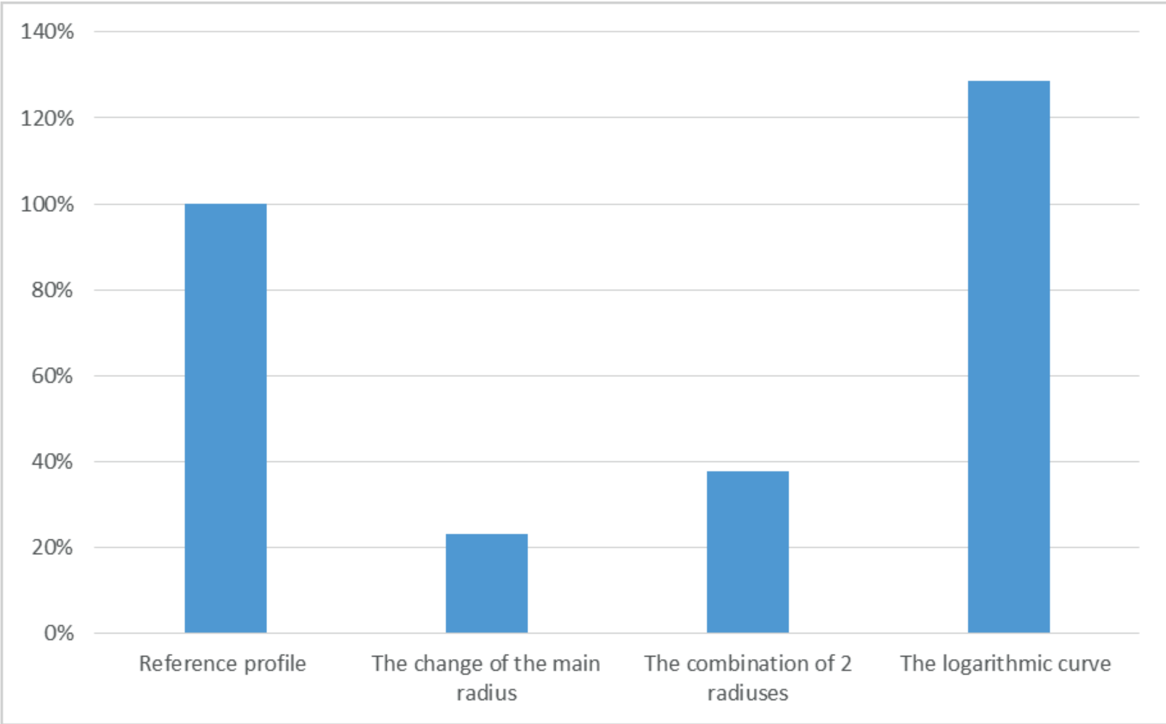

***Figure 4** Comparison of calculated lifetimes of analysed geometries*

values that negatively affect the bearing durability. The new geometry of the spherical roller bearing formed by the logarithmic curve is the most appropriate for optimization of the spherical roller bearing regarding its durability and lifespan [8].

Evaluation and selection of the most appropriate design of the new geometry are shown in Table 1 and Table 2, respectively.

For the better evaluation of analysed geometries durability of individual analysed geometries was calculated according to the Lundberg-Palmgren theory:

$$\ln\frac{1}{s} \approx A * \frac{N^e * \tau_0^c * V}{z_0^h}, \qquad (1)$$

$$\tau_0 \approx 0.256 * p_o, \qquad (2)$$

$$z_0 \approx 0.25 * 2b, \qquad (3)$$

where: S is the probability of survival,
N is the number of load cycles,
V is the stressed volume,
e, c, h, A are material constants defined by experiments,
p_0 is the pressure present at the contact point,
$2b$ is the minor axis of the ellipse [9].

Calculation of a total lifetime of the bearing was based on partial lifetimes of bearing rings. As far as a logical comparison is concerned, 100 % is assigned to the reference geometry.

In a new design 1 (Cylindrical surface at the point of contact), the calculated pressures are well above those of the reference bearing. Therefore, the analysis of the new design 1 is excluded from further comparison.

Comparison of the calculated lifetimes of analysed geometries is shown in Figure 4 [10].

5 Conclusions

Spherical roller bearings can be optimized by modification of the geometry of the rolling element, i.e., the spherical roller. The most appropriate geometry seems to be the one formed by the logarithmic curve after a comparison of lifetimes of the bearing with the new geometry of the rolling element (Figure 4). The logarithmic curve is described by equations, while in this case a parameter of a loss of the logarithmic curve profile, i.e., a modified surface of the spherical roller. The optimal value of the parameter is 0.00035 mm which is similar as in the case of the rolling bearing with the logarithmic profile.

The new geometry of the rolling bearing composed by the logarithmic curve increases the total carrying capacity and thus bearing durability by more than 25 %. This new geometry does not form the strain peaks that negatively affect the total bearing durability.

Acknowledgment

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BASIC COMPARISON AND EVALUATION OF FUNCTIONALITY AC-AC MATRIX CONVERTER CONCEPTS FOR HEV VEHICLE - PART II

The paper deals with a modeling and simulation of the direct AC-AC propulsion system and compares two matrix converter concepts with five-phase traction induction motors (IM) for the hybrid electric vehicle (HEV). The simulation results of [3x5] matrix converter and 4Q-converter are done using Matlab-Simulink environment. Part I deals with a theoretical study of converter concepts for hybrid electric vehicle, since the configurations of [3x5]+[0x5] matrix converters with five-phase motor(s) have not been analyzed so far. Based on simulation results the comparison and evaluation of the property and quality of the quantities of different type of the matrix powertrain are discussed in Part II.

***Keywords:** AC/AC powertrain, 3x5 matrix converter, 0x5 matrix converter, five-phase induction motor, electric drive, 4QC converter, modeling and simulation, HEV vehicle*

The article is a continuation of Part I [1].

1 Introduction

The paper [2] compares a [3x3] matrix converter (MxC) and 3-phase VSI converter with an active front end for a 7.5 kW induction motor drive. It has been shown that the matrix converter's semiconductor losses are smaller at full load operation for the same silicon area in both converters. A one-third reduction of the device current rating of the MC is possible, resulting in comparable thermal device stress. The overall passive component count and rating are only slightly better for the MxC but the absence of bulky smoothing capacitor is evident what emphases also work [3].

A novel enhanced AC/AC series/parallel HEV powertrain has been introduced in Part I of [1], Figure 1.

An indirect space-vector modulated three-phase AC-DC matrix converter for hybrid electric vehicles in [4], and with improved efficiency in [5]. The configurations of [3x5]+[0x5] matrix converters with five-phase motor(s) are not analyzed in available literature so far.

2 Comparing simulation results of both concepts of MxC propulsion powertrain

Modeling approach of PMSG generator was taken from [6] and [7]. Modeling of matrix converter with indirect control and supposing multi-phase commutation was adapted for five-phase from [8-11] without special IM control. Model of five-phase IM can be found and taken from [12]. The connection of the control scheme of AC/AC powertrain with internal-combustion engine and synchronous generator together with a five phase induction machine and matrix converter are depicted in Figure 2.

The simulation results of the proposed powertrain are shown in Figures 2-4. Autonomous drive mode of HEV powered by ICE/SG is shown in Figure 3a-e. It can be seen as waveforms of input/output quantities of [3x5] MxC as phase motor current/voltage and generator current/voltage, respectively. The entire control scheme in Matlab/Simulink environment is shown in Figure 2 - where matrix converter is presented by block 3x5 MxC.

There are simulation results of the start-up of AC/AC powertrain in Figure 3a and 3c. After start-up of ICE/SG during 0-2 sec with one no-load IM, the IM is loaded by torque equal 20 Nm. Steady-state results of voltages and currents of SG and IM are given in Figure 3b and Figure 3d-e. They show a good quality of the quantity waveforms, mainly of phase-current of IM. Any special control of IM has not been used.

Autonomous drive mode of HEV powered by AB accu-battery using 4QC and [3x5] MxC is shown in Figure 4. Wave-forms of input/output quantities of 4QC and [3x5] MxC can be seen there.

There are results of the start-up of AC/AC powertrain powered by accu-battery and 4QC converter in Figure 4a-c and Figure 4f-g. The total course of the start-up is similar to the previous one (in Figure 3c) but DC current is taken from accu-battery AB and input currents of [3x5] MxC are different due to 4QC operation. During start-up, the IM is no-loaded. The steady-state voltage of 4QC, phase-voltage, and current IM are given in Figure 4e and Figure 4h. Phase-current of IM (Figure 4h) is similar to that of IM powered by AB without 4QC (Figure 5e - the next). Any special control of IM has not been used.

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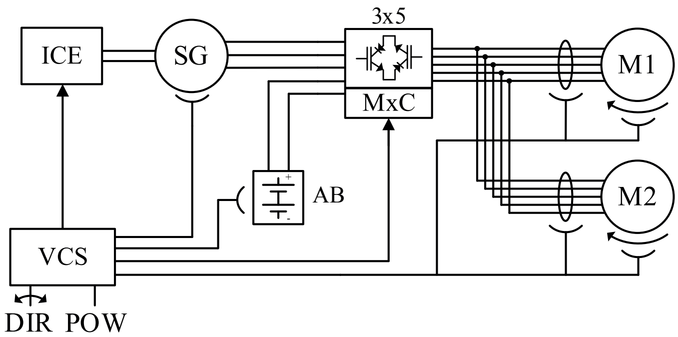

Figure 1 *Novel enhanced AC/AC series/parallel HEV with one MxC converter and two traction motors M1, M2 with independent control*

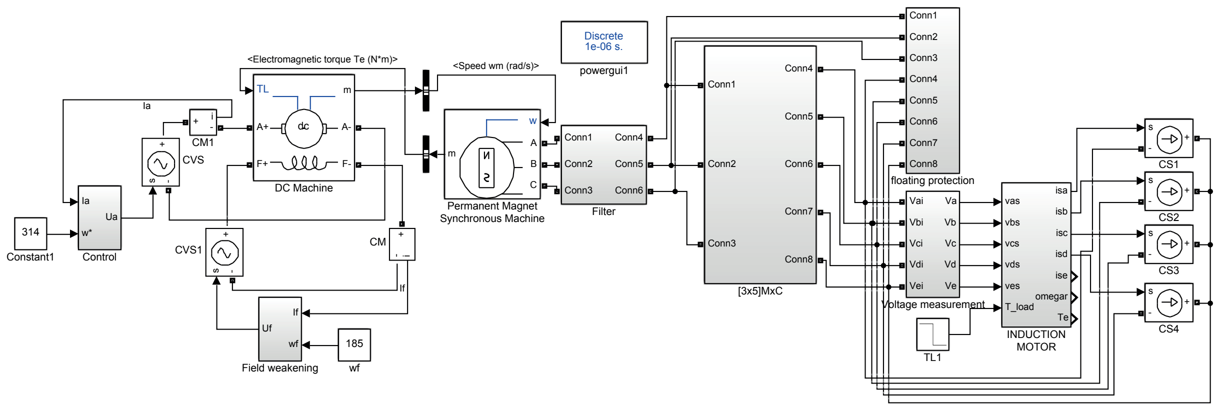

Figure 2 *The control scheme of AC/AC powertrain with ICE/SG unit, [3x5] matrix converter and 5-phase IM in Matlab/Simulink environment*

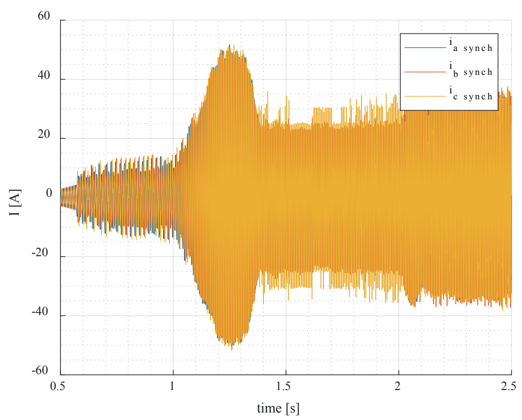

Figure 3a *Start-up of SG - phase-currents*

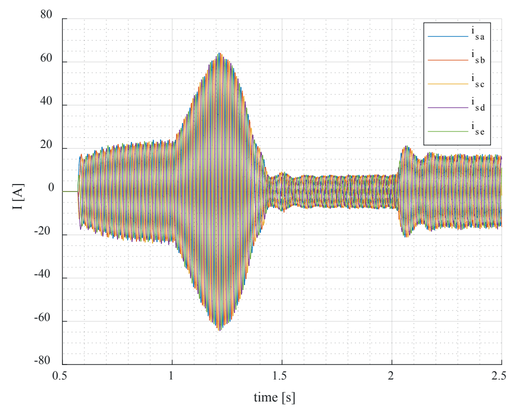

Figure 3c *Start-up of IM - phase-currents*

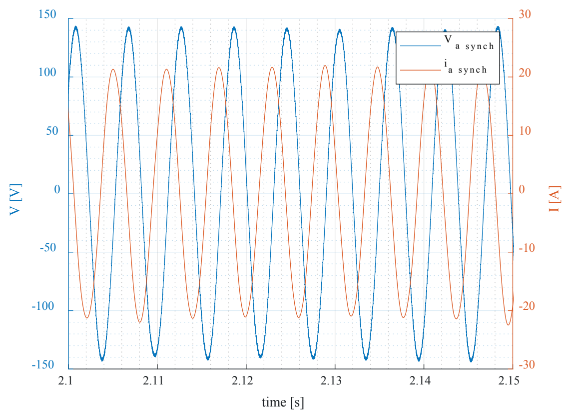

Figure 3b *The SG - phase-voltage/current in details*

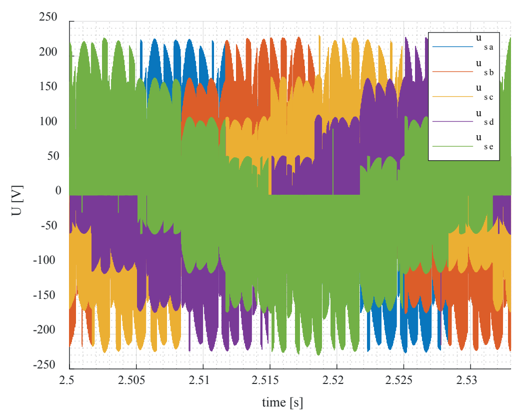

Figure 3d *The IM phase-voltages of IM*

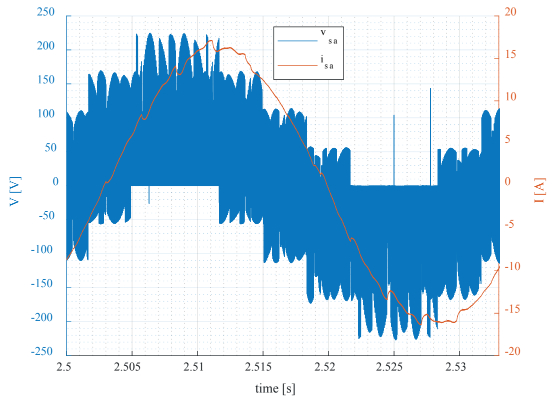

Figure 3e *The IM phase-current and voltage in steady-state in detail*

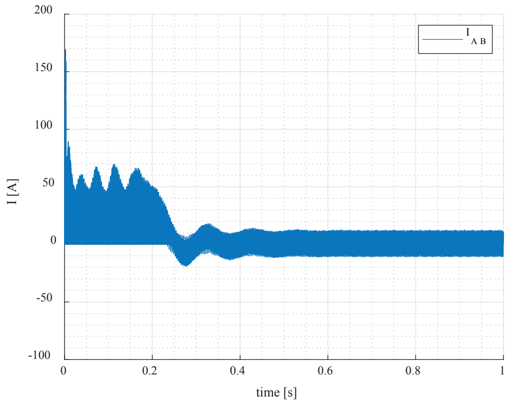

Figure 4a *The current taken from accu-battery*

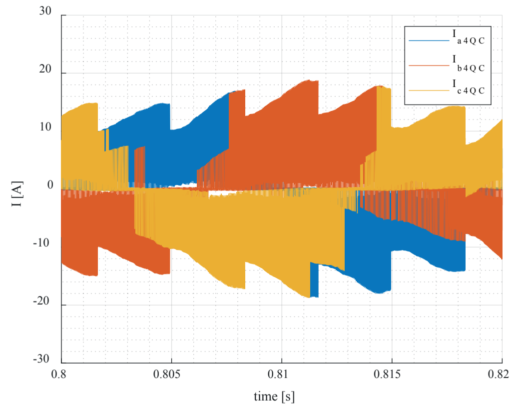

Figure 4d *The 4QC phase-currents in detail*

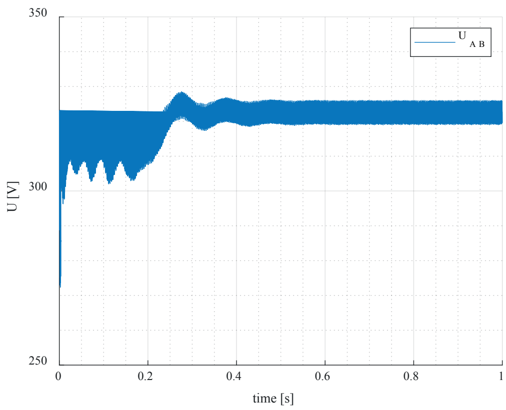

Figure 4b *The accu-battery voltage*

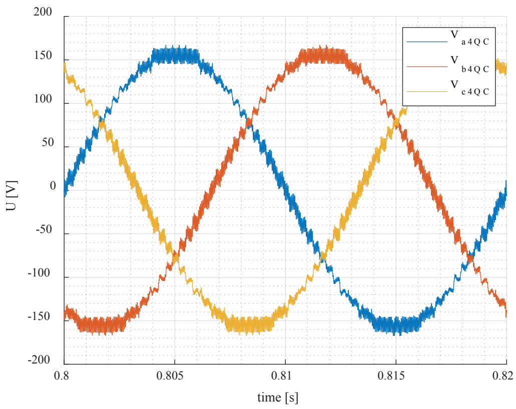

Figure 4e *The 4QC phase-voltages in detail*

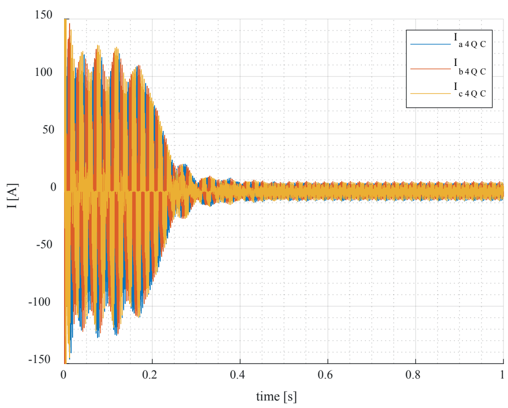

Figure 4c *Start-up 4QC currents of traction mode*

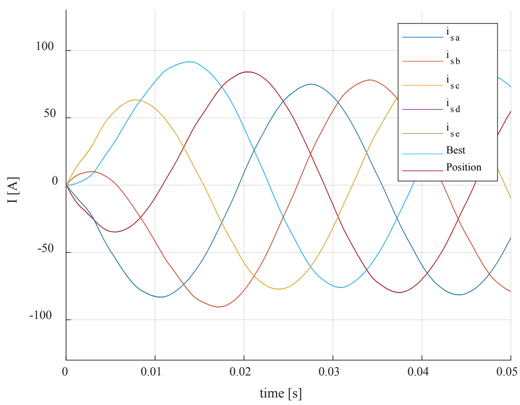

Figure 4f *Start-up currents of IM*

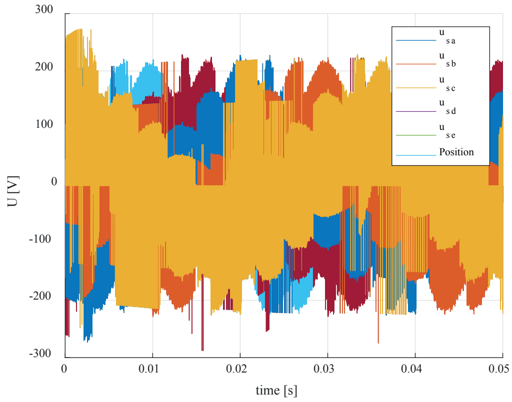

Figure 4g *Start-up voltages of the IM motor*

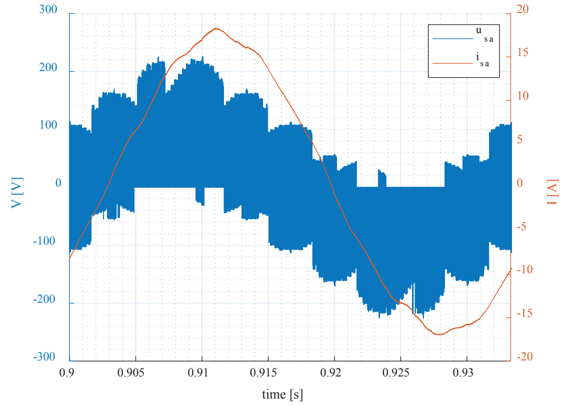

Figure 4h *The phase voltage and current in detail*

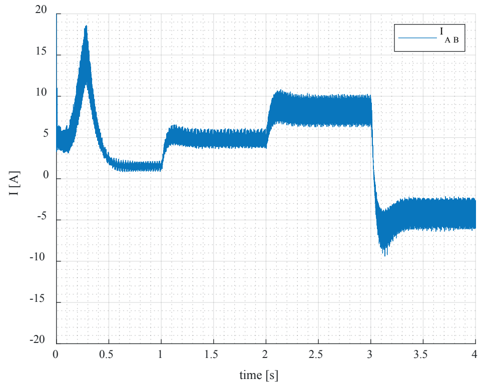

Figure 5a *The current taken from AB accu-battery*

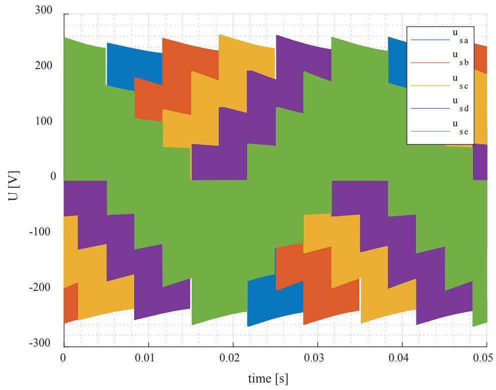

Figure 5d *The stator voltages of the IM motor*

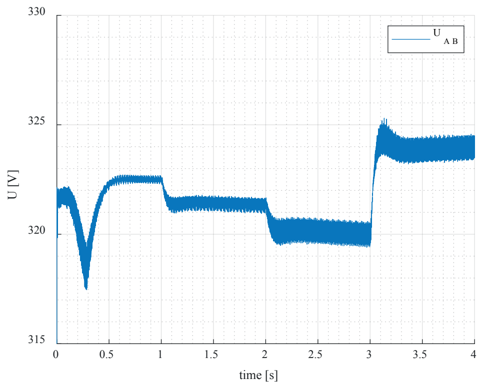

Figure 5b *The accu-battery voltage*

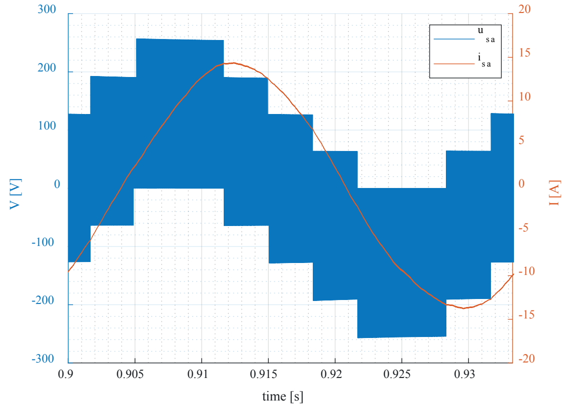

Figure 5e *The phase voltage and current of the IM motor in details*

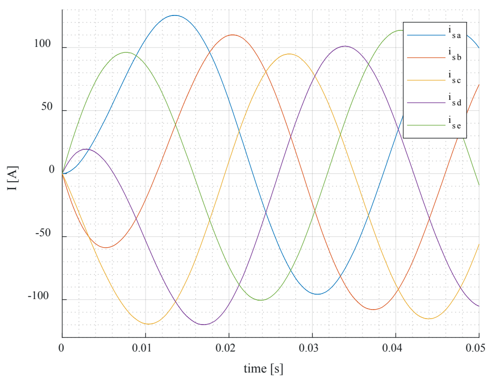

Figure 5c *The stator currents in details*

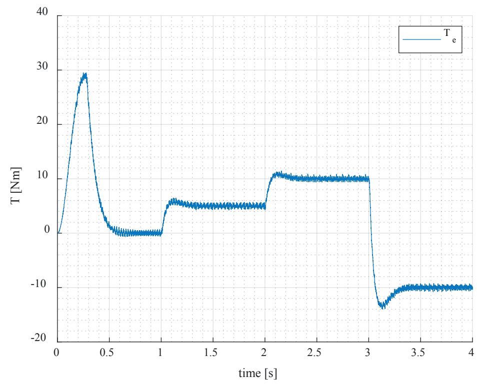

Figure 5f *Time course of motor torque*

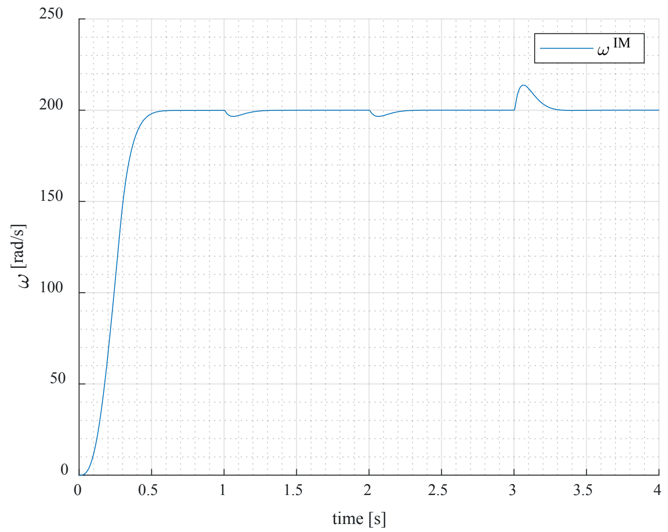

***Figure 5g** Time course of angular speed*

Autonomous drive mode of HEV powered by AB accu-battery using [0x5] MxC is shown in Figure 5a-g. The waveforms of input/output quantities of [3x5] MxC operated as [0x5] MxC converter can be seen there.

The start-up of IM supplied by accu-battery AB is shown in Figure 5a, Figure 5c and Figure 5e. After start-up of ICE/SG, in time of 1, 2 and 3 sec, the IM has been loaded with torque 5, 10 and -10 Nm, respectively. Steady-state of phase voltages and currents are presented in Figure 5d and Figure 5e. Comparison to previous result mode (Figure 4a-c) shows that start-up of IM is faster, and shape of phase-voltage of IM slightly different one but the phase-current is slighly better. Torque and angular speed circumstances are depicted in Figure 5f-g.

Comparison of autonomous modes in Figure 4 and Figure 5 shows that the concept of AC/AC powertrain with 4QC features:

worse quality of quantities waveforms as accu-battery current and output phase current and voltage of the IM motor

worse energetic efficiency because of adding of 4QC into the power chain.

A similar situation is regarding to charging of accu-battery by concept with 4QC, and starting-up of ICE/SG module using the 4QC unit or [0x3] and [5x3] MxCs, respectively. Comparison of autonomous modes in Figure 4 to previous Figure 2 and Figure 3 it should be noted that 4QC converter and input - 3-phase - LC filter in front of matrix converter are not necessary, therefore, the efficiency can be better.

3 Conclusion

Regarding comparison of [3x5] matrix converter system with auxiliary 4QC and auxiliary [0x5] MxC the second one is clearly better in the:

- battery autonomous traction and a braking regime where 4QC should be completed by [3x5] MxC since auxiliary [0x5] MxC should not be,
- also, charging mode from ICE/SG unit with 4QC needs either control by ICE engine or further DC/DC converter since auxiliary [0x5] MxC is not needed .

Total comparison and evaluation can be done until when all operation modes of both concepts (with 4QC and with [0x5] MxC) will be simulated and their result known. Both of those concepts make possible to also combine (parallel) modes of the HEV powertrain.

Proposed paper provides detailed study of the functionality of ac-ac matrix converter serving within the modified power train of the HEV vehicle concept. Due to high degree of complexity, the presented approach shows mostly the simulation analysis and comparison between front-end VSI propulsion system and ac-ac matrix converter system, and comparison of two variants MxC: with- and without 4QC battery converter.

Experimental verification will be realized within future research tasks based on the received results of expected behavior [13-14]. These results will be consequently published as a separate scientific paper.

Acknowledge

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Libor Hadacek - Lenka Sivakova - Radovan Sousek - Mikael Zeegers

ASSESSMENT OF SECURITY RISKS IN RAILWAY TRANSPORT USING THE FUZZY LOGICAL DEDUCTION METHOD

The aim of the paper is to inform about the possibilities of using a fuzzy logical deduction in security practice. The fuzzy logic deduction allows to record the management experience in IF - THEN rules and does not require a precise description of the parameters of the controlled function. This property is an important asset for risk assessment in an incompletely defined environment. The application of the method is demonstrated in the security risk assessment of the physical protection of the national railway with a focus on the corridor railway lines and with regard to the future construction of high-speed railway lines in the Czech Republic. At present, it is a generally accepted fact that securing basic transport functions is a prerequisite for successful crisis management. These functions can be specified as road and rail negotiability.

Keywords: *fuzzy logic deduction, security, safety, rail, crisis management*

1 Introduction

Security management activities in an organization involve a great amount of decision-making on strategy and tactics of risk management [1-3]. Security managers have to make decisions despite uncertainties, inaccuracies, or incompleteness of input data [4-5]. They use quantitative tools to make decisions that require a certain level of input data precision. Furthermore, they can also apply semi-quantitative analytical methods based on a point scale. In the case of more independent variables, their point values are usually obtained using binary operations. This results in the value of the output dependent variable being the same for a different combination of values of the input variables.

A possible method of making decisions with uncertainty or incompleteness of input data is the application of fuzzy logic. Fuzzy logic isused in controlling processes of industrial products. For example, their principles control the image processing processes or automatic washing machines programs.

To control processes in an incompletely defined environment, it is appropriate to use a fuzzy logical deduction. Fuzzy logical deduction (FLD) is a part of fuzzy logic in a broader sense. FLD was described by prof. V. Novak in [6] in 1995 with the aim of creating an exact formal theory.

2 Model of risk assessment using the fuzzy logical deduction method

In common life, an event can be described by the two-state logic. Individual values can be assigned a value of 1 or 0 that corresponds to states such as on and off. Fuzzy logic expands the two-logic logic to multi-valued logic. An example of the difference between two-state logic and fuzzy logic is shown in Figure 1.

The fuzzy logical deduction is based on the basic rule of human logical thinking. Deduction, i.e. drawing conclusions, is implemented through formulas. The most important rule used is the modus ponens rule. Formally, it is possible to write it as follows:

$$\frac{A, A \Rightarrow B}{B}. \tag{1}$$

In this rule, there are *A*, *B* formulas. The rule modus ponens says that if we know the fact labeled by formula *A* and we know that the fact *B* is based on fact *A*, then we can assume that the fact *B* is valid. In classical logic, true and false formulas are examined in models, while fuzzy logic examines formulas whose truth value in models is different [7]. The principle of fuzzy logic deduction is illustrated by the general fuzzy controller shown in Figure 2. The general fuzzy controller consists of blocks of fuzzification, knowledge base, inferential mechanism, and defuzzification.

In the fuzzification process, the input independent variable is assigned a language expression. It is a variable whose values can be words or some natural language expressions [7]. An example of the names of selected language expressions is given in Table 1.

The extensions of evaluation predictions are constructed identically in all contexts. Typical elements have a degree of competence in the given extension of the evaluation prediction equal to 0.9 or 1. The example of the

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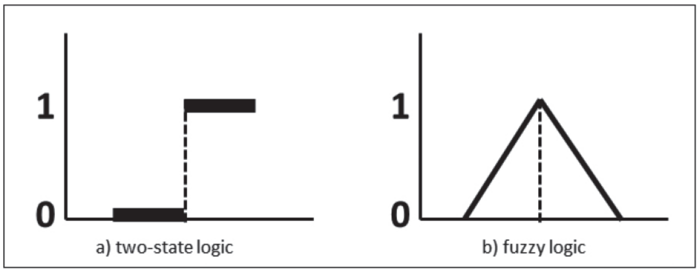

Figure 1 *Difference of two stage logic and fuzzy logic*

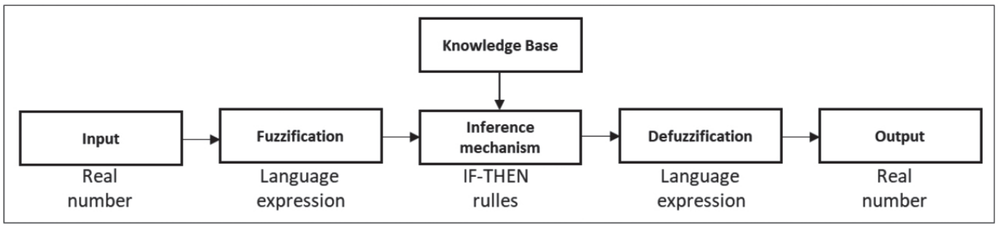

Figure 2 *General scheme of fuzzy controller [7]*

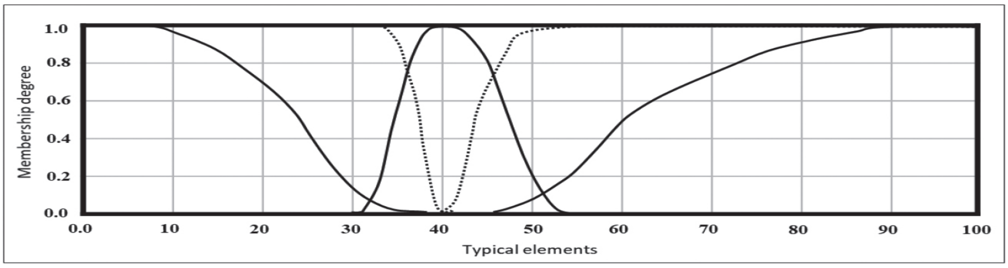

Figure 3 *Extension of evaluation predictions [7]*

Table 1 *Names of selected language expressions [7]*

Number	Languge expression	Abbreviation
1	Small	Sm
2	Roughly Small	Ro sm
3	Midle	Me
4	Roughly Big velky	Ro Bi
5	Big	Bi

Table 2 *Example of IF-THEN rules*

Number	X_1 is A_i	&	X_2 is B_i	=>	Y_1 is C_i
1	sm		Ze	I	ze
2	sm		Sm	I	sm
3	sm		ro sm	I	ro sm

course of selected extensions of the evaluation predictions for the context $\langle 0,40,100 \rangle$ is given in Figure 3 [7].

A set of rules is stored in the knowledge base. An approximate knowledge of the regulatory strategy is sufficient to create the rules. The strategy is described using the IF-THEN fuzzy set of rules [7]:

$$R_n = IF\ X\ is\ A\ THEN\ Y\ is\ B\,, \tag{2}$$

where:
R_n is the rule and n is the rule number,
X is the assessed object,
A is object property,
Y is a dependent variable,
B is object property.

In order to develop a controlling strategy, the expressions of a natural language, whose meaning is generally known, are used. The individual rules are made up of vague statements characterizing the properties of the input variables based on the results of the controlled process observation. An example of creating rules is given in Table 2.

In the inference mechanism, logical deduction is applied in the decision on the input variables according to the respective rule.

The conversion of a language expression into a real number occurs in the defuzzification process. Defuzzification is an operation that assigns an element from its carrier to the fuzzy set.

$$DEF(A) \in Supp(A)\,. \tag{3}$$

For defuzzification, the method of DEE (Defuzzification of Evaluative Expressions) is applied in combination with the fuzzy logical deduction. The reason for using it is a smoother course of the resulting function. The method is described in detail in [8].

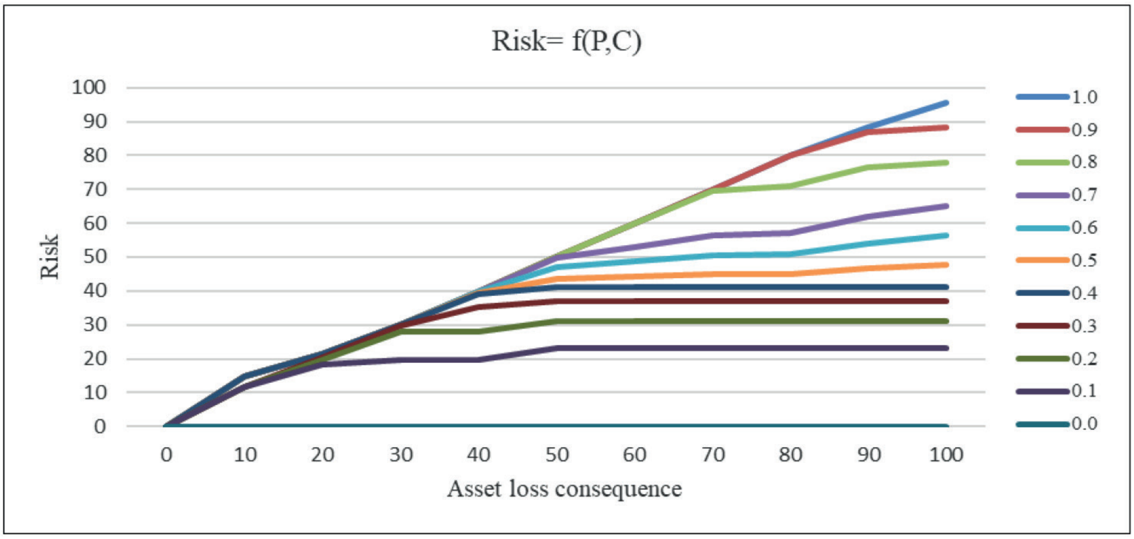

Figure 4 *The value of the risk is a function of an event probability and an asset loss consequence*

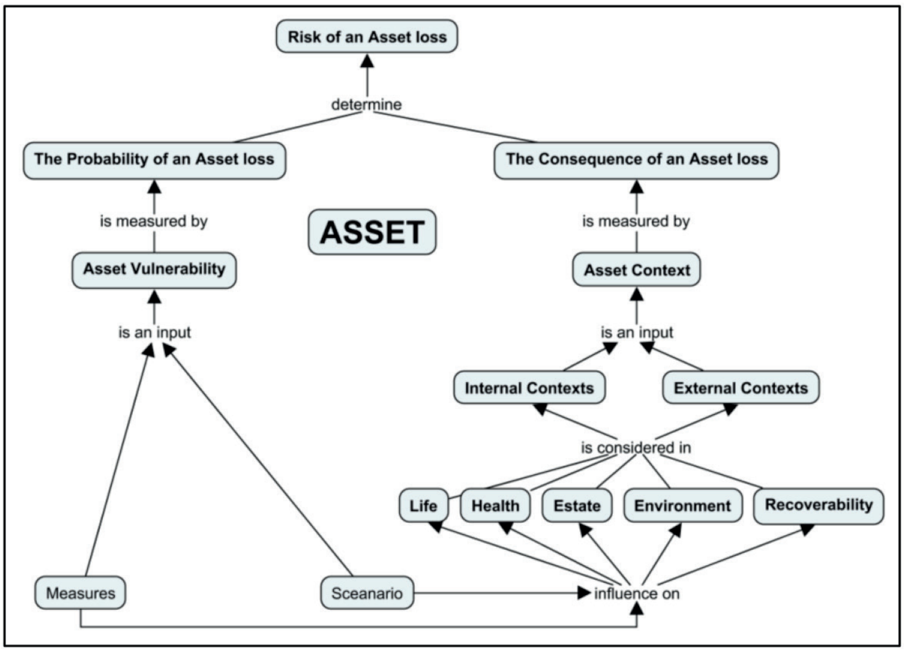

Figure 5 *The model of fuzzy controllers system for determining of the risk of an asset loss*

Determining the value of the risk by the FLD method is based on the same principles as the traditional method of determining the risk value, as described in the technical standard [9]. The risk values presented in Figure 4 are based on Table 5. The method of determining the values changes the established linear perception of the course of risk values. The created lines of risk are similar to those of the output characteristics of the transistor.

The proposed procedure eliminates the lack of a traditional risk-setting method. For example, with a probability value of 0.1 and the consequence value of 100, the resulting value of risk is 10. If the probability is 1 and the magnitude of consequence is 10, then the risk value is again 10. When applying the FLD method to determine the risk values, in the first case the risk value is 23.1 and in the second case, the result is 14.7, as can be seen in Table 5.

Fuzzy controllers can be connected together. This feature allows you to solve a complex task when only one set of rules is not sufficient. Assessing security risks is a complex task, the result of which supports the decision-making process of security management on the use of risk management strategies. Security risks are, by their nature, intentional, thoughtful and purposeful acts of a person who implements a scenario of an attack [10]. Due to the uniqueness of the location of the protected object, a number of uncertainties and incompleteness of the input data can be considered. A model of the fuzzy controller system for determining the value of the risk of an asset loss is shown in Figure 5.

The asset is related to the internal and external context. Contexts include the number of casualties. Other contexts include damage to property and the environment. The time context is the period of recovery of the asset to its original state after the effects of the scenario. The level, scope, and effectiveness of asset risk management measures are influenced by the scenario. The relationship between measures and scenarios is applied in an expert judgement on asset vulnerability. A measure of the asset‘s vulnerability is the probability of its loss. The consequence of the loss of an asset is a measure of the asset‘s context. The risk of loss of an asset depends on the probability of loss of the asset and the consequence of its loss.

For the purposes of the risk assessment procedures outlined in this text, we applied definitions of the event, occurrence, possibility or probability of occurrence, risk, and risk levels as set out in the technical standard [11].

Vulnerability means the property of any material object, technical means or social entity to lose the ability to fulfill its natural or established function due to external or internal threats of different nature and intensity. [12]

It can be concluded that the vulnerability characterizes the ability of the physical protection system to prevent the loss, damage or destruction of the protected object. It qualitatively or quantitatively expresses the degree of probability that something will happen, i.e. probability of loss of a protected subject. It follows that the probability of asset loss is a function of vulnerability.

3 Assessment of the risks of physical protection of high-speed rail

The software application „Analysis of Specific Risks of Physical Endangerment of the High-Speed Railway Infrastructure“ was developed for the solution of the security risks of high-speed railway lines using the fuzzy logical deduction method. For the purposes of this paper, the issue of high-speed lines has been reduced to the level of corridor tracks where the speed is 160 km/h.

3.1 Asset

According to the technical standard [13], the asset is anything that has value for the organization. The definition can be extended to the importance of the asset for its owner. The types of railway infrastructure assets can be considered, for example, a bridge, a tunnel [14], a station head, a grade separation structure or a track section [15]. Assets are entered into the database manually or from pre-prepared xls files.

For the purpose of assessing the risks of physical protection of the high-speed rail infrastructure, the infrastructure asset is characterized by the following fields:

a) Type - general designation of the group of assets,
b) Asset name - a closer unique identification of the asset,
c) Asset location - place, premises, space (regional headquarters, track section, ID),
d) GPS coordinates - the location of the asset in map coordinates,
e) Description of the asset - where other asset properties are specified.

3.2 Scenario

The scenario is a set of conditions and/or events that can cause a security incident. A deliberate anthropogenic threat is an individual or group of individuals with motivation and ability to act deliberately to cause loss or damage to the asset. The method of the threat manifestation is described by the scenario. The list of threats is specified in the threat catalog. When creating the threat catalog, legal provisions and the experience of experts from previous events are used. For each scenario, the following characteristics are given:

a) Threat,
b) Direction of an attack - it is important for the choice of preventive measures,
c) Time Attributes (seasons, time, opening hours),
d) Method attributed (tools, weapons, vehicles),
e) Description - other data supporting the expert judgment on the vulnerability of the asset.

3.3 Installed measures

For the purpose of physical protection, it is important to know the security features used to deter, slow, detect, and interrupt the attacker‘s progress. In particular, these include the construction of windows, doors, roof skylights, ventilation ducts and other openings of the building shell that can facilitate unauthorized entry [16]. For buildings with a perimeter, knowledge of fences, gates, barriers etc. is important. Details of current measures are listed in the following fields:

a) Asset - the name of the asset,
b) Safety / Security region - the area of safety or security, e.g. physical protection,
c) Type - general designation of the measure, eg. fencing,
d) The title of the measure - closer measure specification,
e) Level - the quality of the measure, e.g. burglary resistance,
f) Place of use - name of the security barrier, e.g. perimeter,
g) Purpose - which part of the security system is protected,
h) Date of commissioning - significant for systems degrading with time,
i) Description - a more detailed description of the measure, the item is not indexed,
j) Photo - this item allows you to attach a digital photo to the description.

3.4 Asset context

The process of determining the asset context, based on the technical standard [11], consists of subprocesses:

***Table 3** Formalized vulnerability sentences and language expressions*

Number	Semantics of Vulnerability	Language expression	Abbreviation
1	Not assessed	Zero	Ze
2	Protection multiply exceeds the requirements	Small	Sm
3	Protection exceeds the requirements	Roughly small	Ro Sm
4	Protection meets the requirements	Very Roughly small	VR Sm

***Table 4** Groups of risk values*

Number	Groupe title	Extent
1	Low risk	0.0-30.0
2	Moderate risk	30.1-36.9
3	Very high risk	37.0-60.0
4	Extreme risk	60.1-100.0

***Table 5** Risk values determined from the characteristic values of the input variables [18]*

Asset loss probability	1.0	0.0	14.7	21.3	30.2	39.9	50.0	60.0	69.9	79.8	88.2	95.6
	0.9	0.0	14.7	21.3	30.2	39.9	50.0	60.0	69.9	79.8	86.8	88.3
	0.8	0.0	14.7	21.3	30.2	39.9	50.0	60.0	69.5	71.1	76.5	78.0
	0.7	0.0	14.7	21.3	30.2	39.8	49.7	52.8	56.3	57.1	61.9	65.2
	0.6	0.0	14.7	21.3	30.2	39.8	47.2	48.6	50.6	50.9	54.0	56.3
	0.5	0.0	14.7	21.3	30.2	39.4	43.7	44.1	45.0	45.0	46.6	47.6
	0.4	0.0	14.7	21.3	30.2	39.0	41.3	41.3	41.3	41.3	41.3	41.3
	0.3	0.0	11.7	20.2	29.8	35.2	36.9	36.9	36.9	36.9	36.9	36.9
	0.2	0.0	11.7	19.8	27.9	27.9	31.1	31.1	31.1	31.1	31.1	31.1
	0.1	0.0	11.7	18.3	19.8	19.8	23.1	23.1	23.1	23.1	23.1	23.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	10	20	30	40	50	60	70	80	90	100
		Asset losss consequence										

determining contexts and determining risk criteria. The context is defined as the goal the organization seeks to achieve in its internal and external environments. The external and internal contexts justify the reason why preventive measures are planned and applied for the asset.

For the purpose of assessing the risks of physical protection, the targets are set as the number of casualties, the economic impact on property and the environment and the time necessary to restore the asset's function. External target values are as the same as internal target values, exept restoration. Restoration in external means the restoration of damage in external area or the reputation of the asset owner. The organization considers the importance of goals in both environments to be equivalent.

In the created SW application, three experts separately assess the level of achieving the context objectives of the context. Answers are formulated in numerical ranges or a formalized sentence. By selecting a predefined answer, it is possible to answer the question „what maximum value of the given context can the attack scenario achieve?" An example of formalized sentences for recording the vulnerability analysis results, including associated language expressions, is given in Table 3.

In the risk criteria identification subprocess, the organization, besides other aspects, determines the levels of risk. According to the technical standard [17], the risk levels can be divided into three groups (low, large, extreme), four groups (low, medium, very large, extreme) or five groups (low, medium, large, very large, extreme). For the purpose of assessing the risks of physical protection, it is appropriate to use the four groups of risk levels, as listed in Table 4.

A four-level risk classification allows security management to select an appropriate security strategy for risk management.

3.5 Security risk assessment

The resulting risk value is the output of the fuzzy controller - the value of the risk. The rules for the determination of risk values using FLD were adopted

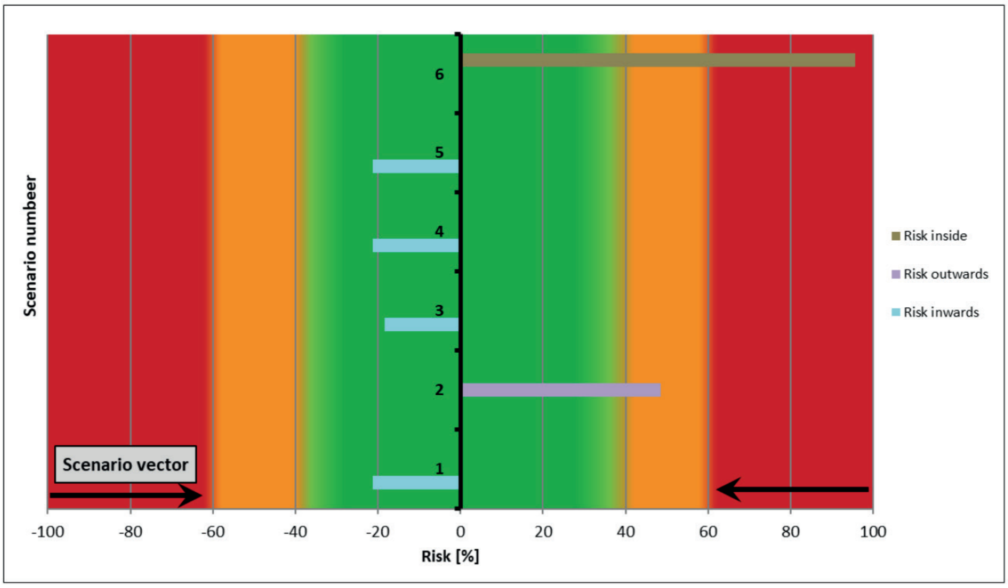

Figure 6 *Results of risk analysis*

Table 6 *Summary of links of terms for risk solution*

Risk treatment	Example
Risk treatment strategy	restriction, mitigation, transfer, preservation, avoidance
Safety / Security region	Physical Protection, Fire Protection, Information Security
Measures group	routine security precautions, physical security etc.
Typ of measure	fence, gate, door, PIR detector, detection camera, site security
Safety / Security element	door RC 3, switchboard 3
Reason of measure	mechanical barriers, detection systems, camera systems

from [18], where was for the calculations used the LFLC[1] program. The risk values determined by the FLD method are shown in Table 5.

The input variable „Consequence of the asset loss“ and the input variable „Probability of asset loss“ are defined by the characteristic values corresponding to the range of the minimum and maximum risk values.

3.6 Risk evaluation

The last step of the risk assessment, according to [11], is the risk evaluation. An example of a possible graphical representation of the risk values is shown in Figure 6.

The x-axis shows the risk values. Risk values with a „-“ sign are not mathematical. The use of a minus sign helped to separate the risks of vector scenarios from the external environment, where the risk source is outside the protected zone, from other risk vector groups. Positive risk values are in the graph represented by risk vectors from the inside out, from the protected to the unprotected zone and the vectors of internal risks, i.e. risks within the protected zone. The y-axis shows the numbers of the scenarios under consideration.

Splitting the chart into two parts and coloring the groups of risk values makes the significance of the risks evaluated more transparent. The risk values groups are color-coded in accordance with the technical standard [17].

3.7 Risk treatment

In the process of risk treatment, measures are implemented with regard to risk treatment strategies selected in the Risk Assessment process. Risk treatment is carried out through one of the strategies [19]:

a) Restrictions - the use of preventive measures to minimize the probability of loss of the asset and the consequences of loss of the asset,
b) Mitigation - limiting all negative consequences of an event,
c) Transfer - sharing the cost of losses with another entity,
d) Preservation - knowingly accepting the costs of losses,
e) Avoidance - the non-possession of the asset to which the risk relates.

Each of the risk treatment strategies includes at least one of the security area. More than one strategy and more than one security area can be selected. Security areas consist of groups of measures. There are different types

[1] LFLC – Language Fuzzy Logic Controler developed in the Institute for research and Application of Fuzzy Modeling, University of Ostrava, http://irafm.osu.cz/en/c100_software/

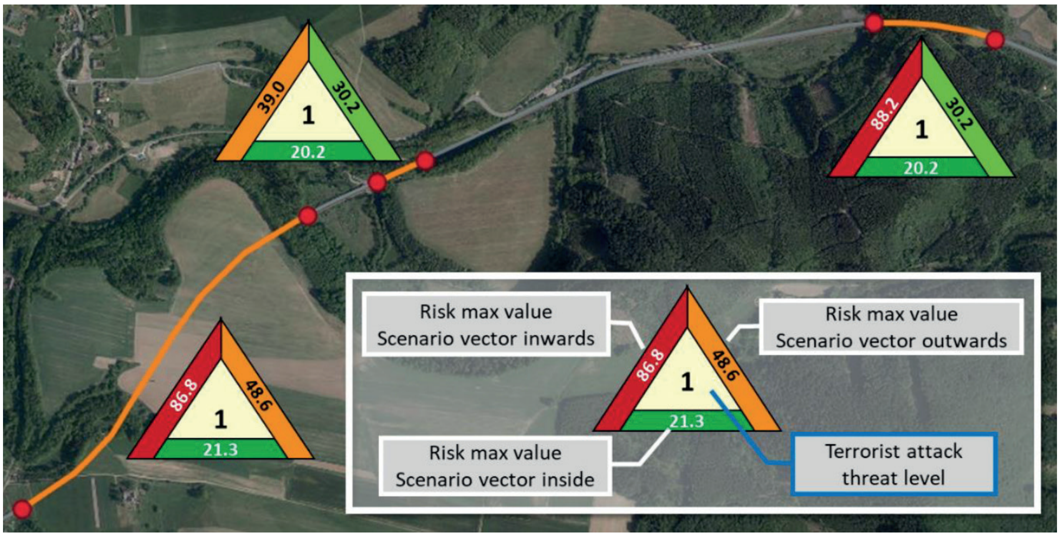

Figure 7 *Interpretation of the risk assessment results in the map*

of measures in the group of measures. Security features marked with an exact security feature specification are assigned to the type of measure. Each type of measure has a specific purpose in the physical protection system. A summary of the concept links is given in Table 6.

For example, physical protection is a security area from a „limitation“ strategy. The groups of measures include technical measures, routine security precautions, and physical security. The technical measures group includes the types of measures, mechanical barriers, detection systems, camera systems and others. Types of measures in the group of mechanical barriers include fences, gates, barriers, doors, locks and others. A door is considered as a security feature when it meets the requirements of EN 1627 RC 3. Using the security features of the different types of measures of the measure groups, a physical protection system is created.

New measures can be added to the protection system. The current measure may be replaced or removed. To record details of the measure proposal in the software, the same fields as described in Subchapter 3.3 are filled in, supplemented by the following fields:

a) Duration - the time needed to implement the measures,
b) Feature description - a more detailed description of the measure, the item is not indexed,
c) Cost of measure installation - costs of installing measures,
d) Cost of measure operation for one year - cost of measure operation in 1 year.

The selected procedure was used to maintain consistency between two processes in the software application. Appropriate costs of installing measures are the costs which cover the approved organization‘s risk management scenario.

3.8 Interpretation of results of the security risk assessment

The results of security risk assessment are interpreted in the form of text, tables, charts, drawings in the map. Here, all the data put in and created in the assessment processes and subprocesses are applied. The interpretation method depends on the purpose and the recipients of the data. It is necessary to consider whether this is the interim information needed for the experts or the final report to the evaluator.

A possible interpretation of the risk assessment results in the map is shown in Figure 7. For the assessment, three tunnels were selected. The scenarios under consideration were divided into three vector groups. For the assessed asset, the maximum risk values for each attack vector and the information on the threat level of terrorist attack by the Ministry of the Interior of the Czech Republic are clearly outlined. The resulting risk values and degree of threat by a terrorist attack are demonstrative and can not be considered realistic.

4 Conclusion

The text summarizes the basic theoretical knowledge necessary to determine the risk value by the fuzzy logical deduction method. The example of railway transport infrastructure objects was used to demonstrate the procedure for the creation of the structure of fuzzy regulators for the determination of the risk value in the field of physical protection.

The described procedure is applicable by the security management to determine the security risk values without detailed knowledge of the fuzzy logic deduction theory and software ownership. It is relatively easy to apply it in railway transport conditions.

The proposed risk assessment method, using a fuzzy logical deduction, enables the risk criteria and the content of the auxiliary databases to be tailored to specific user conditions. The maximum range of risk values and risk assessment criteria are set with respect to the asset holder's security documentation. The selected risk assessment process increases the number of potential users of the software application.

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THE CONTINUOUS MONITORING OF SELECTED RAILWAY STRUCTURES USING THE AUTONOMOUS DATA LOGGER

This contribution focuses on issue of the autonomous monitoring of selected dynamic parameters of the railway lines test sections under conditions in the Czech Republic. Description of the possibilities of such data collection, including the designed hardware and software, is a part of this contribution. At the same time, the contribution describes application of such a measuring system, comparing the selected dynamic parameters of the two types of switches, the first one was a switch with a standard fastening node, the other one with an elasticized fastening node. Recommendations and conclusions of railway infrastructure manufacturers and railway line managers are parts of this contribution, as well.

Keywords: *data logger, vibrations, monitoring, railway*

1 Introduction

The railway line (or the tram line) represents a multi-layer system determined for the motion of railway vehicles including the equipment necessary for ensuring the safety and smoothness of the railway traffic. The traffic line is formed by the superstructure and the substructure. By the substructure is understood the railway earth bed and the structures that completely or partially substitute protective structures and equipment. Its task is to support the superstructure. The track bed forms the boundary between the substructure and the superstructure [1].

The superstructure is formed by the railway track, which carries and directs vehicles. The superstructure is constructed either as a classic one with the gravel ballast or as a slab track. It should be mentioned that in the Czech Republic the ballast-free track represents the so-called non-conventional structure of the superstructure. Its application occurs especially in special cases like for instance is the tram track, the underground or the track passing through tunnels. The rail of the ballast-free track is mostly fixed to a concrete slab or sleeper, which is fixed to the slab. It should be noted that the text to follow deals with the problems focused on the classic superstructure.

The fundamental part of the superstructure is formed by rails, turnouts, fasteners, sleepers and the railway bed. Rails, together with sleepers, fasteners and the track fastenings, constitute the track length. Its main function is to carry the vehicle and the load, to lead the vehicle geometrically along the trajectory, and by its elasticity to absorb dynamic effects and also to distribute the load into other layers of the superstructure and substructure.

The main function of the gravel ballast is to resist the vertical, cross and longitudinal forces and at the same time to hold the track length in a precise geometrical position. This function is conditioned by suitable properties of gravel grains. Their size must be optimal, the compaction must be sufficient (single grains must be mutually placed so that there may be the smallest possible space between them) and they must be mutually wedged in by their sharp edges [2].

Vibrations of the superstructure are affected by its quality, by operation and structural conditions, climatic phenomena and especially by the dynamic loading by the wheel pairs of the rail vehicles. Related to the rising speed on the railway tracks, the dynamic effects acting on the rail structure increase, as well. These effects negatively influence the rails and lead to the development of failures and defects. Defects usually become evident in the disintegration of the geometric parameters of the rail, which consequently leads to the repeated increase of dynamic effects, which has negative affect on the functionality of the whole system. The result is a malfunction of the entire system and thus also endangering the continuity and safety of the rail traffic. It may be unambiguously said that the solution of the majority of structural problems rests in the right understanding of dynamic effects acting in the railway track structure.

The basic claim put on single parts of the railway tract is their functional reliability together with the safety of the railway operation. Although the superstructure has been practically developed to its perfection during more than 150-year railways, new technical solutions can still be found. This holds good especially for different types of turnout structures, various rail fastenings, various types of rail pads, sleepers, anti-vibration measures etc. It is suitable to say that each part of the rail structure is exposed to considerable static and dynamic stresses.

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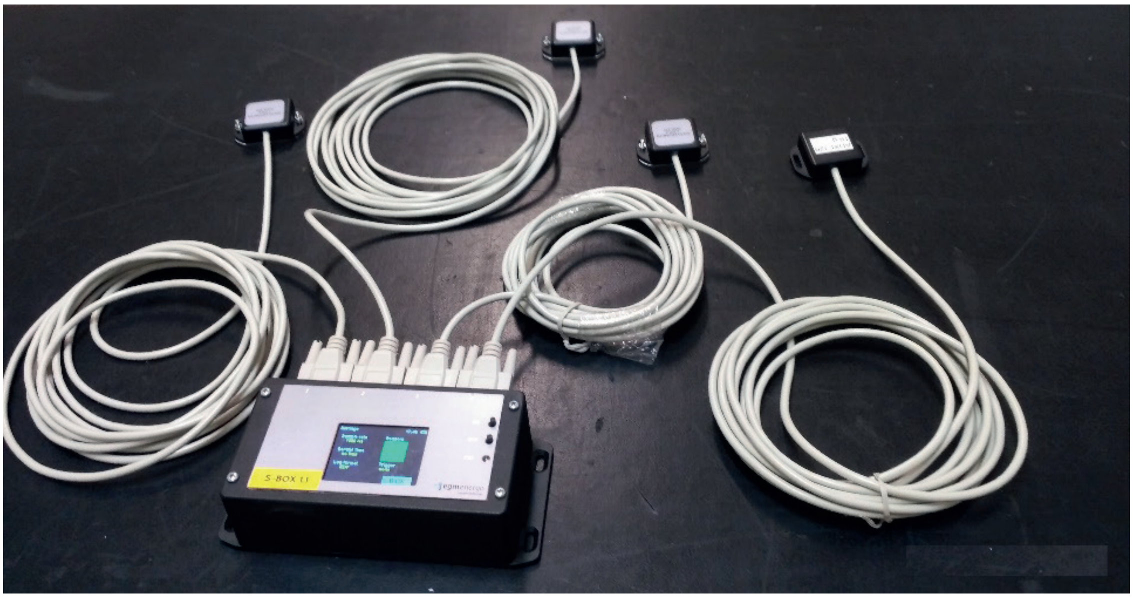

Figure 1 *The data logger set with acceleration sensors*

Permanent pressure on increasing the transport speed and the operational load of tracks causes a magnificent development of new technologies in the railway traffic. Concerning the modernization of railway lines, this qualitative shift also refers to the Czech and Slovak railway tracks [3]. Decision on modernization of the lines has become an impulse to develop all the branches of the railway traffic both in the field of vehicles and in the field of the infrastructure. Development and application of new experimental procedures for evaluation of the quality and usefulness of particular structural solutions must be in accordance with this trend.

2 The measurement technology

Measurements performed on real railway structures are very important. Field measurements take account of the stochastic character of effect of the train sets and properties of the railway line construction. For that purpose, the so-called test sections have been established in the railway network in the Czech Republic to test new structures of the superstructure and the substructure in the long run. Demands put on test sections are usually very strict. This applies primarily to quality of construction and/or reconstruction, the monitoring of selected parameters, and the access and establishment of measuring points. It should be noted that a new structure to be tested is applied in a track together with its reference, classic variant, i.e. construction without innovation.

It should be mentioned that the short-term measurements have currently prevailed. This means that selected parameters of the railway line have been measured for one or several days. The repeatability of those measurements over a period of one year has been relatively low, with the measurements being usually repeated twice a year. This procedure is appropriate in some cases, while for some structures it would be useful to apply a continuous approach. At the beginning of the Fourth Industrial Revolution, it is certainly worth considering thinking about the implementation of the smart railway structures, which would automatically inform a main system of their status and/or any changes in their status.

To achieve this state, the railways structures (superstructure, points, etc.) have to be provided with an autonomous measuring device that would perform continuous measurements, process the measured data and transfer it to a main evaluation system based on proposed scenarios. Therefore, the authors of this contribution have developed a low-cost automatic measuring system [4]. The system allows not only the “smart” collection of basic data but includes also a set of algorithms enabling information on status of the transport structures and their components to be gathered in the real time and stored for future use as required by an administrator or the design department and/or for monitoring of an impact on the surroundings. The system has been primarily designed to monitor and evaluate selected dynamic characteristics (vibrations, deformation). The monitoring system provides large data volumes, however, not all the data need to be stored. It is more useful to pre-process data continuously and to store only selected information. The data storage process includes algorithms of intelligent sorting and processing.

3 Description of the measuring system

The entire measuring system was designed as a two-level one. The first level is a data logger, the second is an evaluation software running on a main computer [4].

The data logger (Figures 1 and 2) is designed as a separate measurement point. It may be used throughout the construction of a railway superstructure with the possibility to record up to 12 analogue quantities in the form of an electric voltage of 0V to 5V. It is primarily intended to record vibrations, noise, deformation, displacements and

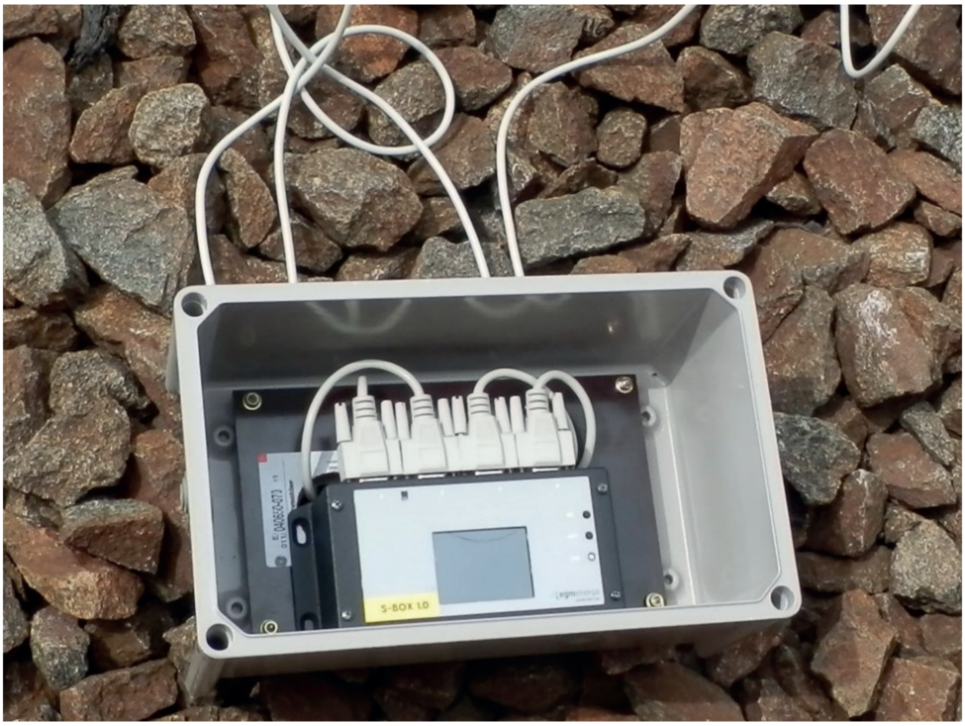

Figure 2 *The in-situ view of the data logger*

temperature. Quantities are continuously stored on an SD card.

The data logger is built on the microcomputer Teensy platform with a 32-bit ARM Cortex-M4 processor. It can be programmed very similarly to the well-known Arduino system directly via a USB connector. The system is designed to capture a large number of time records of any length at a sampling rate of 100 Hz to 4000 Hz. This range of sampling frequencies is sufficient to measure vibrations on the track structures. Note that in this area the signals are evaluated up to about 1 kHz. The Teensy microcomputer board was completed with additional components for measurement purposes. It was mainly the part forming the measurement chain, power module, data logger synchronization module, data storage to SD card module and a data communication module with a main system. A substantial part of the work was devoted to development of a data logger control system and application software.

The system is equipped with a real-time clock with the possibility to synchronize more of the same data loggers. Measurement and data storage can be done either on external interruptions (change of logic level using, e.g. the gate trigger) or at the set signal level on the selected measurement channel.

After measuring and storing the recording (time events), the system is set to a standby mode to wait for further measurement. The measuring system is equipped with a touchscreen with possibility to set the basic parameters and operations – methods of starting, stopping, setting of measuring time, basic sampling frequency, selection of measuring channels, etc.

The display shows bar charts of the minimum and maximum of all the channels before starting the measurement. The touchscreen makes it possible to select the appropriate number of measuring channels to measure and display averaged maximum and minimum values before measuring to calculate the sensitivity of, for example, the accelerometer sensor. At the same time, it is possible to specify the limit values, whereby the logger reports to the main system a serious problem found in design and sends the data for immediate processing. During the ordinary operation, the main system automatically selects data from individual data loggers for further processing according to the schedule.

The electronics of the data logger is placed in a durable box. The Sub-D9 connectors are used to connect sensors in the proposed version. The system has its battery, as well as the possibility of external charging/powering, for example, by solar panels or by electricity network. The device is designed to be used in real weather conditions. It can be attached to the parts of the railway superstructure (under the rail, on sleepers, etc.).

Several triaxial MEMS-type accelerometer sensors were designed and manufactured for the data logger, two with a measuring range of 200 g (expected use on the rail), two of 16 g (assumed use on a sleeper), two with a switchable measuring range of 2 g/6 g (assumed use outside the track skeleton, possibly in gravel). The MEMS chips from the Analog Devices Company were used to assemble the sensors supplemented with electronics to ensure their power supply and adaptation to the data logger. The produced data logger was tested in the laboratory and field during the year 2019, including the comparative measurements with the Dewetron 2500 system. The

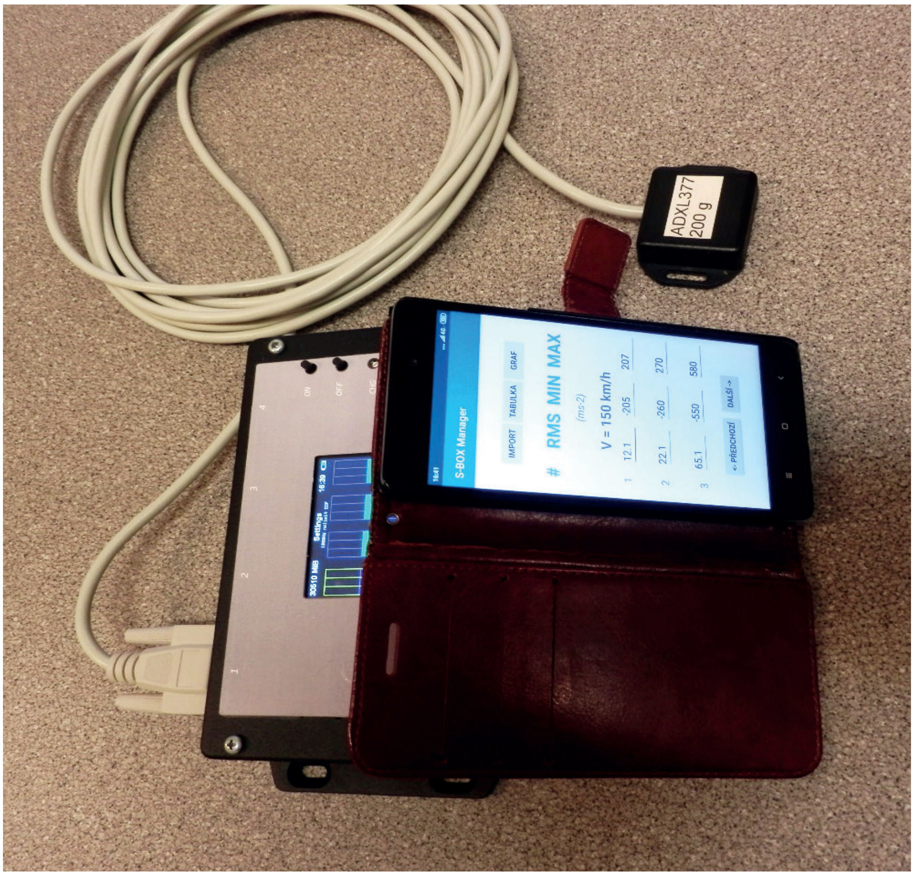

***Figure 3** Demonstration of application uploaded to a mobile phone and connection between the mobile phone and a data logger*

measuring string was calibrated using a calibration sensor 8305 from Brüel Kjaer and a vibrating calibrator V21D from Metra Mess und Frequenztechnik.

The proposed data logger communicates with a main system in line with current and new trends using WLAN Wi-Fi radio non-cellular technology. The assumed data transmission reaches tens of meters.

The data logger comes with software created to allow the data transfer to the main system and their further data processing. Currently, the software provides the ability to create images with two types of charts. On the left-hand side, there are the time courses of the measured quantity while their amplitude spectra are on the right-hand side. At the same time, other characteristics are identified and counted, e.g. global maxima and minima, RMS values, or floating RMS vector. The software database can be completed with characteristics of locomotives and carriages. By using this data, it is possible to detect the passing train from the measured records. The data read from the data logger, as well as their calculated characteristics, are further stored in created structures of the SQL database. From this database, the pre-processed data can be loaded into the main analysis system. At the end of the data logger description, it is also necessary to mention the possibility to read and analyse the measured data using a mobile phone with the Android operating system. An application was created to read and analyse data over a Wi-Fi connection (Figure 3).

4 The measurement description

Monitored switches No. 3 and No. 4 (Figure 4) are situated in the Trebova deviation of the railway station of Usti nad Orlici. Both switches are located on a high embankment. They have the same slenderness (1:12 – 500), both are run by most trains alongside the tip of the frog, and have the same frogs (UIC 60 superstructure, ZPT-monoblock frog). Switch No. 4 has a standard fastening using ribbed plates on concrete sleepers with Skl 24 clamps and it is located on track No. 2. Switch No. 3 has a new UNO3718 fastening using ribbed plates on concrete sleepers with Skl 24 clamps and it is located on track No. 1. The main difference between the above fastenings is mainly in the pad under the foot of rail. Switches are placed on the pre-stressed concrete VPS sleepers.

The dynamic effects were measured after the frog replacement on the new explosion-reinforced manganese frog constructions. It was done both for comparison of both constructions and for verification of measurement methodology based on use of autonomous data logger. The measurement was carried out simultaneously on both switches; the measurement conditions were identical for both measured structures.

The selected design for measuring and investigating the dynamic effects was the switch frog [5]. When a wheel of a train set is passing through, there is a shock and vibration in the frog. The load is distributed through the

Figure 4 *Measurement place, the view of switches No. 3 and No. 4*

wheel, into the frog, into the elastic fastening, in which the vibration in the spring washer is partially damped. Part of the vibration spreads and continues through the sleeper to the gravel bed. The energy generated by impact and surface roughness of the wheel-rail surface result in shock and vibrations being passed into the entire superstructure and the ballast bed.

In the rail bed, the gravel grains vibrate, which leads to abrasion. Due to abrasion, the rail bed becomes clogged, the bearing capacity is reduced and the support of the frog structure on the sleeper-gravel bed contact is also worsened. All these can lead to incorrect wheel guidance on the wing rail and can accelerate aging, material degradation in construction and GPK disintegration [6].

Vibrations spread from the source to the structure, in particular in the longitudinal and vertical directions. At the same time, transverse vibrations due to the sinusoidal movement of the wheelset in the rail are also passed into the frog based on the position of the wheel set entrance. Piezoelectric acceleration sensors were chosen to capture

Figure 5 *Location of acceleration sensors*

the description of vibrations spreading. Piezoelectric sensors belong among the most commonly used sensors for these measurements. Advantages of these sensors are stability, wide frequency range and power supply independence. Location of the accelerometers was designed on the base of the wing rail, on the sleeper under the frog tip and in the gravel bed. A three-axis sensor was designed and placed on the heel of the wing rail, which allowed monitoring the dynamic shock caused to the tip of the frog in the vertical direction, transmitted to the foot of the wing rail.

This sensor records vibrations caused by the movement characteristic of the wheelset in the longitudinal and transverse directions. The movement of the wheelset is described as a sinusoid and affects the magnitude of the lateral impact of the phase of movement in which the wheelset enters the frog. The next site under investigation was the transition from the foot of the wing rail to the sleeper under the frog tip. A uniaxial accelerometer sensor was used to detect vibrations on the sleeper. The same was true of monitoring the propagation of vibrations into the gravel bed. To measure the vibrations in the gravel bed, the accelerometer sensor was mounted on a special hemisphere implemented in the gravel layer [7].

The designed data logger was used for measurement of the selected dynamic parameters of both switches for subsequent comparison and evaluation of the effect of application of the spring-loaded fastening in the switch on the vibrations spreading of the switch structures. Note that for this contribution, the transmission of vibrations from the wing rail near the frog tip through the sleeper to the gravel bed was measured (Figure 5). The set of sensors was supplemented with an auxiliary accelerometer, which was placed 2 m from the frog tip for easy determination of travel speed.

5 The vibrations assessment methodology

The test measurement was performed at both positions during the two working days in May 2019 and included train sets in passenger, express and freight train categories. Two developed data loggers were used for measurements. Measurements were performed under the same climatic conditions. The time course of vibration acceleration was the quantity recorded. The start and data storage were accomplished at the pre-set level of a signal detected by the accelerometer placed on a wing rail. Data was transferred to a main computer and evaluated daily. Train sets passing through points were recognized in a main computer by analysing the acceleration measured in a wing rail. A support-vector machine was used to recognize train sets. It is a very promising classification method allowing the train sets to be recognized by an acceleration signal measured in a wing rail by using derived characteristics, such as the floating RMS, the number of local maxima, deviations, etc. Besides, it is also quite convenient to put together a database of locomotives, coaches, and/or whole train sets and their wheel base for the comparison purposes. A classifier had to be set before the measurement itself. The speed of passing train sets was calculated from signals derived from the two accelerometer data recorders (a reference recorder and a recorder placed in a wing rail) and the known distance between them. A method for determining the speed of train sets is based on measuring the time of a wheel passing gradually through two acceleration recorders.

It should be mentioned that vibrations transfer from a wing rail in the vicinity of the crossing frog point through a sleeper to a ballast bed was measured for this contribution. In total, 3 measuring points (Figure 5) were fixed on each switch on which the acceleration sensors (wing rail, sleeper near the fastening and gravel bed near the fastening) were attached. The gravel bed vibrations were measured by an acceleration sensor placed in a special hemisphere pad. This was embedded in the gravel bed in the sleeper crib. Along with the measurement of vibrational characteristics,

***Table 1** Comparison of the effective acceleration values of both monitored turnout structures*

Train	SWITCH NUMBER	V [km·h^{-1}]	EFFECTIVE VALUES OF VIBRATION ACCELERATION [m·s^{-2}]		
			KK_z	P_z	SL_z
RAILJET	3	130	52.3	8.9	3.7
	4	130	38.2	15.0	7.4
PENDOLINO	3	146	64.4	9.8	2.8
	4	160	51.5	13.3	5.9
LEO EXPRESS	3	132	52.3	8.0	2.8
	4	130	36.8	14.1	4.8
REGIOJET	3	131	53.9	10.7	3.7
	4	127	43.4	16.6	6.3
R 361	3	120	53.9	9.8	2.8
	4	120	31.6	11.6	7.2

KKz wing rail, vertical direction
Pz sleeper - main branch at frog, vertical direction
SLz gravel ballast, vertical direction

a large number of other parameters were measured. Their comparison and analysis are not parts of this paper.

For evaluating vibrations during the passage of train sets around a stationary measuring station, it is advantageous to use the so-called effective value of acceleration a_{ef} or the effective value of acceleration value L_{aef}. This quantity best describes the vibrational behaviour of the passing train. The spreading of vibrational waves from moving trains is characterized by the dependence of the values of the vibration acceleration on the frequency. Therefore, the frequency analysis was also used in the evaluation.

After analysis of the issue, monitoring measurements and calculations, the following methods and parameters were used to analyse the measured data:

- Time waveform of acceleration of the vibration
- Levels of the effective acceleration value
- Frequency analysis using the amplitude spectrum of the linear axis

The mathematical definitions of the individual parameters used to compare the two constructions are briefly summarized. The effective acceleration value is defined by the equation [8]

$$a_{ef} = \sqrt{\frac{1}{T} \cdot \int_0^T a^2(t) \cdot dt} \ \ [\mathrm{m \cdot s^{-2}}], \qquad (1)$$

where $a(t)$ is the instantaneous acceleration value and T is the time for which the effective acceleration value, i.e. the passage time of the train set before the tested construction, is to be determined.

The acceleration frequency spectra were calculated by applying the Fourier transform according to the equation [8-9]:

$$AS_a(f) = \int_{-\infty}^{\infty} a(t) \cdot e^{-j2\pi ft} \cdot dt \ \ [\mathrm{m \cdot s^{-2}}], \qquad (2)$$

where f is the frequency, t time, and $a(t)$ the acceleration course in the time domain and $AS_a(f)$ its representation in the frequency domain, j is the imaginary unit.

6 The measurement assessment

From the measured records, the basic vibration characteristics, i.e. the effective value of the acceleration value a_{ef}, were calculated for each switch and each position of the acceleration sensor, and amplitude spectra for each category of the train. From the calculated data of the effective vertical acceleration value and the time course of acceleration, a table was created for both investigated structures and basic graphs and these were compared. Note that the calculated values given in the table were averaged for each category of the train. The comparison of L_{aef} values for both measured structures is presented in Table 1. Table 1 shows the following:

The RailJet set has a higher effective vertical acceleration value in the vertical direction for the frog of the switch No. 3. The expected difference is in the effective values on the sleepers, the vibration dampening is higher on the frog at the switch No. 3. The values in the gravel bed are slightly lower for the switch No. 3.

For Pendolino, the effective vertical acceleration values are, according to expectations, the greatest compared to the other kits. Despite different speeds, the acceleration values of the individual sensors are in a similar ratio to the

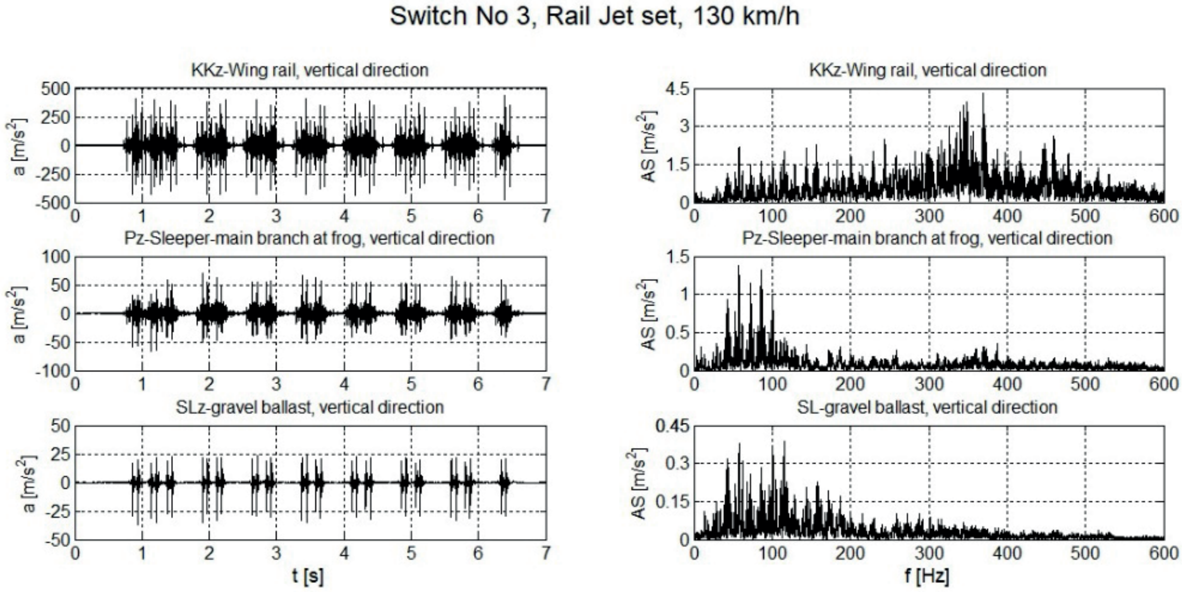

Figure 6 *Time and frequency characteristics of switch No. 3, RailJet, speed 130 km·h*$^{-1}$

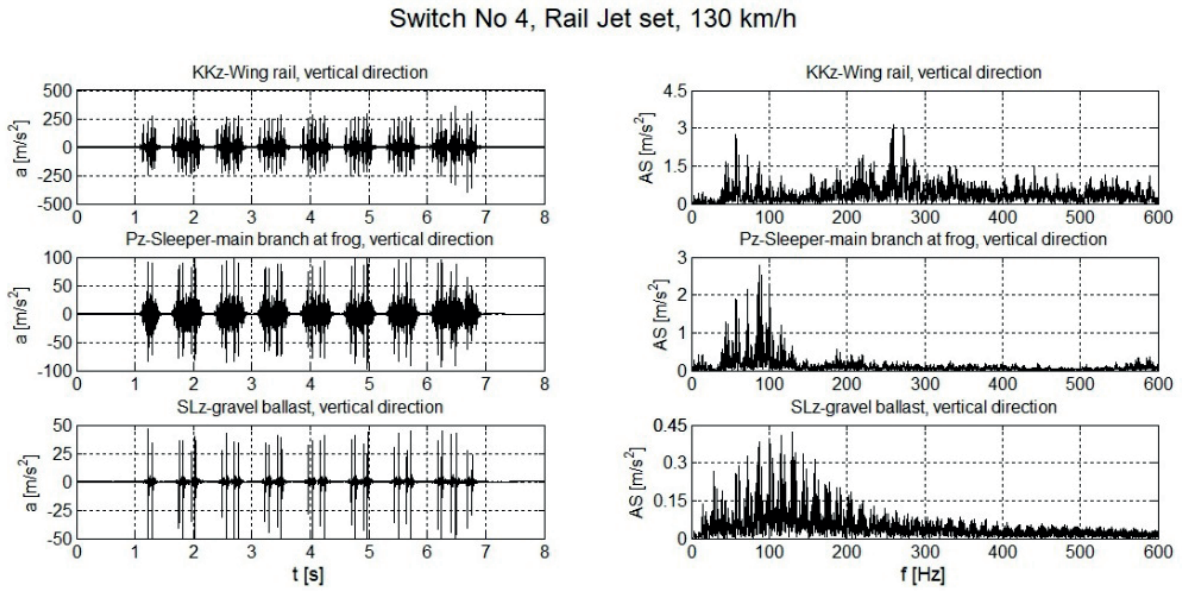

Figure 7 *Time and frequency characteristics of switch No. 4, RailJet, speed 130 km·h*$^{-1}$

RailJet. The same finding applies to Leo Express, RegioJet and 361 series locomotive sets.

In addition, in this case it is important that values in the rail bed are lower for the switch No. 3, i.e. the switch with a sprung fastening against the switch No. 4, i.e. with the classical fastening construction. Note that the attenuation in the track bed is the lowest when the RegioJet was passing through.

Table 1 shows that there is a positive effect of the sprung fastening in the switch No. 3. Due to its use, there is a higher attenuation of vibrations passing from the wing rail to the gravel bed. Analysis and comparison of time records and their amplitude frequency spectra also show similar conclusions. This is evident from the graphs in Figures 6 and 7. The graphs in Figure 6 show the time and frequency characteristics of a switch with a classic mounting node and the graphs in Figure 7 show the outputs of a switch with a flexed mounting node when a high-speed train travels at a speed of 130 km·h^{-1}. Note that the time and frequency characteristics of vibration measurements are represented by six graphs in both figures. The graphs on the left represent the measured waveforms of the vibrations acceleration at each acceleration sensor. The graphs on the right represent the calculated amplitude frequency spectra.

These graphs show several differences between the two structures. The acceleration values on the wing rail are higher in the switch No. 3 compared to the switch No. 4. The same applies to the amplitude spectra. Only for switch No. 3, maximum spectrum values occur between 300 Hz and 400 Hz compared to Switch No. 4, where peaks are achieved at two frequency intervals (60 Hz to 70 Hz, 200 Hz to 300 Hz). On the sleeper, the lower values were obtained in the switch No. 3 compared to the switch No. 4. This also applies to the frequency spectra. The significant frequency range here is from about 40 Hz to 120 Hz.

Likewise, the lower values of the switch No. 3 in the ballast bed were achieved. This applies to both time and frequency domains.

7 Conclusions

A simple diagnostic system developed at the authors' workplace was presented in the paper. It was designed to be used not only to capture basic dynamic data within railway structures. This system can become a basis for a wider implementation of the concept of intelligent sensing of selected physical quantities on railway (switch) structures and their processing in the form of intelligent diagnostics.

In addition, such a system will find use not only in the field of long-term monitoring of test sections. Based on experience with the presented measuring system, the team recommends continuing in its development. Certainly, it would be appropriate to complement this system with additional sensors and transducers. It would be very beneficial to supplement the proposed equipment with the possibility of measuring the travelled load. A very interesting application area would certainly be integration of the designed data logger into the diagnostic system, which would automatically evaluate the state of the switches, including the occurrence of failures and defects.

From the results, it can be stated that evaluation confirmed the elastic behaviour in the frog seating in the switch No. 3. When moving from wing rail to sleeper, the vibration acceleration values exhibit greater damping than the frog classically imposed.

Based on the work, the authors tested whether the proposed methodology, including the equipment used, was satisfactory. It is sufficient to measure such a range. It represents a suitable complementary method of measurement to diagnose and monitoring the behaviour of the structure. At the same time, the team recommends the use of measuring stones for further measurements, which have a more suitable location and measure the dynamic effects under the tip of the frog in the gravel bed. Note that those were also developed at the Institute of Railway Structures [10].

For more accurate evaluation, it is necessary to carry out measurements more often, preferably continuously using measuring devices built into the measured sections and structures, or more often so that statistical analysis can be included in evaluation. A very interesting idea could be the installation of sensors in the production of switch sleepers located under the frog, where the sensor would measure directly on the contact surface of the sleeper and gravel.

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ANALYSIS OF THE ACCEPTANCE FACTOR OF ANDROID-BASED PARKING INFORMATION SYSTEMS IN INDONESIA

Parking is an unrelenting problem, with more vehicles having an impact on the way how to park a vehicle. Some experts have made various breakthroughs in overcoming parking problems; one of them is using smartphone technology as a system to facilitate the way to park. This study aims to analyse user acceptance using the Unified Theory of Acceptance and Use of Technology UTAUT method with structural equation models (SEM-PLS), against 221 respondents. The result is that performance expectations, effort expectancy, and social influence variables have a significant effect on behavioural intention. Then the facilitating conditions variable and behavioural intention significantly influence the use of behaviour for using smartphone parking systems. Furthermore, this research is expected to help the government to find out what factors affect the parking system.

Keywords: *parking, android, smartphone, UTAUT*

1 Introduction

The problem of parking is classic in big cities, because it has occurred since many years ago. The problem is that because the parking fee is considered the only potential source of income for regional government development financing [1]. Therefore, in this case, the government is competing to find ways to increase the source of income through parking by improving the existing system. Furthermore, the most important thing is a great system and infrastructure so that the parking process can run smoothly [2].

In previous studies, Android-based parking systems have been developed to prevent queues and cost-effectiveness [2-3]. However, in its journey, it required socialization and education to the community in its application. There are various models of parking systems that have been made by experts. Some using personal computers (desktop PCs) and other use smartphones. Along with the changing times, the use of desktop-pc is considered to be lagging behind because besides that, it has to take up space and it is not easy to move.

The use of desktop-pc is only suitable for buildings, schools, or private companies in a limited scope. The next parking system is the Parking Meter, commonly called "ATM Parking" in Indonesia. This system is considered quite useful because it does not require parking attendants in its application. However, many people do not use Parking ATMs because there are no officers to guard [3]. Furthermore, the application of the parking system uses smartphone technology Thus latest technology offers digital payment facilities, besides it is easily carried by parking attendants, so officers can adjust the parking area while parking the vehicle. This study aims to analyse the acceptance of smartphone technology parking systems with the Unified Theory of Acceptance and Use of Technology (UTAUT) Model, to determine application performance, ease of use, social influence and to determine user intentions and technology acceptance [4].

2 Literature review

Indonesia is a developing country; currently, major cities in Indonesia have implemented a variety of parking systems as a way to increase its regional income sources. According to its development, there are several types of parking systems that have been developed in Indonesia, and the first is a desktop-based application system This application can run by itself or independently without using a browser or internet connection on a computer autonomously, with a specific operating system or platform [5]. The second type of application is web-based; this application can run using a web technology or browser. This application can be accessed anywhere as long as there is a supportive internet connection without the need to install on each computer, such as a desktop application, only by opening a browser and going to where the application server is installed.

The third type of application is mobile-based, this application is at a glance almost the same as web-based, but there are four differences when viewed from features, user interaction, location awareness, and push notification. While viewed from application connections, there are two types of connections, namely online connections, which means we are currently connected to the internet or cyberspace, connected to it through social media accounts, e-mails, and other types of accounts that we use or use

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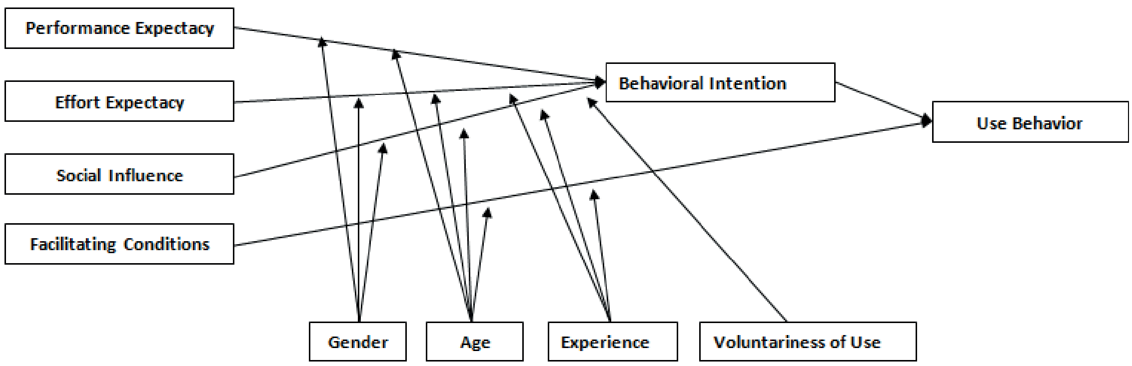

Figure 1 *UTAUT model framework [12]*

via the internet. While offline is a term for a situation we are not connected to the internet; more precisely it is not connected. In connection with the application to be analysed, the analysis is a mobile-based application with an online connection [6].

According to Regional Regulation No. 9 of 2001 concerning Parking Taxes Parking is a non-moving condition of a vehicle that is not temporary. Parking Tax, from now on referred to as Tax, is a tax imposed on the operation of Parking Spaces. Parking space is an off-street parking space provided by individuals or entities, whether provided in connection with the principal of the business or provided as a business, including the provision of Motorized Vehicle Storage and Garage of Motorized vehicles that collect fees. [7] As it was revealed that roadside parking is managed directly by the City Government while off-street is managed by the private sector for public use.

The difference between Parking Tax and Parking Levies on the edge of public roads from now on, referred to as levies, lies in the use of the parking space. In levies are levied on payments for the use of public roadside parking spaces, which are still government-owned facilities. As determined by the Mayor or Regent, Parking Taxes are imposed on payments for the operation of parking spaces outside the road body, which means privately owned facilities and usually managed by a private agency. The potential increase in local revenue through parking is high because one of the sources of regional income is from fees and parking taxes [8]. At present, parking management on public roads is mostly done by the private sector in the name of associations or community groups, so that the parking fund does not contribute positively to local revenue.

The potential income from parking can change along with the business progress of the community [2, 9-10]. For example, the addition of a parking space affects the potential increase in parking revenue; Besides that, location and usability also affect the income. There are three main elements in the transportation system, namely vehicles, lane infrastructure, and terminals. The traffic goes to a destination, and after reaching that place the vehicle needs a stop. The stop is then called a parking space. For a vehicle transportation system to be more efficient, places that are considered capable of arousing travel movements must provide adequate service facilities. Increasing population and increasing vehicle ownership will lead to increased demand for roads to accommodate traffic activities [11]. Based on the literature review above, the following framework is as presented on Figure 1.

Performance Expectancy - as the degree to which a person trusts by using the system - will help that person to gain performance gains on the job. In this concept there is a combination of variables obtained from previous research models about the acceptance and use of technology models [4]. The variables are: perceived usefulness [13], extrinsic motivation [13], job fit [14], relative advantage [15] and outcome expectations [4]. Based on empirical evidence, they are separated into performance expectations and personal expectations [13, 16]. Usefulness - a level where someone believes that the use of a particular subject - will be able to improve the work performance of that person. From some of the explanations presented above, it can be concluded that someone trusts and feels using an information technology will be very useful and can improve performance and work performance [17].

Effort expectancy is the level of ease of use of the system that will be able to reduce the efforts (energy and time) of individuals in doing their work [4]. These variables are formulated based on three constructs in the previous model or theory, namely Perceived Ease of Use (PEOU) of the Technology Acceptance Model (TAM) model, complexity of the Model of PC Utilisation (MPCU), and ease of use of Innovation Diffusion Theory (IDT) [4]. Davis, et al. [13] identified that ease of use influence the use of information technology. The ease of use of information technology will cause a feeling in a person that the system has a use and, therefore, creates a sense of comfort when working with it [18]. Several indicators of the ease of use of Information Technology (IT), namely: IT is elementary to understand, IT do easily what is desired by its users, user skills will be increased by using IT, and IT is very easy to operate. From some of the explanations given above, information technology users believe that information technology that is more flexible, easy to understand, and easy to operate will generate interest in using information technology and so will use information technology [4].

Social Influence is defined as the extent to which an individual perceives the interests that are trusted by

***Table 1** Construct performance expectations*

Construct	Definition	Item
Perceived Usefulness [13]	The degree to which a person believes that using a particular system would enhance his or her job performance.	Using a mobile-based parkingapplication system will increase the effectiveness of my activities.
Extrinsic motivation [13]	The perception that users will want to perform an activity because it is perceived to be instrumental in achieving valued outcomes that are distinct from the activity itself, such as improved job performance, pay, or promotion.	-
Job-fit [22]	How the capabilities of a system enhance an individual's job performance.	The use of a mobile-based parking application system can reduce the time needed to work.
Relative Advantage [15]	The degree to which using innovation is perceived as being better than using its precursor).	Using a mobile-based parking application system can increase my productivity.
Perceived Usefulness [13]	Outcome Expectations related to the consequences of behavior. Based on empirical evidence, they are separated into performance expectations and personal expectations	With a mobile-based parking application system will improve the quality of the results of parking activities and will increase the quantity for the same amount of effort.

***Table 2** Construct effort expectations*

Construct	Definition	Item
Perceived Ease of Use [4]	The degree to which a person believes that using a system would be free of effort.	Learning to operate a mobile-based parking system is easy for me. It would be easy for me to become skilled in using a mobile-based parking system.
Complexity [4, 22]	The degree to which a system is perceived as relatively difficult to understand and use.	Using a mobile-based parking system involves very little time to carry out mechanical operations (e.g., Input vehicle license number data).
Ease of Use [4, 15]	The degree to which using innovation is perceived as being difficult to use.	Interacting in operating a mobile-based parking system is very easy for me.

***Table 3** Construct Social Influence*

Construct	Definition	Item
Subjective Norm [12, 14, 22]	The person's perception that most people who are important to him think he should or should not perform the behavior in question.	People who influence my behavior think that I should use a mobile-based parking system.
Social Factors [23]	The individual's internalization of the reference group's subjective culture and specific interpersonal agreements that the individual has made with others in a specific social situation.	The management of this business has been helpful in the use of a mobile-based parking system. In general, the organization has supported the use of a mobile-based parking system.
Image [16]	The degree to which the use of an innovation is perceived to enhance one's image or status in one's social system.	People in my organization who use a mobile-based parking system have more prestige and have a high profile then those who do not

others who will influence him using a new system [17]. Social influence is a determining factor for behavioural goals in using information technology which is represented as subjective norms in the Theory of Reasoned Action (TRA), TAM, Theory of Planned Behaviour (TPB), social factors in MPCU, as well as images in IDT [4]. Moore and Benbasat [15] state that in specific environments, the use of information technology will increase the status (image) of a person in the social system. Social influence has an impact on individual behaviour through three mechanisms, compliance, internalization, and identification [4, 19-20].

Facilitating Conditions are defined as the extent to which a person believes that organizational and technical infrastructure is available to support the system. In this

Table 4 *Construct Facilitating Conditions*

Construct	Definition	Item
Perceived Behavioral Control [5, 22]	Reflects perceptions of internal and external constraints on behavior and encompasses self-efficacy, resource facilitating conditions, and technology facilitating conditions.	I have the resources necessary to use a mobile-based parking system. I have the knowledge necessary to use a mobile-based parking system.
Facilitating Conditions [13]	Objective factors in the environment that observers agree to make an act easy to do including the provision of computer support).	The guidance was available to me in the selection of the mobile-based parking system.
Compatibility [13, 16]	(The degree to which an innovation is perceived as being consistent with existing values, needs, and experiences of potential adopters).	I think that using the mobile-based parking system fits into my work style.

Table 5 *Construct Behavioural Intention*

Construct	Definition	Item
Behavior Intention [4, 11, 24]	The degree to which a person has formulated conscious plans regarding whether to perform a specified future behavior.	I wish to use a mobile-based parking system in the next three months I feel benefited from using the mobile-based parking system for the next three months.
Satisfaction [25-26]	Favorable intentions to use or acquire the product again or revisit service.	I will use the mobile-based parking system when parking my vehicle in the next three months. I will continue to use the mobile-based parking system if the facilities are improved.

Table 6 *Construct Use Behaviour*

Construct	Definition	Item
Use Behaviour [11, 20, 27]	Reflects perceptions of the system and potential future use.	I often use a mobile-based parking system. I prefer to use a mobile-based parking system compared to a manual system. Most of my activities are done using smartphones online. Every parking my vehicle always uses a mobile-based parking system.

Table 7 *Demographic Respondent*

No	Street Name	Age				Gender		Total
		17 - 27	28 - 38	39 - 49	> 49	M	F	
1	Street Brawijaya	11	25	8	4	35	13	48
2	Street Majapahit	11	7	11	2	27	4	31
3	Street Gadjah Mada	9	15	12	1	33	4	37
4	Street Pahlawan	14	10	13	0	31	6	37
5	Street Raden Wijaya	20	10	11	0	29	12	41
6	Street Empunala	12	6	7	2	21	6	27

concept there is a combination of variables obtained from previous research models about the acceptance and use of technology models. The variables are: perceived behavioural control [21], facilitating conditions [22], and compatibility [15].

3 Methodology

This is an explanatory research. It used a survey method to get the data from a particular natural place but the researchers do the treatment in collecting data, for example by distributing questionnaires, tests, and structured interviews [23]. This research was conducted using the UTAUT model, a research model that was built to analyse what factors influence the acceptance and use of technology. The object of this research is the parking area of Mojokerto City - East Java. The type of data in this study is primary data using field research, which is research conducted by directly visiting the places that are used as research objects. The objects in this study are the original constructs in the UTAUT model to find out the factors of user acceptance and use of the Ayo application in Mojokerto. The indicators to measure each construct in UTAUT are a derivative of the constructs previous studies and are presented in Table 1 to Table 6.

4 Results and discussion

From the results of a survey conducted obtained data from 221 of 300 targeted questionnaires. The data on the results of respondents can be seen in Table 7.

Based on Table 7, the average age of 17-27 dominates more than parking application users of ages 28-38 and the specimen is dominated by male gender, this is in accordance with a survey conducted by the Association of Indonesian Internet Service Organizers [28], which states that Generation Z widely uses users of new technology systems, and men are individuals who are very curious about new things especially smelling of technology [29]. So that in the future, the mobile-based parking application system is more readily accepted and implemented.

The level of validity can be measured by comparing the value of r count with the value of r table for a degree of freedom (df) = n - k with alpha 0.05. If r count is greater than r table and the value of r is positive, then the item or statement is said to be valid. Besides, the validity of the instruments also needs to be tested statistically, by looking at the level of significance for each instrument, in this case, using Pearson's total correlation score while the reliability test uses Cronbach's alpha, where an instrument is said to be reliable or reliable if it has a reliability coefficient of 0.60 or more. Validity and reliability tests were carried out and tested on 221 respondents randomly. The complete results of testing the validity and reliability are presented in Table 8 and Table 9.

Next is the hypothesis testing stage, which is analysing whether there is a significant influence between the independent variables on the dependent variable. The path coefficient can see hypothesis testing, which shows the parameter coefficient and the statistical significance value t. The significance of the estimated parameters can provide information about the relationship between the research variables. With a limit to reject and accept the hypothesis using a probability of 0.05. See Figure 2 and Table 10.

The first hypothesis test result is the relationship between the Performance Expectancy variable and to Behavioural Intention showing a p-value of 0.019 <0.05. Based on these results it can be concluded that Performance Expectancy has a positive effect on Behavioural Intention (H1 accepted). This result is in line with research conducted by [30-32], which states that performance expectancy has a significant effect on behavioural intention. In this case, the ability of the applied mobile parking application can accommodate the intention to use in terms of the parking attendant or the customer.

The second hypothesis results are the relationship between the Effort Expectancy variable and Behavioural Intention showing the value of p-value <0.001 <0.05. Based on these results it can be concluded that Effort Expectancy has a positive effect on Behavioural Intention (H2 is accepted). According to research from [4, 33], that effort expectancy directly and positively affects the intention. In this digital era, the use of smartphones is very familiar with the public, with an attractive appearance and precise information delivery, making it easier for users to use the mobile parking application so that it can lead to the intention to use the application.

The third hypothesis is that the relationship between Social Influence variables with Behavioural Intention shows the value of p-value <0.001 <0.05. Based on these results it can be concluded that Social Influence has a positive effect on Behavioural Intention (H3 accepted). A significant part of the research has proved that social influence has been profoundly affecting human behaviour in general and technology adoption in particular [34]. The mobile parking application implemented by the government with the help of advertisements on the media regarding the ease and benefits of the application can lead to social issues in the intention to use.

The fourth hypothesis is the relationship between the Facilitating Conditions variable and the Use Behaviour showing the value of p-value <0.001 <0.05. Based on these results it can be concluded that the Facilitating Conditions have a positive effect on the Use Behaviour (H4 accepted). There have been many studies that discuss the effect of facilitating conditions with use behaviour whose results have a positive effect, such as research conducted by [4, 18, 32, 35-36], which states that the increasing features of an application will have an impact on user behaviour to use increasingly. The mobile-based parking application system is an innovation implemented by the government, has a breakthrough in the form of ease in the parking process, which is usually managed manually transformed into digital automation

The results of the fifth hypothesis are the relation between variable Behavioural Intention and Use Behaviour, showing the value of p-value <0.001 <0.05. Based on these results it can be concluded that Behavioural Intention has a positive effect on Use Behaviour (H5 accepted). [21, 37] stated the relation between intention to use and use in

Table 8 *Validity*

Variable	Dimension	Indicator	Coeff. Correlation	Results
Performance Expectancy	PE1	1	0.780	valid
	PE2	2	0.890	valid
	PE3	3	0.804	valid
	PE4	4	0.830	valid
Effort Expectancy	EE1	1	0.779	valid
	EE2	2	0.795	valid
	EE3	3	0.784	valid
	EE4	4	0.791	valid
Social Influence	SI1	1	0.805	valid
	SI2	2	0.836	valid
	SI3	3	0.825	valid
	SI4	4	0.872	valid
Facilitating Conditions	FC1	1	0.814	valid
	FC2	2	0.846	valid
	FC3	3	0.831	valid
	FC4	4	0.846	valid
Behavioral Intention	BI1	1	0.807	valid
	BI2	2	0.831	valid
	BI3	3	0.760	valid
	BI4	4	0.802	valid
Age	kkp6	1	1.000	valid
Gender	KS6	1	1.000	valid
Experience	KS5	1	1.000	valid
Voluntariness	V	1	1.000	valid
Use Behavior	KS1	1	0.806	valid
	KS2	2	0.838	valid
	KS3	3	0.733	valid
	KS4	4	0.835	valid

Table 9 *Reliability*

Variable	Cronchbach Alpha	Results
PE	0.896	Reliable
EE	0.867	Reliable
SI	0.902	Reliable
FC	0.902	Reliable
BI	0.877	Reliable
Age	1.000	Reliable
G	1.000	Reliable
E	1.000	Reliable
V	1.000	Reliable
UB	0.879	Reliable

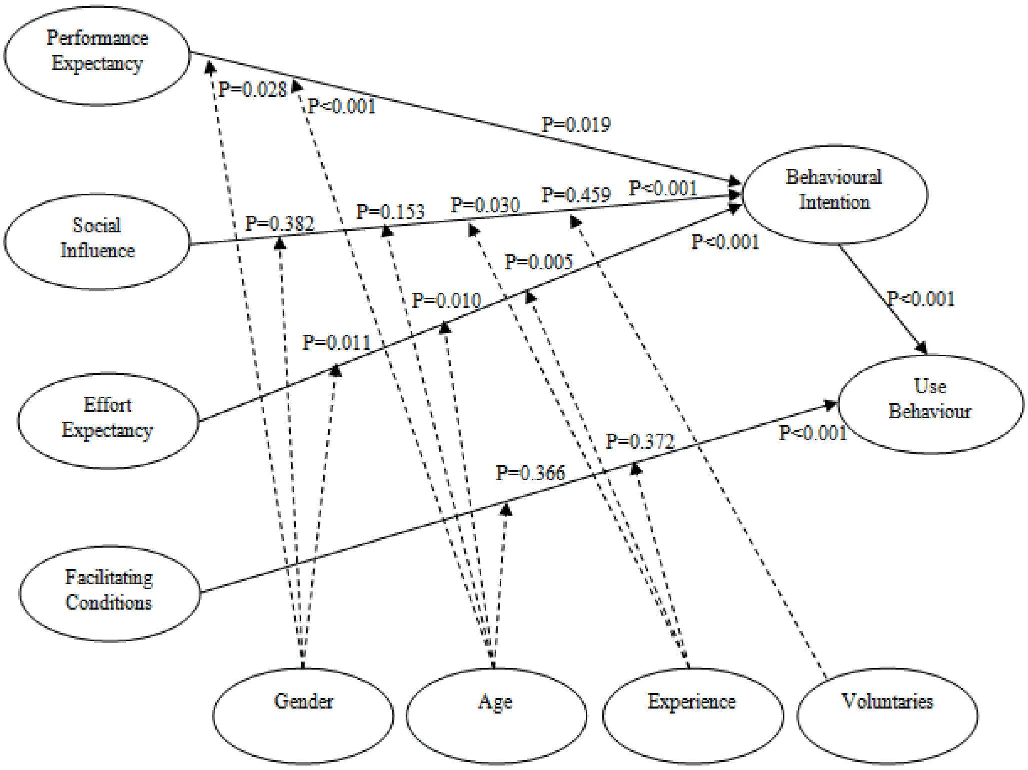

Figure 2 *Model analysis using warp PLS*

Table 10 *Summary of results*

Variable	P-value	Results
Performance Expectancy --> Behavioral Intention	0.019	Accepted
Effort Expectancy --> Behavioral Intention	<0.001	Accepted
Social Influence --> Behavioral Intention	<0.001	Accepted
Facilitating Conditions --> Use Behavior	<0.001	Accepted
Behavioral Intention --> Use Behavior	<0.001	Accepted

social psychology, based on TRA by [38], which states that the intention to conduct a behaviour is the most significant predictor of the performance of that behaviours. [39-42] in his research found that intention to use has a direct positive impact on the use of mobile-based systems, based on TAM, researchers such as [4, 27, 43] support the idea that intention to use has a direct positive influence on the use of technology.

Furthermore, according to the results that the gender variable moderates the performance expectancy variable with behavioural intention with a p-value of 0.028 <0.05 and the gender variable moderates the effort expectancy variable with a behavioural intention with a p-value of 0.011 <0.05, otherwise the gender variable does not moderate social influence variable with behavioural intention with p-value 0.382 <0.05. The age variable moderates the performance expectancy variable with behavioural intention with p-value <0.001 <0.05 and the age variable moderates the effort expectancy variable with behavioural intention with a p-value value of 0.010 <0.05, otherwise the age variable does not moderate the social influence variable with behavioural intention with p-value 0.153 <0.05 and age variable does not moderate the facilitating conditions variable with use behaviour with p-value 0.366 <0.05. The experience variable moderates the social influence variable with behavioural intention with a p-value of 0.030 <0.05 and moderates the effort expectancy variable with a behavioural intention with a p-value of 0.005 <0.05, otherwise the experience variable does not moderate the facilitating conditions variable with use behaviour with a p-value value 0.372 <0.05. Also, finally, the voluntary variable does not moderate the social influence variable with behavioural intention with a p-value of 0.459 <0.05.

5 Conclusion, implication and suggestion

The aim of applied research is to find solutions to improve practice; In accordance with this goal, this study adopts the UTAUT model to identify the factors that influence the acceptance of parking services based on mobile application systems implemented by the government, and in this case the performance expectations, effort expectations, social influence, and facilitation conditions are identified as factors that influence the intentions and behaviour of mobile parking of government services. Also, the moderate role of age, sex, experience, and voluntaries was confirmed.

The development of cellular telephone network technology has now entered its fifth generation, and fast connectivity is one of the benefits that can be felt by various sectors, one of which is the parking system [44]. Based on this research, it can be seen in the performance expectancy, effort expectancy, and social influence variables that the user feels that the presence of a smartphone in a parking system can increase productivity and influence the behavioural intention variable to intend further to use the application [4]. Moreover, the facilitating conditions and behavioural intention variables influence the use of behaviour, which means that the facilities that support and the intention to use can improve the user's attitude in using the application [4, 15, 38].

The impact of this research is felt directly by the local government in regulating the parking system, with this system parking management becomes more organized than before, and can eliminate the collection of illegal parking, which in turn can increase regional income. Based on the research conducted by [9, 45-46], regarding parking application technology, they argue that the mobile parking application in order to be accepted and implemented must have many facilities and conveniences. [45] conducts research by carrying out Car Parking Management and Monitoring System (CPMMS) technology by mapping available parking slot quotas so as to determine the nearest parking space, then research conducted by [9] with the application of Radio Frequency Identification (RFID) technology that is useful to determine capacity parking through data collection at the entrance and exit at the parking area, then there is a study conducted by [46] who applies the number plate recognition, which aims to recognize the vehicle plate number.

Research from [7], regarding parking behaviour in Indonesia, states that many people prefer to park their vehicles on the side of the road. From the technology that has been done by researchers beforehand, that the application of the technology is not suitable to be applied on the road because besides the behaviour of Indonesian people who have not been disciplined and structured parking with the technology is more suitable to be applied by the private sector where there are entrances and exits such as in malls, school or office building.

In the future, suggestions for improving the quality and service of the application need to add features for government-managed payments such as toll roads, electricity, water, and synergy with government-managed payments such as the maintenance of a license (license) to motor vehicle tax. Parking fees are relatively cheap, but parking is one of the factors contributing to revenue for the government [8, 47]. So the government must pay attention to this.

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APPLICATION OF SIMULATION METHODS FOR STUDY ON AVAILABILITY OF ONE-AISLE MACHINE ORDER PICKING PROCESS

The main aim of the paper is the analysis of simulation model reflecting selected in-warehouse logistics processes in the aspect of their availability. For this purpose, one-aisle machine picking problem with use of a stochastic random simulation is studied, with a special focus on reliability of the system to disturbances and maintenance scheduling. The methodology in the research consists of classic measures of reliability. The model is designed in order to analyze availability of selected parameters of randomly generated order picking process. One of key-results of the paper is answer for question if a mean time to failure can be treated as a value of time when the first failure in the system occurs. A summary of the contribution includes discussion and the perspectives for further research in the subject matter.

Keywords: *availability, MTTR, MTBF, MTTF, failure rate, failure frequency, warehouse*

1 Introduction

The order picking (later: OP) process is deliberated as one of the most important among processes in internal logistics. It is believed as such because this process is the most labor consuming one and it determines the level of service experienced by the down-stream customers [1]. Moreover, it engages most of resources of all processes realized in logistics facilities (that aspect is connected to labor consuming), which is confirmed in [2]. In addition, this process is considered to be the most time consuming [3-4]. All these aspects aim to find out that it is highly cost-consuming process. Authors of [5] estimated OP cost - they stated that the cost incurred during OP processes is from 55% to 75% of total cost for all logistics processes in warehouses (it is also mentioned e.g. in [6-7]). OP process consists of roughly three phases. The first one is travel to the predefined storage location which is non-value-adding according to [1], the second one is search of the exact location wanted. This phase can be significant while picking of small parts, and it is considered also as non-value-adding phase. The third phase is connected to three actions: reach, take, and deliver to the appropriate in/out spot. This is a value-added and the most resistant to automation activity.

As it was mentioned in many references, the scope of scientific elaborations on OP processes is very broad. The authors deal with e.g.: strategies used to achieve efficient OP process (e.g.: [8-10]), cost estimation based on highly detailed and hierarchical analytical or numerical models, and reduction of processes duration (or indirectly, by reduction of traveled distance between picking points, as in [3, 11-12]. Many other authors attempted to reduce OP process time, as in: [7, 13-14].

In order to achieve as much as realistic simulation model as possible, during its building some events, which potentially disrupt a regular material-flow should be included. This kind of events can be implemented accurately or randomly. Retooling, maintenance times, accidents, machine failures and many other kinds of disturbances can be included in simulation to make it firstly more realistic, more adequate to real logistics facility, and secondly to execute what-if analyses in order to be ready for unpredicted failures or "catastrophes", which might took place in a logistics facility implemented into simulation model. In many simulation software there are at least two options for failures modeling [15]. The first one is using statistical distribution and the second one is application of certain areas based on reliability theory. In the model used for this study second option was implemented. By the way, paraphrasing of "failure" meaning given in [16], it is understood in the paper as a unit/machine/mean of transport/device which has not met user/customer/operator requirements in some way during its functioning.

Taking into consideration all the above statements, a model for OP analyses in one aisle in OP area was developed (this one aisle is operated by one automated machine: an automated storage and retrieval system AS/RS). The main objective of this model is to obtain a sequence of any number (by default, one hundred) of durations of OP process taking place within OP area in a hypothetical

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warehouse. This paper is connected to the simulation model presented in [17] (briefly described in third section of the paper, the one connected to methodology). For this paper, the model would be analyzed in the context of the accessibility of machine contributing to OP process operation and in the context of other concepts related to mentioned accessibility. Therefore, it can be assumed that the following parameters are analyzed with use of the model: availability, mean time to failure, mean time between failures, mean downtime, mean time to diagnose, mean time to recovery, failure rate, etc. One of the aims of the article is to answer the following research question. Can the simulated times up to the first failure of the means of transport and the times obtained on the basis of calculated statistical values for selected accessibility characteristics be treated identically? In other words, can the mean time to failure, calculated from the generalized mean time to failure equation, be treated as the value of time when the first failure in the model occurs? It seems to be important question, especially that a wide range of innovative concepts make transport systems (and equipment) more efficient and competitive [18], therefore these systems and equipment need to be analyzed adequately.

2 Literature review

Several equations for assessing availability of agents (e.g. means of transport) taking part in a process can be found in literature. These equations are based on available data on damage to components over time. These data are used in order to create an availability model, which is designed to reproduce as faithfully as possible an operating process of a machine/vehicle, etc. However, when hypothetical facilities are analyzed, no historical data is connected to any failures in the process. For this reason, a simulation modeling may be implemented for analyses. Simplifications are adopted for such models, which are described in methodology section.

The origin of using mean time between failures (MTBF), mean time to recovery (MTTR) was in computer science and information technology and later in operational management. At first, it was used in order to determine the durability of hard drives. Author of [14] described core principles of reliability in software engineering.

As Authors of [19] mentioned, most of companies implement lean management for their operational realization. One of the methods, which is connected to lean management is Total Productive Maintenance (TPM). MTBF, MTTF, MTTR and OEE (Overall Equipment Effectiveness) are some of many key performance indicators (KPIs) allowing to analyze disturbances and failure rates of production processes. In the mentioned paper, it is used for windscreen wipers production, assembly process and internal transport analyses. Meanwhile, Authors of [20] use the term of mean time between overhaul furthermore - since this parameter is used mostly for engines, it is not considered here.

Research results on this subject in the context of logistics (and especially intralogistics) are published much less frequently. Authors of [21] used chosen KPIs in order to analyze the system composed of a machine, a warehouse, a vehicle and customers. Authors realized it in order to choose a suitable vehicle type according to different costs of this system taking into consideration MTTR and MTBF. Authors of [22] prepared a multicriteria rating of the batch process method, including four KPIs as technological aspects evaluation in this method. KPIs were also used in [23] in order to reduce intralogistics costs of spare parts and semi-finished products while implementation of digitization in maintenance. Authors of [24] used chosen KPIs in order to analyze buffers next to assembly lines system with material handling. However, several publications touched devices availability analyses for internal logistics, these were hardly connected to treat it as the main subject matter.

3 Methodology, research conditions and assumptions

The methodology consists of several parts. At first, it involves data compilation and pre-processing (despite the model consists of hypothetical data, these must meet requirements related to the real-world facilities). Secondly, it involves data exploration (mostly, statistics exploration). Third part includes developing and experimenting with the simulation model, while the last part entails evaluation and interpretation of results of the experiments.

In modeling theory, the category of models, which selected parameters can be described by random variables, distinguishes deterministic and stochastic models. In a deterministic model none of random variables are implemented. Stochastic model contains at least one variable of random kind [17, 25-26]. The model considered in this paper is stochastic one.

The main assumptions of this simulation model are connected to the fact that it realizes a sequence of randomly matched picking lists. The particular picking list is described by two parameters. The first one is the number of lines in each picking list that correspond to assortment of products to be picked during certain order realization. The second parameter is the quantities of items of a certain product to pick from a certain shelf in OP area. The number of lines in each picking list (of a j-th element in the sample for k-th experiment) reaches the scope of $w(j,k) = \{1,\ldots,10\}$, and the quantities of i items to pick (per line in a k-th experiment) are within the scope of $p(i,j,k) = \{1,\ldots,10\}$. Picking lists are generated as a result of initiation of adequate procedure with pseudorandom number generator (PRGN) included in the simulation model, and this PRGN is defined and constructed by first author based on the logistics map. It starts from random numbers uniformly distributed between 0 and 1, generated by a suitable standard random number generator ($p^*(1,1,k)$ in Equation (1)), and obtains the sizes of items to be picked using bifurcation of the logistics map (value 4 in Equation (1) ensures that the data structure is chaotic), inspired by [27] (in order to obtain integer values of $p(i,j,k)$, a multiplier by 10 is entered). A picking list in the model is a series of orders not known in advance that have to be served one after another. More details and PRGN verification are given in [28].

$$p(i,j,k) = [10 \cdot 4 \cdot (1 - (p^*(i-1,j-1,k-1))) \cdot \\ \cdot p^*(i-1,j-1,k-1)] \\ p^*(1,1,k) \in (0;1\rangle \quad (1)$$

In order to generate picking lists, logistic differential equation is used in the model. It ensures gaining PRGN values which are more random than in the case of using simply probability distribution. Empirical research with use of simulation model proved that in the case of using chosen probability distribution results were repeatable in the case of 80% of experiments [17]. In order to exclude repetition, logistic differential equation was introduced.

The simulation model allows to study several parameters connected to reliability and availability of means of transport used in examined logistics facility. Mentioned parameters are directly connected to reliability or having an impact on it (indirect impact). These parameters are: processing time, recovery time, cycle time, capacity, mean time to repair, availability. Moreover, the group of parameters can be broadened by another ones, which might be useful in a study of reliability and availability of machines and means of transport that are not unambiguously defined in the software and require to be redefined in simulation model. These parameters, not exclusively, are mean time to failure (MTTF), mean time between failures (MTBF), estimated percentage of simulation time during which a mean of transport failure may occur ($f(k)$; this is parameter similar to unavailability - the difference is that $f(k)$ is stochastic parameter, which value is drawn on the basis of PRGN built into the software and its value in relation to availability η_T is characterized by the relation $f(k) < 1 - \eta_T$, whereas unavailability $\widetilde{\eta_T}$ is characterized by the following relation $\widetilde{\eta_T} = 1 - \eta_T$.

The simulation model has been satisfactory verified before and verification proved that the difference between the results of the simulation model and the analytical model is at acceptable level of 3.5%. The model was not validated, since it is hypothetical warehouse.

According to [29], the availability is equal to the probability of a unit/machine/mean of transport when it is operated correctly and without any malfunctions. It is determined by Equation (2), where: η_T is parameter of availability (unitless parameter), T is total operating time [min] and T_{out} is a sum of individual periods of downtime [min].

$$\eta_T = (T - T_{out})/T \quad (2)$$

According to [29], mean time to repair (known also as mean time to restore, mean time to recovery as in [12] or mean downtime, [min]) *MTTR* is total downtime T_{out} [min] divided by the numbers of malfunctions n_{out} (unitless parameter) given according to Equation (3).

$$MTTR = T_{out}/n_{out} \quad (3)$$

MTBF is mean time between failures or disruptions in the operation of a product, process, procedure, design, machine, unit, mean of transport. Mean time between failures assumes that a product - or any other mentioned entity - can be repaired, and a product can then resume its normal operations [30]. According to [29], the mean time between failures *MTBF* is given according to Equation (4) in [min].

$$MTBF = (T - T_{out})/n_{out} \quad (4)$$

And based on Equations (2)-(4), the availability can be expressed by MTTR and MTBF parameters, as in Equation (5) - as such is exposed also in [15].

$$\eta_T = MTBF/(MTBF + MTTR) \quad (5)$$

MTTF (Mean Time To Failure) determines the average operating time of a device from the beginning of its operation or from its last repair to the first failure [31]. This parameter is particularly important for systems in which single operations last a long time - small values of MTTF significantly reduces a probability of correct completion of a single operation. In a lot of design, components and devices, a value of MTTF is especially near to a value of MTBF (Mean Time Between Failures). Typically, MTBF is slightly longer than MTTF [31]. MTTF should be used for non-repairable items, however it has been studied here in order to examine the interdependence of different parameters of this type.

In the paper [32] and book [33], the availability is given as Equation (6).

$$\eta_T = MTTF/(MTTF + MTTR) = MTTF/MTBF \quad (6)$$

Equation (5) is used in the case, when it is dealing with impact of a repairable element on availability of a system (refurbishing/remanufacture is not understood as repair, but rather replacement). And the Equation (6) is used when it is dealing with impact of a one-off/non-repairable element on availability of a system, in which it operates (an element could be refurbished/remanufactured) [30]. The simulation model is assumed to deal with a situation, where replace parts in equipment subject to failure is possible - therefore Equation (5) is used.

Failure rate [min^{-1}] is the total number of detected defects divided by the total number of samples observed, and according to [32] is as given in Equation (7).

$$\mu = 1/MTBF \quad (7)$$

Failure frequency (unitless parameter), according to [32], is given as in Equation (8).

Table 1 Summary of the parameters for assessing the availability of AS/RS

k	*f(k)* [%]	*MTTR(k)* [min]	η_T [-]	Operating time [min]	*MTTF(k)* [min]	*MTBF(k)* [min]	$\mu(k)$ [min^{-1}]	Failed [%]	$\tau(k)$ [-]
1	10	1	90	1683.94	8.10	9	0.11111	10.04	169.0675760
2	10	3	90	1737.26	24.30	27	0.03704	10.19	59.0089313
3	10	9	90	1801.22	72.90	81	0.01235	9.20	18.4124711
4	10	27	90	1808.93	218.70	243	0.00412	9.28	6.2173594
5	10	81	90	1682.32	656.10	729	0.00137	8.75	1.8173210
6	10	243	90	1666.35	1968.30	2187	0.00046	14.78	1.0135246
7	20	1	80	1750.16	3.20	4	0.25000	20.17	353.0072720
8	20	3	80	1793.90	9.60	12	0.08333	20.23	120.9686567
9	20	9	80	1914.29	28.80	36	0.02778	21.06	44.7943860
10	20	27	80	1972.89	86.40	108	0.00926	18.70	13.6640900
11	20	81	80	1929.83	259.20	324	0.00309	18.06	4.3028061
12	20	243	80	1666.35	777.60	972	0.00103	20.85	1.4297694
13	30	1	70	1865.32	1.63	2.3	0.42857	30.23	563.8862360
14	30	3	70	1892.27	4.90	7	0.14286	30.87	194.7145830
15	30	9	70	2027.49	14.70	21	0.04762	31.09	70.0385157
16	30	27	70	2054.09	44.10	63	0.01587	26.63	20.2594136
17	30	81	70	2214.97	132.30	189	0.00529	25.92	7.0879040
18	30	243	70	1860.62	396.90	567	0.00176	23.19	1.7756287

$$\tau = T_{out}/MTTR \tag{8}$$

Literature distinguishes three types of availability: inherent, operational and achieved.

Inherent availability (η_{TI}) is understood as availability of a system with respect only to operating time and corrective maintenance. Parameter η_{TI} is equal to η_T, given as Equation (5). It does not include standby and delay times and mean logistics delay time (MLDT) [34].

Achieved availability (η_{TA}) is understood as availability of a system with respect to operating time and both corrective and preventive maintenance (unitless parameter). It ignores mean logistics delay time (MLDT) and may be calculated according to Equation (9) in [min], where *MTBM* [31] is mean time between maintenance in [min] and *MMT* is mean maintenance time in [min] [35]. *MMT* is a measure of maintainability duration - preventive and corrective maintenance are taken into account. It is calculated by adding the preventive and corrective maintenance time and dividing it by the number of scheduled and unscheduled maintenance operations during a stated period [36].

$$\eta_{TA} = MTBM/(MTBM + MTT) \tag{9}$$

Operational availability (η_{TO}) is differentiated from achieved availability by the fact it includes mean logistics delay time (MLDT). MLDT is the indicator of an average time a system is awaiting maintenance and generally includes time for locating parts and tools; locating, setting up or calibrating test equipment; dispatching personnel; reviewing technical manuals; complying with supply procedures; and awaiting transportation [37]. Operation availability (unitless parameter) may be calculated according to Equation (10) [38].

$$\eta_{TO} = MTBM/(MTBM + MTT + MLDT) \tag{10}$$

The entire simulation model is predefined, verified and realistic thanks to usage of PRGN of two kinds: the predefined in simulation software and the one prepared by paper's first author - specifications of them are given in the paper. The software predefined PRGN includes MLDT (it was assumed that MLDT is a result of PRGN implementation), therefore instead of computing operation availability, in this paper inherent availability is computed.

4 Results discussion

Results of *k* experiments on the model are gathered in Table 1 and Table 2. Experiments allowed to obtain several facts connected to availability, based on values given in Table 1:

- with the increase of *MTTR(k)* (η_T = const) values of operating time oscillate similarly as mean values of OP times given in Figures 1-3;
- with the increase of *MTTR(k)* (η_T = const), *MTTF(k)* and *MTBF(k)* increase exponentially (Figures 4-6)

Table 2 *Usage of AS/RS, where: mean value of OP process time* $\overline{t(k,PS)}$*, standard deviation,* $s_{t(k,PS)}$ *and mean squared error of the mean value* $s_{\overline{t(k,PS)}}$

k	Operational Working [%]	Operational Waiting [%]	Failed [%]	$\overline{t(k,PS)}$ [min]	$s_{t(k,PS)}$ [min]	$s_{\overline{t(k,PS)}}$ [min]	k	Operational Working [%]	Operational Waiting [%]	Failed [%]	$\overline{t(k,PS)}$ [min]	$s_{t(k,PS)}$ [min]	$s_{\overline{t(k,PS)}}$ [min]
1	77.54	12.42	10.04	16.84	0.94	0.09	10	63.28	18.02	18.70	19.73	1.16	0.12
2	78.75	11.06	10.19	17.37	1.07	0.11	11	65.00	16.94	18.06	19.30	1.73	0.17
3	80.19	10.61	9.20	18.01	1.01	0.10	12	58.13	21.02	20.85	16.66	0.98	0.10
4	76.25	14.47	9.28	18.09	0.77	0.08	13	47.12	22.65	30.23	18.65	0.53	0.05
5	81.96	9.29	8.75	16.82	0.95	0.10	14	46.33	22.80	30.87	18.92	1.47	0.15
6	67.74	17.48	14.78	16.66	0.98	0.10	15	45.63	23.28	31.09	20.27	2.15	0.22
7	62.38	17.45	20.17	17.50	0.79	0.08	16	51.07	22.30	26.63	20.54	1.80	0.18
8	60.51	19.26	20.23	17.93	0.77	0.08	17	52.40	21.68	25.92	22.15	2.48	0.25
9	60.60	18.34	21.06	19.14	1.57	0.16	18	55.40	21.41	23.19	18.61	2.49	0.25

Table 3 *Comparison of MTTF and FTOF (in relation to operating time)*

k	*MTTF(k)* [min]	*FTOF(k)* [min]	k	*MTTF(k)* [min]	*FTOF(k)* [min]	k	*MTTF(k)* [min]	*FTOF(k)* [min]
1	8.10	14.90	7	3.20	138.33	13	1.63	4.25
2	24.30	42.20	8	9.60	41.50	14	4.90	24.90
3	72.90	179.10	9	28.80	220.40	15	14.70	47.56
4	218.70	413.80	10	86.40	379.10	16	44.10	95.10
5	656.10	1180.90	11	259.20	1283.43	17	132.30	275.00
6	1968.30	*	12	777.60	*	18	396.90	1205.70

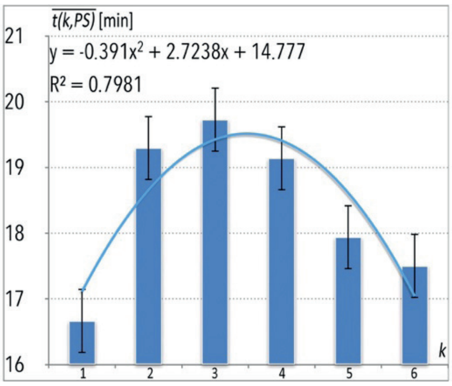

Figure 1 *Mean value of OP process time that accrue on the experiments k = {1,…,6}*

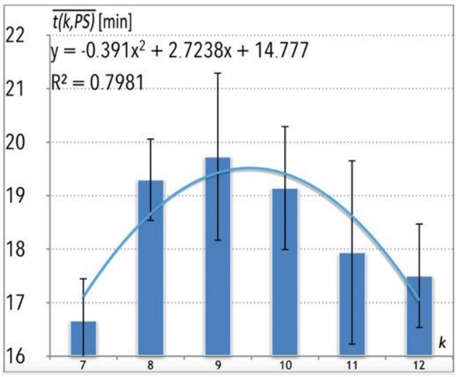

Figure 2 *Mean value of OP process time that accrue on the experiments k = {7,…,12}*

which confirms the theory and confirms that the simulation model was verified accordingly;

- 10% reduction in availability results in a halving of *MTTF(k)* and *MBTF(k)* values (Figures 4-6);
- with the increase of *MTTR(k)* (η_T = const), failure rate $\mu(k)$ and failure frequency $\tau(k)$ decrease exponentially, proportional to values of *MTTF(k)* and *MTBF(k)*, Figures 7-8;
- failure rate $\mu(k)$ and failure frequency $\tau(k)$ decrease with reduction of availability η_T;
- as it was mentioned before, MTBF is a little bit longer than MTTF - this research proved the theory; and the difference between *MTBF(k)* and *MTTF(k)* is equal to c.a. *MTTR(k)* (MTBF can be understood as a sum of MTTF and MTTR);
- the Figures 1-3 show the duration of OP process obtained for 18 simulation experiments - the values of OP process time are given as average values from 100-elements samples (100 runs of the simulation model). Figures 1-3 show that the duration of OP process does not increase while MTTR increasing, however changes of durations for consecutive experiments can be described by second-degree polynomial functions with determination coefficient, each given in consecutive figure, for every next experiment. Nevertheless, increasing of *f(k)* parameter and decreasing of availability η_T make OP process

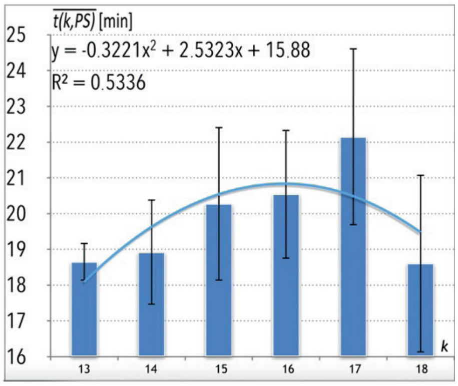

Figure 3 *Mean value of OP process time that accrue on the experiments k = {13,...,18}*

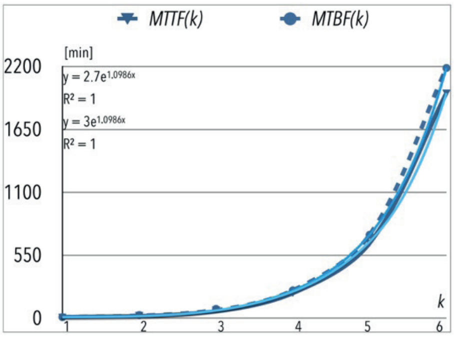

Figure 4 *Comparison of MTTF and MTBF that accrue on the experiments k = {1,...,6}*

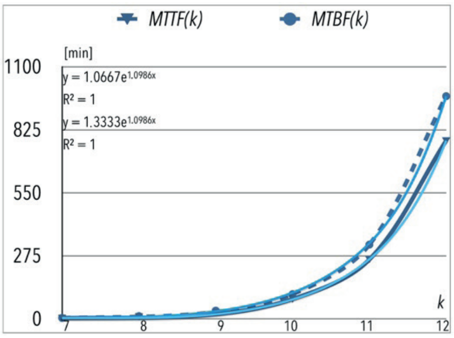

Figure 5 *Comparison of MTTF and MTBF that accrue on the experiments k = {7,...,12}*

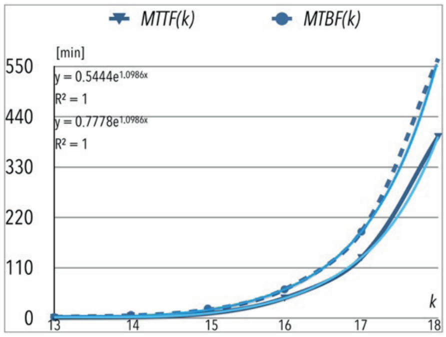

Figure 6 *Comparison of MTTF and MTBF that accrue on the experiments k = {13,...,18}*

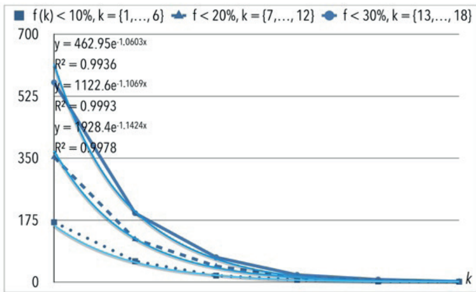

Figure 7 *Changes of failure frequency* $\tau(k)$ *that accrue on the experiments k = {1,...,18}*

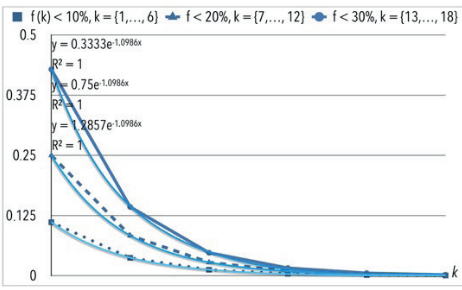

Figure 8 *Changes of failure rate* $\mu(k)$ *that accrue on the experiments k = {1,...,18}*

times longer what was expected. In all three cases of *f(k)*, the best approximation turns out to be the polynomial of the second degree. All trend diagrams are plotted within the limits range of the standard deviation accompanying the bars of the average duration of OP processes for the individual experiments with consecutive numbers of *k*;

- MTBF should be as short as possible and it is an overall indicator of reliability and effectiveness/efficiency, therefore MTTR should be as short as possible.

Comparison of MTTF and first time of failure FTOF is given in Table 3. In the case of records with asterisks, the failure did not occur during the experiment; after two days of operation time the simulations were interrupted.

5 Conclusion

Availability analysis allows to determine when a machine should be replaced or when a machine should be passed for technical inspection. In such cases, each component of a machine would have to be treated separately and not as a whole. For key machines the following principle is generally adopted: preventive replacement of parts every 85% MTBF [39]. This can be understood that a device should be inspected after this time. At current stage of the model, it can only be concluded that some unspecified failures may occur. It is worth noting that in the model, it is not so much the device's interference analysis that is important, but the process of internal transport and OP technologies. With this assumption, the model is fully functional, and the analyses are satisfactory.

In the introduction section of the paper research question was given: can the mean time to failure, calculated from the generalized mean time to failure equation, be treated as the value of time when the first failure in the model occurs? Based on the data obtained during computation with the model, the answer is "no", because of difference in pair of values *MTTF(k)* and *FTOF(k)* given in Table 3. However, after computing Pearson correlation coefficient for MTTF and FTOF, the value of the coefficient is 0.88, therefore the correlation is strong and positive (two pairs of values were excluded, $k = \{6, 12\}$ - in their case any failure did not occur during the experiment; after 2 days of operation time the simulations were stopped). The FTOF values for each k were obtained from individual experiments - in future studies further experiments will be conducted in order to enrich verification of the research question.

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FORMATION AND OPTIMIZATION OF TRANSPORT NETWORKS IN THE CONDITIONS OF THE DIGITAL INTEGRAL ENVIRONMENT FOR TRANSPORTATION

The article provides a brief description of the digital integrated transportation support environment. The methods of choosing the base route in the formation of transport networks in the conditions of the formation of a digital integrated environment are presented. It is shown that the means of solving the problem of optimization of transport networks is a developed modeling complex, which consists of a set of models with the necessary degree of detail. The paper presents a functional diagram and a brief description of the complex. The complex functions taking into account the replenishment, improvement and updating of models, allow you to combine different types of models and use the necessary of them when solving specific problems of transport network optimization. The modeling complex allows to significantly simplify the optimization of transportation networks. On the basis of the proposed mathematical apparatus, the software of an automated system has been developed, which is designed to function in a digital integrated environment, a brief theoretical description of which is given.

Keywords: *digital integrated environment, basic route, route criteria and parameters, transport network, optimization, models, modeling complex*

1 Introduction

The problem is the organization of the information space in which both carriers and customers would feel comfortable is very urgent now. To solve this problem, it is necessary to create a digital integrated environment - which is the main component of a unified information space to meet the needs of the transportation of passengers and goods, where user work is positioned as an electronic service. The digital integrated environment should have a modular structure that will enable the connection of new routes, new carriers, as well as representatives of related organizations to provide additional services. When creating new routes, it is necessary to evaluate the parameters of the routes and optimize the movement of route vehicles. Consequently, an important step in the development of a digital integrated environment for transportation is the optimization of route transportation networks.

The digital integrated environment for transportation is a single information space implemented by software and hardware, which provides the opportunity for interaction between carriers and consumers. The digital integrated transport environment is designed to provide information on all types of transport networks, including urban, regional, intercity, personal and freight transport

The tasks of modeling and optimizing route transportation networks were taken up by many specialists. A great contribution to the mathematical formulation of optimization problems and the development of models of the movement of route vehicles made Varelopulo, Lieberman, Arak, Ligum, Levinson, Black, Vuchic, Schnabel, Lohse, Fernandez and other scientists.

Today there are many mathematical models of optimization of transport networks [1- 2]. However, all these models are separated and presented in different ways, have a different form of recording, different representation of input and output parameters, the same parameters in different models have different units of measurement, etc. At the moment there is no single unified form, a single method of representation of such models, while individual models do not allow to fully solve the necessary optimization problems in a digital integrated environment. Therefore, the development of new more effective models, approaches and software to optimize transport networks applicable in the digital integrated environment is an urgent scientific problem.

2 Transport network design and optimization

A single information space for transportation is a space for interaction between participants in the transportation process: employees of transport companies, customers, authorities and other parties interested in the quality of transportation. A single information space for transport provision arises as a result of the formation of an appropriate digital integrated environment, including [3-4]:

- automated control systems of transport companies;
- clients of transport companies and authorities;
- governmental institutions;

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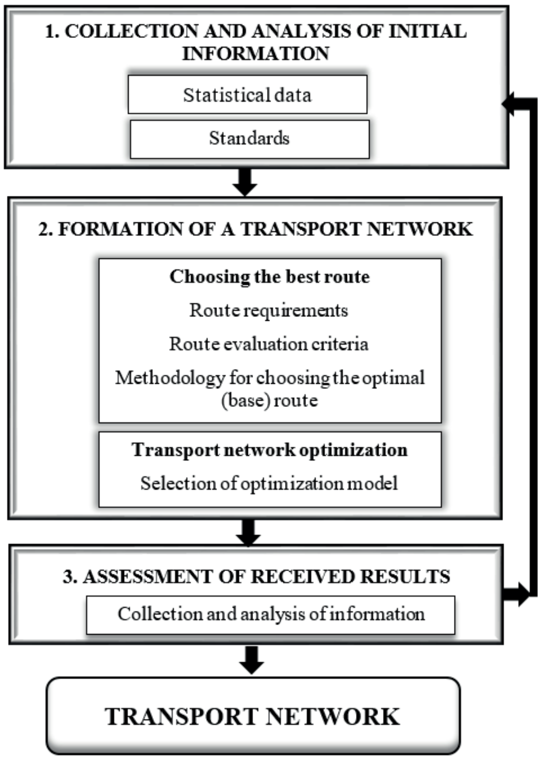

Figure 1 *Scheme for transport networks design*

- corporate and local telecommunication networks, expert systems, technological databases and reference books;
- regulatory databases;
- specialized data processing centers that provide timely processing of large volumes of information;
- on-board devices and mobile devices that collect data directly during transportation;
- digital communications in the form of global telecommunication networks, connecting all the listed components into the information environment.

However, the digital integrated environment is not yet a single information space. A single information space, in addition to solving other important tasks, requires the development of standards and protocols that ensure a wide exchange of information between its components. To do this, the digital integrated environment must be provided for joint work and efficient data exchange between:

- automated transport management systems;
- digital interfaces of clients of transport companies;
- a single portal of public services for the access of employees and customers of transport companies to information;
- geographic information systems, including electronic maps, 3D-terrain models and decrypted satellite photos;
- a unified system of identification, authentication and authorization of users of the digital platform;
- payment service to pay for transportation, mutual settlements of participants in the transportation process, payment of taxes and fees;
- a system of reference books, classifiers, registers and other regulatory reference information.

The concept of using such a space involves registering a participant in the transportation process on the service portal, either as a client or as a representative of the carrier. The client should be given the opportunity to choose transportation services based on their preferences. For example, if cargo is transported, the determining factors should be the parameters of the cargo, as well as the customer's preferences - price, speed of delivery, etc. Based on these and other input data, the route is built. On the way of the cargo, the points of trans-shipment are determined, and the client receives information about the route and the final cost of the service. When implementing passenger transportation, it is necessary to take into account not only price and time parameters, client preferences for choosing possible intermediate points (cities, attractions), with an opportunity of creating a route map with the necessary transport documents, up to booking hotel rooms and excursions.

To implement a digital integrated environment, it is necessary to solve a number of problems: development of a methodology for creating a digital integrated environment for transport; development of standardization methodology in the field of digital transportation management; development of a set of models for the implementation of a digital integrated environment; development of the concept of connecting carrier modules; development of an intelligent interactive interface with a digital integrated environment (carrier/customer). In addition to the above, an important task in creating a digital integrated environment for providing transportation is the task of forming and optimizing transportation networks. A transport network is a set of possible routes of all modes of transport included in the process of transporting passengers or goods between two endpoints. Since several modes of transport can be used for one route, such a system can be called an integrated transport infrastructure or environment. The process of creating transport networks is presented as a diagram in Figure 1.

The process of design of transportation networks includes three main stages:

Stage 1. Collection and analysis of initial information. Information is collected from video monitoring systems and DVR systems. They also include video monitoring of public transport and outdoor security cameras. To collect and analyze initial information, the following are needed: systematization and standardization of video recording systems; systematization of information processing. It is necessary for the control system to include the means of satellite navigation.

Stage 2. Formation of the transport network.

2.1 Choosing the best route for inclusion in the transport network

At this stage it is necessary to make an informed decision about which route should really be included in the transport network, using the method of choosing the optimal route (it is reasonable to call it a base route) from a variety of alternatives.

Generally, when there is an ambiguity in the choice of a route (usually this occurs under conditions of uncertainty in the initial information), i.e. the only best option cannot be found. You can get only a few («area») rational options. Considering this circumstance, one should first identify this set of rational routes, the final choice of the optimal (base) route that will be included in the transport network is made by applying various expert procedures. With such a final choice, certain formalized techniques can be applied (for example, expert assessment methods, hierarchy analysis method), however, the main role belongs to the person - the expert.

2.2 Optimization of transport networks

The study of modern methods for optimizing transport networks has shown that since the beginning of the 2000s, new approaches to building and optimizing transport networks have been actively introduced in European countries [5]. Existing optimization models should be considered here and/or completely new ones should be developed.

Stage 3. Evaluation of the results obtained is also carried out by collecting information from video monitoring systems, from entrance and exit turnstiles, etc. Analysis of video processing is carried out using innovative technologies in the field of artificial intelligence. When analyzing the video sequence, additional opportunities arise for the control of emergency situations. The processing of information received from video monitoring systems can be performed locally or centrally. Local processing of information requires the presence of an on-board specialized computer on a vehicle or traffic control means (traffic lights). The result will be transferred to the dispatch center. Centralized processing of information reduces the requirements for local computing facilities, but increases the load on data transmission channels. At this stage, a set of measures to ensure reliability and information security is being developed.

The result is a transport network - an electronic map with complete information about the state of traffic flows, emergency situations and the loading of vehicles on routes.

3 Choosing the optimal route for the transport network

Passenger or cargo can be moved between two endpoints using several modes of transport. Each type of transport has its own network of routes that are already formed and regularly used in various geographical areas. When you include any type of transport in the integrated transportation system, all its routes in the corresponding geographical territory are added to the database and can be used to build the necessary integral (composite) route. By integral route we mean a route using various modes of transport. When creating a digital integrated transport support environment, existing routes can be completely transferred to the digital integrated environment, and new routes will be added taking into account the existing ones.

To determine new routes, it is necessary to evaluate the parameters of routes and optimize transport networks. Estimation of route parameters and optimization of transport networks leads to increased profitability and quality of services of transport companies.

When choosing the best route one should use an appropriate method of selecting the best option from a variety of alternatives. The choice of a route is a multi-criteria task, and many of these criteria are difficult to describe accurately. It is necessary to determine and take into account all the requirements for the route, parameters and criteria for its evaluation. Route parameters are - mode of transport, traffic fluctuations, peak loads, risks, cargo parameters, infrastructure condition, range, time delays of the route, tax rates, volume and condition of the fleet of transport companies, quality of delivery and many others.

Under the conditions of the formation of a digital integrated environment, when choosing a base route to form a transport network, it is advisable to use interactive decision-making methods, since this allows using the creative capabilities of a person - decision-maker (DM) [6-7]. An expert acts as a decision maker, for example, he can be a transport company manager, government official, etc. However, in the process of developing the digital integral medium of transportation, there will be a tendency to unite the means of neural networks, expert systems in creating multi-stage decision support systems for the formation of route networks.

The choice of the base route should be made taking into account all the factors that determine the quality of such a decision, including technical and organizational, as well as cost, and time ones. This requires the use of specific techniques and methods involving the use of intuition and the decision-maker's experience. Decisions made must be steady and regular. Stability of solutions should be understood as the property to remain unchanged with respect to changes in a priori probabilities affecting the values of the estimated functionals. Decision stability analysis allows DM to identify solutions with a certain guaranteed level. A stable solution is different in that it is resistant to DM errors in terms of a priori probabilities. Regularity of decisions means that a complete regular solution has the property that it is optimal for all criteria considered, but this is extremely rare. In this case, it is advisable to use the set with partial regularity of the solution, which is optimal only for individual criteria.

In formal terms, the following decision-making conditions that arise when choosing a base route during the formation of a transportation network [8-9] can be distinguished: certain conditions when all the information for forming a base route is precisely known; conditions of uncertainty, when, in addition to unambiguous source data, there are random variables with precisely known probabilistic characteristics, as well as quantities for which their probabilistic description is not precisely known or not known at all.

A study of decision making methods showed that for conditions of certainty of initial information about routes, it is advisable to use the lexicographic method of organizing a variety of alternative options when choosing a base route [10]. The essence of the method is to streamline the decisions in order of criteria importance. In the process of choosing a base route from the set of route parameters, you should choose the one that, in the specific application conditions, reflects the necessary route properties, for example, time delays, and gives it a criterion function.

As practice shows, the majority of decision-making tasks on choosing a route to include it in the transport network are solved under conditions of uncertainty of the initial information. Analysis of existing approaches to solving the problem of choosing the base route in the face of uncertainty of the initial information showed the feasibility of a two-stage decision-making process. At the first stage, a set of rational routes is determined on the basis of formal methods, on the second, a basic route is adopted on the basis of expert procedures. Effective ones are the methods of analysis of payment matrices with the allocation of the main criterion and the method of analysis of hierarchies, respectively [11-12].

For the conditions of uncertainty of the initial information, the general algorithm for choosing the base route to be included in the transport network can be represented as follows:

A. Data input.
B. Criteria analysis.
C. The definition of a set of rational routes based on the method of analysis of payment matrices with the selection of the main criterion.
   - C.1 Selection of representative combinations of source data.
   - C.2 Search and preliminary analysis of solutions.
   - C.3 Calculation of the payment matrix.
   - C.4 Analysis of the payment matrix and the choice of rational decisions.
D. Selecting the base route using the hierarchy analysis method.
   - D.1 Assessing the importance of criteria by pairwise comparisons.
   - D.2 Calculation of criteria weights.
   - D.3 Comparison of the importance of alternatives by criteria.
   - D.4 Calculate the weights of alternatives for each criterion.
E. The end of the algorithm.

For the analysis of routes, the selection criteria proposed for the conditions of uncertainty are used - Wald, Laplace, Savage, Hurwitz criteria or their combination [13].

4 Optimization of transport networks based on the modeling complex

When modeling transportation in Russia, the software packages PTV Vision, AIM Sun and others are mainly used. Their main disadvantage is the closed architecture, that is, the impossibility of adding fundamentally new designs (calculation models). Existing modeling tools use only separate models and methods that do not allow to fully and adequately solve the tasks set for transport workers. A means of solving the task of optimizing transport networks is a modeling complex, which consists of many models that have the necessary degree of detail:

$$M = \{M_1, \dots, M_i, \dots, M_s\}, \tag{1}$$

with M_1, M_i, M_s being specific models.

The complex can include both analytical and simulation models for optimizing route networks. The functional diagram of the modeling complex is presented in Figure 2.

The fundamental properties of the modeling complex:

- property of integration, that is, the complex must integrate models depending on the specific situation (task);
- the property of evolution, which consists in the fact that the modeling complex, in fact, should be a working space for the gradual improvement of the transport network;
- the property of duality, reflecting the possibility of representing the complex, on the one hand, as a model

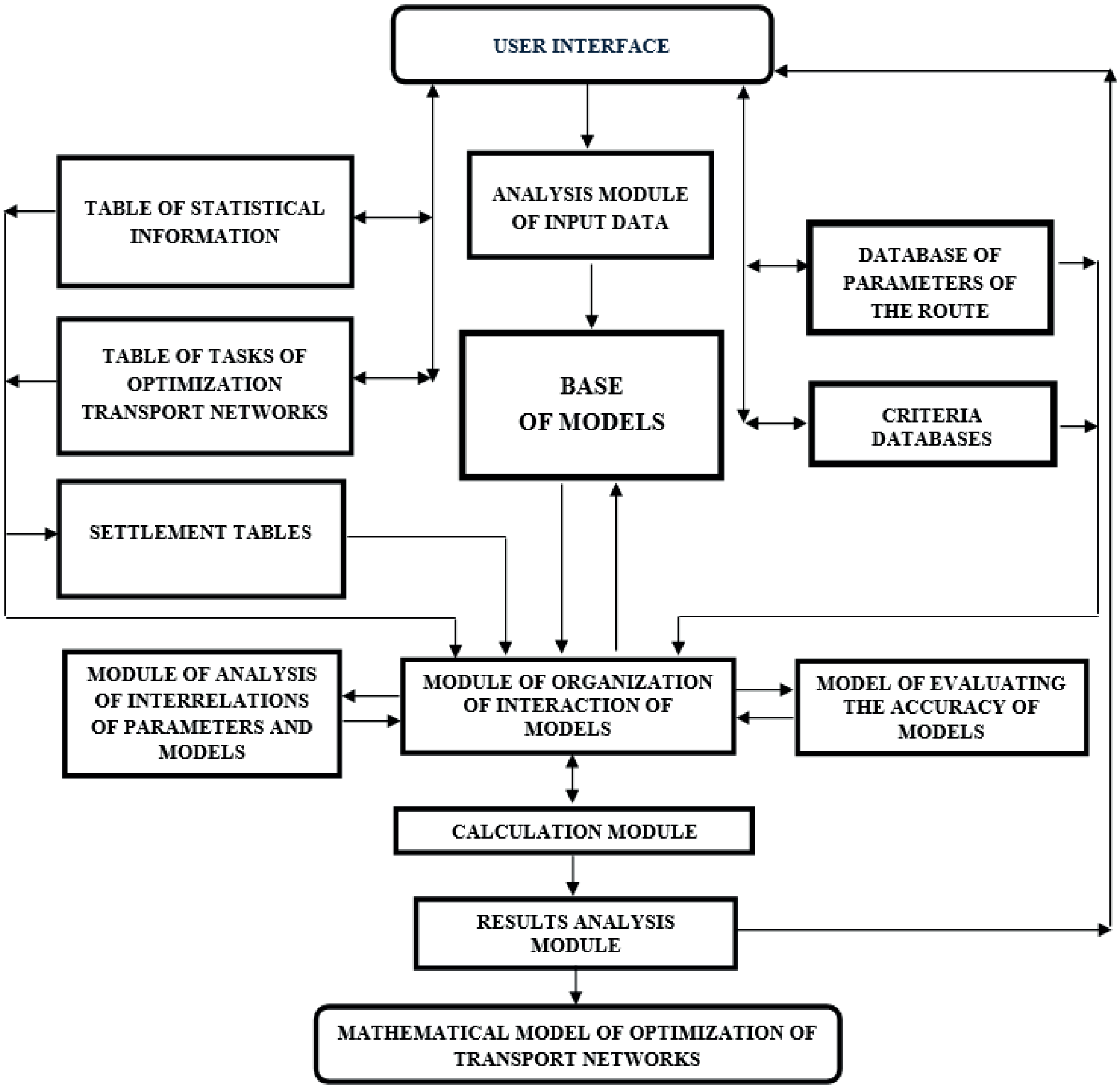

Figure 2 *Functional diagram of the modeling complex*

of the object under study, and, on the other hand, as a model, reflecting the process itself of optimizing the transport network;

- versatility or applicability for solving an unlimited set of various problems of optimizing transport networks, taking into account the necessary parameters, criteria and restrictions;
- the property of development, which consists in the fact that the complex is created and operates taking into account the replenishment, improvement and updating of optimization problems and models of their solutions; the complex allows you to combine different types of models and use the necessary ones in solving specific problems of optimization of transport networks in a digital integrated environment of transport.

Requirements for the modeling complex: adequacy; the possibility of refining the model when developing the transport network and the possibility of multi-level modeling; correctness of work; the ability to process data of large dimensions; effective software implementation; reliability; convenient visual perception.

In order to overcome the current diversity of the representation of the existing models for optimizing transportation networks, a single form and a unified methodology for presenting models, their input and output parameters, and units of measurement of parameters have been developed for the modeling complex.

The models of the complex should be presented in the form of the following dependence:

$$model_{\text{model number}}: \{input\ parameters\} \Rightarrow \{output\ parameters\} \quad (2)$$

or , $$M_i : \mathrm{X}^{\mathrm{in}}_{\mathrm{pri}} \Rightarrow \mathrm{X}^{\mathrm{out}}_{\mathrm{pri}} \quad (3)$$

with $\mathrm{X}^{\mathrm{in}}_{\mathrm{pri}} = \{x^{in}_{pri1}, \ldots, x^{in}_{prin}\}$ being input parameters for the M_i model,
$\mathrm{X}^{\mathrm{out}}_{\mathrm{pri}} = \{x^{out}_{pri1}, \ldots, x^{out}_{pril}\}$ being output parameters (parameter) M_i.

Taking into account Equations (2) and (3), Equation (1) is represented as a system of models as follows:

$$M=\begin{Bmatrix} M_1:\{x^{in}_{pr11},x^{in}_{pr12},\dots,x^{in}_{pr1f}\}\Rightarrow\{x^{out}_{pr1},\dots\}; \\ \vdots \\ M_i:\{x^{in}_{pr1},x^{in}_{i2},\dots,x^{in}_{prij}\}\Rightarrow\{x^{out}_{pri},\dots\}; \\ \vdots \\ M_s:\{x^{in}_{prs1},x^{in}_{prs2},\dots,x^{in}_{prsn}\}\Rightarrow\{x^{out}_{prs},\dots\}. \end{Bmatrix}, \quad (4)$$

The output parameters of one model / models can be input parameters for another or other models. The number and types of models are determined by the nature of the problems of optimization of route transport networks.

It must be emphasized that Equations (2) and (3) determine only the form of representation of models, i.e. how various models for calculation should be presented in the base of complex models. This is necessary to simplify the work with various models of the complex, and to implement the fundamental properties of the modeling complex.

The composition of the modeling complex. Interface of user allows for problem-oriented communication between the user and the system that implements the operation of the complex.

In the databases (DB), the models and parameters of the models are presented, as well as the optimization criteria for transport networks. The tables contain a list of specific optimization problems and statistical information.

The module analysis of input data. The functional purpose of the module is to form a data structure. Data entry and selection of the optimization task is carried out at the user's request, while reading information from the corresponding tables and the database. The composition of the input data used may vary from one task to another.

The module of the organization of the interaction of models. Here processes of the organization of interaction of models are realized. On the basis of existing tables and databases, statistical processing of information about objects takes place - reduction of the dimension of the feature space, i.e. the selection of such a subsystem of features that would be smaller in volume than the prior space of features, and provided an acceptable solution. The analysis of the characteristics of models, analysis and coordination of units of measurement of input and output parameters of models in the process of solving each specific problem of optimization of transport networks, for example, the problem of calculating the coefficient of imposing passenger traffic on the transport network [14-15].

Module for analysis of relation between parameters and models. Functional purpose - determination of the necessary parameters to solve specific problems and the construction of criteria dependence.

Calculation module. The values of parameters obtained on the basis of theoretical calculation methods (by criteria) can be the initial data for subsequent calculations when optimizing transportation networks.

Module for assessing the accuracy of models. It is intended to assess the accuracy of each model considered when solving a specific task, to establish a quantitative relation between the input and output parameters of the models. The module implements the preparation and analysis of model data.

Results analysis module. According to the results of the analysis of the data obtained during the operation of the modeling complex, a message is displayed containing an assessment of the results obtained and, if necessary, recommendations for correcting them or adjusting the initial task of optimizing route networks.

The modeling complex functions as follows. Based on the data entered by the user (this may be an optimization problem, a set of route parameters, conditions and optimization criteria), the input information is analyzed. Next, we determine the necessary optimization tasks for transportation networks (available in the task table or completely new), the parameters to be obtained; necessary for solving selected problems of the model from the database. It is checked whether this initial information is sufficient, if not, then these data are taken from the corresponding tables, database or requested from the user. Selection and analysis of models (from the database models) is carried out in the required order. Then, the organization of the interaction of the selected models, calibration models (if necessary). Next, the resulting solution is analyzed. As a result, a model will be chosen to solve the problem of optimizing transport route networks, corresponding to specified conditions.

Depending on the tasks to be solved and the initial conditions (initial information), various mathematical models and methods that are presented in the model database, for example, methods based on OD-matrices, can be used in the calculations. In interactive mode, the modeling complex offers the user appropriate models for solving problems, and the user himself can specify the necessary models and methods that he will need in the calculations.

5 Software for the system of formation and optimization of transport networks

On the basis of the proposed mathematical apparatus, software of an automated system for the formation and optimization of route transportation networks, designed to work in a digital integrated environment, has been developed.

The automated system was developed by the staff of the department "Computing Systems, Networks and Information Security" of the Russian University of Transport. Programming language is C ++; OS are Ms. Windows 8x and above.

The software complies with the following basic principles necessary for functioning in the conditions of the digital integrated environment for the provision of transport: systemic unity, development, compatibility and standardization. The principle of systemic unity in the creation, operation and development of software

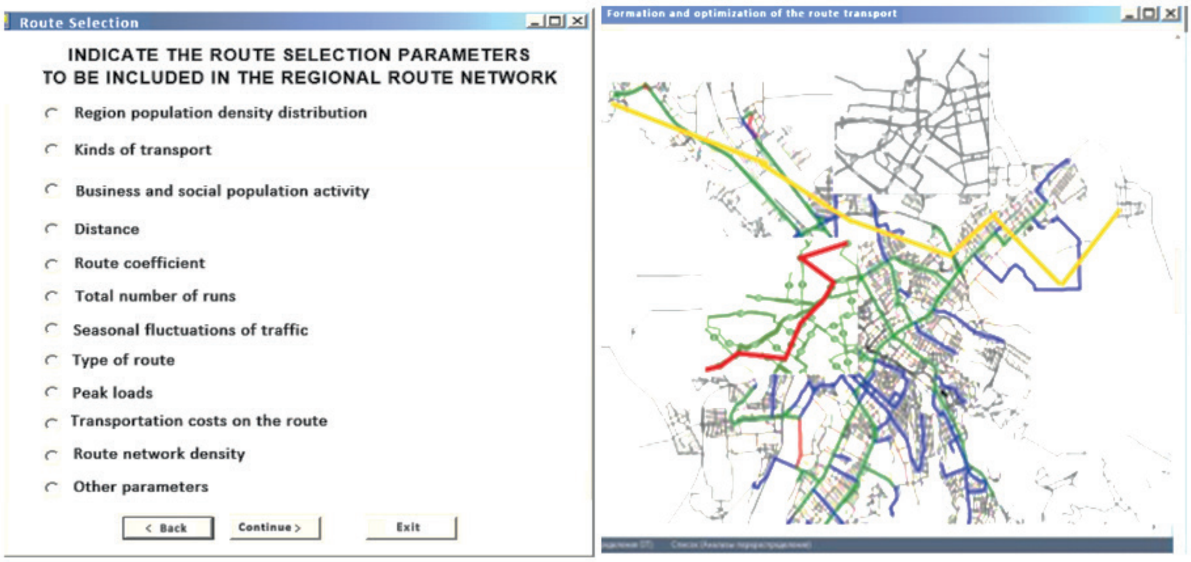

Figure 3 *Software Interface*

Table 1 *Modelling time reduction with the developed software*

Modelling Stages	Time reduction (%)
Information analysis	20 - 30
Estimation of route parameters	10 - 30
Rational options design	10 - 25
Base route selection	15 - 20

should ensure the integrity of the links between system components. The principle of development is that the software must be created and function, taking into account the replenishment, improvement and updating of its components. The principle of compatibility ensures the joint functioning of languages, symbols, codes, information and connections between components and preserve the open structure of the system as a whole. The principle of standardization lies in the unification, characterization and standardization of software that is invariant to routes and transport networks.

When forming the transport network in the developed system, decision-making methods are implemented both under certain and uncertain conditions of the initial information. The relations between the decision-maker and the computer goes through a series of iterative steps, with two points being significant at each iteration: the computer offers the DM a preliminary decision; the DM expresses his opinion about this decision and, if necessary, sets the direction for finding a solution. Analysis of the proposed solution is carried out in a dialogue with a computer. The route that satisfies the DM is taken as the base route.

The system interface is shown in Figure 3.

The left screen shows the selection and analysis of the parameters of the route for inclusion in the route network. The right screen shows the process of formation and optimization of the route transport network.

Table 1 shows the reduction in modelling time as a result of using the developed system.

As a result of the system operation, an electronic map with full information about the optimal (basic) route, the formed transport network, and information about the state of traffic flows will be obtained.

6 Conclusions

In the practical application of the developed mathematical apparatus and the developed software, the effect is expected in the following areas:

- increase the capacity of transport systems, for example, regional;
- improving the economic efficiency of the use of route rolling stock;
- attracting customers by expanding the range of services and customer-oriented approach;
- attracting investments from potential partners wishing to provide their services in the digital information environment;
- increasing the level of comfort and safety of route traffic.

Unlike the existing ones, the developed system allows taking into account all the parameters and characteristics of routes most fully; carry out calculations and processing of data of large dimensions; enables to solve the problems of formation and optimization of route transport networks more adequately and at the lowest cost, allowing to reduce the time, while ensuring efficiency of operation.

It should be noted that in subsequent articles a more detailed description of the developed mathematical apparatus will be presented, the composition and functioning of the modeling complex, including the concept of organizing the interaction of models, the algorithm for linking model parameters, the integration technique, as well as the stages of the automated system and experimental testing of the developed mathematical apparatus and System software.

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Martin Boros - Matej Kucera - Andrej Velas - Jan Valouch

POSSIBILITIES FOR EXPERIMENTAL TESTING OF ALARM TRANSMISSION SYSTEMS

In the current digital era, information is a basis of some systems. In the area of information, great emphasis is also placed on its security and possibilities of use. The basis of the alarm transmission system is information about the protected object, which is transmitted to the remote center of the alarm transmission system.

Operators of alarm transmission system centers should be obliged to carry out regular testing of the availability of individual transmission networks. At present, there is a trend that those tests are carried out by telephone calls between the two technicians and the time of transmission of information is measured utilizing a stopwatch. To automate this process, a test facility has been created that can simulate and record the intrusion of a protected object. Initial experimental tests have ascertained whether it is possible, with the test equipment, to generate the data necessary to assess the reliability of alarm transmission systems.

Keywords: *test facility, alarm transmission system, information, protected object, alarm transmission system center*

1 Introduction

An object protection system can be understood as a thought-out arrangement of security features, measures and their properties that all together create a sense of security. These elements could be divided into four basic groups: passive protection elements, active protection elements, physical protection elements and regime-organizational measures. The passive protection elements include mechanical barrier systems, usually supplemented with apertures. The alarm transmission system, together with the electrical alarm system, video surveillance system, fire alarm system, access control system and others, belong to the group of alarm systems as active protection elements. Given the name of the group, one can say that the basis of an alarm system is an alarm, which can be defined as a warning of the presence of a danger to life, property or environment [1-2].

An alarm transmission system is defined, according to technical regulations, as an alarm transmission device and a network used to transmit the status information of one or more alarm systems to one or more alarm devices of one or more alarm reception centers. In addition to the basic and specific requirements for alarm systems, the technical standards also include the concept of an alarm transmission system monitoring center, which is understood as a continuous service center in which the condition and functionality of one or more alarm transmission systems are monitored. The monitoring center of the alarm transmission system is comprehensively addressed by a separate technical standard which, in addition to the functional ones, includes the design requirements, as well.

Given the nature and importance of the alarm transmission system, one could divide it into three basic parts, which are the transmitting device in the protected building, the transmission path and the receiving device in the monitoring center. The configuration and setting of the alarm transmission system shall, depending on the technical standards, correspond to the logical continuity shown in the block diagram in Figure 1.

There are several definitions in literature of the system reliability, depending on the area in which the system is located. The basic definition, based on technical standards, defines reliability as the property (ability) of a product or system to perform the desired function within a specified time, while maintaining operating parameters. Reliability can be expressed by using one of its basic parameters: no-failure operation, machine life, reparability, machine availability [3].

Based on categorization of the backup transmission paths use, one assumes that the transmission paths designated SP1-6 do not use the backup transmission path. The DP1-4 paths use an alternative, backup path, depending on the capabilities of the attached, protected object.

To increase efficiency and reliability of an alarm transmission system, the connection of the object via a backup transmission path is used in practice, which is used in the case of a primary malfunction. Due to this possibility of connection of objects, the technical standard divides them into two basic groups, whose transfer times

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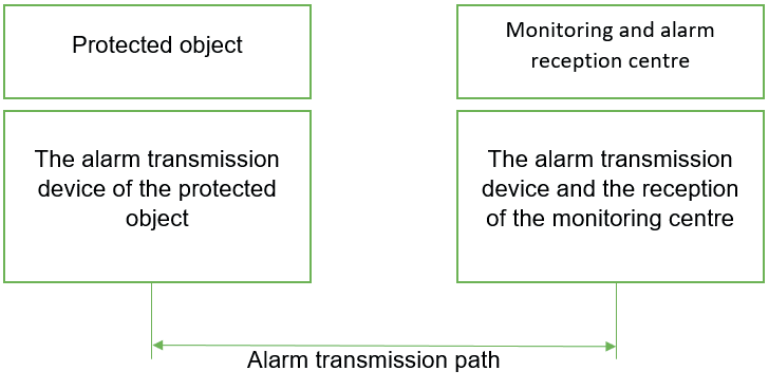

Figure 1 *Block diagram of the alarm transmission system*

Table 1 *Maximum message transmission time and system availability values for weekly and annual periods*

	SP1	SP2	SP3	SP4	SP5	SP6	DP1	DP2	DP3	DP4
Maximum transmission time allowed [s]	480	120	60	60	30	30	120	60	60	30
Weekly period [%]	V	V	V	97.0	99.0	99.8	V	99.0	99.8	99.8
Annual period [%]	V	V	97.0	99.0	99.5	99.9	V	99.5	99.9	99.9

V = optional

could be divided according to the degree of risk. The technical standards for alarm transmission systems define four basic levels of risk in terms of the importance of the connected object, where level 1 represents a low risk and level 4 a high risk. From the above and using Table 1, one can state the following classification:

- Level 1: categories SP1, DP1,
- Level 2: categories SP2, DP2,
- Level 3: categories SP3, SP4, DP3,
- Level 4: categories SP5, SP6, DP4.

Performance of the alarm transmission system, one of the main indicators of system reliability, is influenced by several indicators aimed at the signal transmission. Those indicators could include, for example, message transmission time, connection/connection monitoring, monitoring of the individual parts of the alarm transmission system functioning [4].

The alarm transfer time is determined by the arithmetic mean of the message transfer time and 95 percens of the message transfer time measurement. By this combination, one gets the maximum allowed time of the message transmission from the protected object to the alarm transmission system center. The maximum allowable message transfer time values are shown in Table 1. The message transfer time is the period measured from the moment when the information appears on the interface of the transmitting device located in the protected area to the time it is recorded at the interface of the receiving device located in the alarm transmission center system. Any message transfer time exceeding the maximum allowed message transfer time, specified in Table 1, shall be defined as a transmission system failure.

Reliability of the alarm transmission system is a fundamental probability indicator affecting the cumulative probability of an object protection system.

The basic indicator of reliability, in terms of alarm transmission systems, is their availability. Availability is the percentage of time that the system or parts of it operate according to requirements of the technical standards. One could say that it is an expression of the time during which the alarm transmission system can transmit information from the protected object to the alarm transmission system center without disturbing or devaluing it. The technical standards and the literature refer to the weekly and yearly availability of the alarm transmission system, as shown in Table 1. The calculation and/or expression of availability can be done using formulas to calculate the weekly, monthly and yearly availability values of the alarm transmission system level of table 1 for each class.

Regular tests of connection of the protected object and the alarm system monitoring center should be carried out to obtain the data necessary for expressing availability. Tests of this type are carried out by operators of the alarm system monitoring center every week and are particularly useful for their personal needs. For scientific research, it is necessary to carry out the comprehensive tests covering several parts of the object protection system such as the electrical security system, the camera system and the like [5-6].

2 Methodology

Within the scope and focus of the paper, the focus was set only on experimental testing of the alarm transmission

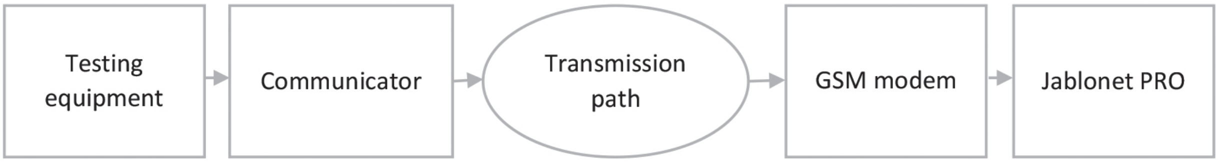

Figure 2 *Block diagram of transmission path connection during experimental testing*

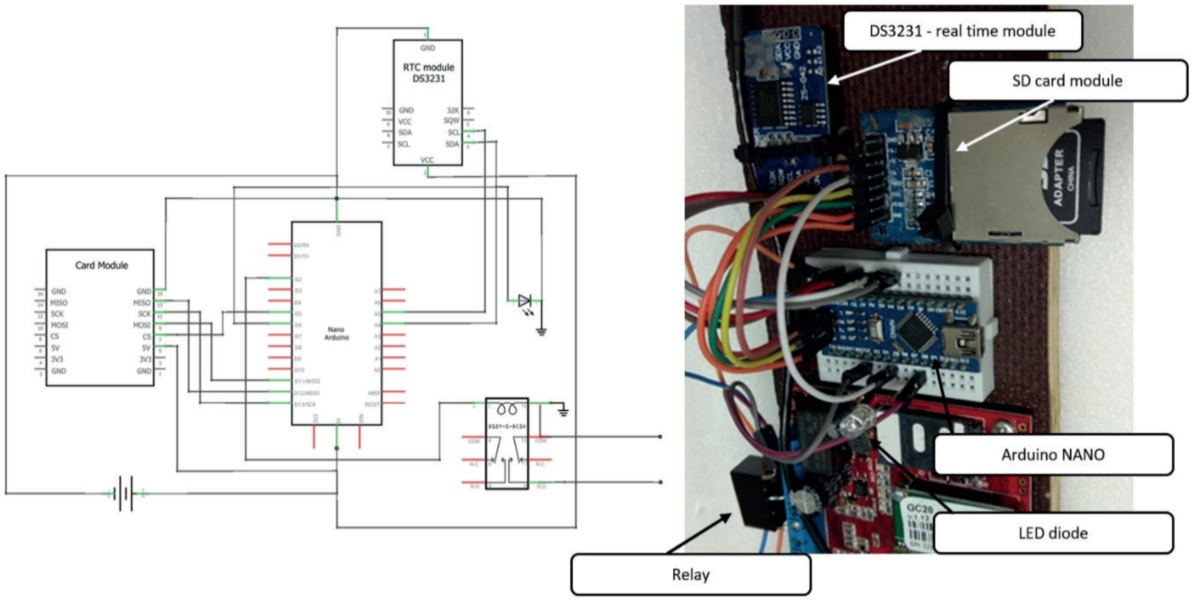

Figure 3 *Wiring diagram of the test device together with an example of real connection of the test equipment*

systems. The experiment, or the method of experiment, has a key position among the methods of quantitative research because it is the only one able to prove or confirm causal consequences, respectively. Its implementation is mostly used to verify experience and to confirm or refute scientific questions or hypotheses. In the experiment, one encounters independent variables that can be modified and changed depending on the requirements to make their impact on results clear.

Through the experimental testing of the alarm transmission system, the scientific activities of the Faculty of Security Engineering focus on creating a database of data designed to assess the reliability of the alarm transmission system. The focus was placed on the transmission information time, from the protected object to the alarm transmission system center. In conducting the experimental tests, the unified connection of the alarm transmission path was used, block diagram of which is shown in Figure 2. The experimental testing was preceded by the creation of a test facility that can be considered as an innovative way of obtaining the data needed to evaluate the object protection system.

The test facility is built using components on the open-source Arduino platform. Testing equipment during experimental testing by connecting components and they aimed to determine the real functionality and possibility of use in practice. Therefore, at this stage of testing, the tester did not have any type of box. The test equipment is designed and constructed to be compatible with transmission equipment operating in different transmission networks. As can be seen in Figure 2, the GSM transmission network was used during the experimental tests [7].

The Arduino platform was chosen because of its extensibility and the considerable amount of free information and knowledge from various online forums. The test device is based on a programmable Arduino NANO motherboard, which is adapted to be used in a plug-in, connection box without soldering. The testing device also includes a real-time module and an SD card slot on which each change of the system status is recorded, an LED for optical status change indication. The block diagram of the test device is shown in Figure 3.

Communicator GC-20A is designed for installation in smaller buildings such as houses, cottages where transmission of many messages is not expected. The communicator uses the Contact ID (CID) encryption to transmit information. The CID is a digital communication format that contains fifteen characters that together form a description of the event with the identification of the location of the alarm in the protected object. The communicator can create a backup transmission path in the form of SMS messages, as GPRS transmission is used as the primary one. The GSM Wireless Airlink Fastrack Xtend EDGE FXT009 GSM modem is a fully programmable GSM modem that can be extended with GPS modules. The modem can be connected via traditional RS232 serial

Table 2 Measured values of experimental testing

	Property - 1	Property - 2	ATS
Availability of the alarm transmission path [%]	90.90	88.10	-
Availability of the alarm transmission system [%]	-	-	76.57

port and USB port. The Jablonet pro is a specialized software enabling the management and development of alarm transmission systems. Thanks to its equipment it can cooperate with many different types of monitoring devices.

Many experimental measurements were necessary to obtain the reliable data on reliability of the transmission systems. As a part of the research into the reliability of alarm transmission systems, in the first phase of testing, measurements from the two different protected objects, in which no electrical security system was installed, were carried out. The measurements were carried out simultaneously for 10 days from both objects to simulate the real use of the system. The basis of the measurements was a testing device from which information was sent to the alarm transmission system center at regular 20-minute intervals about the intrusion of the protected object. In all the cases of this phase of experimental testing, it was the same type of alarm relay message in terms of size. The reason was regular switching of the alarm input of the communicator, to which the unified type of event that occurred during programming was set. Since this was the first stage of experimental testing, focused on the correct functionality of the test equipment, no restrictive conditions for the time of transmission of the message were defined. The first phase was aimed to find out whether the testing device can fully replace the control panel of the electric security system and thus simulate the protected object [8-9].

The ten-day interval was chosen because of the ability to modify the monthly availability formula. It was chosen to base the calculation on monthly availability because weekly availability is a verification calculation based on knowing annual availability. Since those were initial tests, information on the annual availability of the alarm transmission system could not have been provided.

Given the possibilities and focus of experimental testing, the two different protected objects were chosen, with different distances from the alarm transmission system center. The object - 1 was approximately 10 kilometers from the center of the alarm transmission system on the road and the air distance was approximately 6 kilometers. The object - 2 was approximately 16 kilometers from the center of the alarm transmission system on the road and the air distance was approximately 9 kilometers. In addition to different distances of the protected objects, there is also a difference in their location as the object - 1 is oriented to the southeast and object - 2 to the south of the alarm transmission system center. The center of the alarm transmission system is in the premises of the Science Park of the University of Zilina.

3 Results

Using the experimental tests, more than 1200 messages were transmitted from the protected object to the alarm transmission system center to determine the average value of the message time and availability of the alarm transmission system. As mentioned above, to express the availability of the alarm transmission system, the calculation for the monthly availability of the alarm transmission system was used, which is expressed according to the relation:

$$MA = \left(1 - \frac{SF}{43800}\right) * 100\,, \tag{1}$$

where:
MA - monthly expression of the availability of the alarm transmission system expressed as a percentage,
SF - the sum of breakdown times over 30 days, expressed in minutes,
43 800 - the average number of minutes in one month except for a leap year.

Since in the pilot experimental tests measurements lasted only 10 days, the relation for calculation was adjusted. The adjustments consisted of changing the constant value of the average number of minutes per month from 43 800 to 14 600, which is one-third, as the basis was on the SF parameter, which refers to a period of 30 days. Using the adjusted formula, it was found that the real availability of the alarm transmission system during the practical measurements was 76.57%. The availability of the alarm transmission system is decisive for all the alarm transmission routes through which the protected objects are connected to the centralized security desk.

In evaluating the results of experimental testing, it was also decided to determine the availability of the alarm transmission path, i.e. one connected protected object. No attention was paid to this issue in terms of technical literature and technical legislation and standards. Therefore, a relationship was established allowing calculation of availability of the alarm transmission path, which is based on the issue of system reliability and looks as follows:

$$AATP = \left(1 - \frac{NM}{M}\right) * 100\,, \tag{2}$$

where:
APPC - Availability of alarm transmission path,
NM - Number of non-transmitted messages,
M - Total number of messages.

Using Equation (2), availability of the alarm transmission path for each protected object was calculated separately. In the case of the protected object 1, the availability of the alarm transmission path was 90.9% and in the case of the protected object 2 88.1%. The experimental results obtained are also summarized in Table 2.

As can be seen from results in Table 2, the availability of the alarm transmission paths, as well as the alarm transmission system, is relatively low due to the short testing time. It was found as very difficult to compare them with the requirements of the technical standards of Table 1. The reason for the rather large distortion of the resulting data was the malfunction of the receiving device from day 8 until the end of experimental testing on day 10. One could say that this is about 20% of all the data that affected the result. The reason for the malfunction was probably the absence of software used by the operator. The goal was to automate the whole process, so there was no interference with any part of the test. The equipment manufacturer was also informed of these findings, but no comment on the situation was possible to make, as this was a specific situation that could not occur under real conditions. The center of the alarm transmission system is a permanently operated workplace.

If, for example, on the second day of testing, the receiving device malfunctions, the availability value will be at a diametrically different level. In this case, it would not be possible to evaluate the testing. From this point of view, one can state that the ten-day cycle was suitably chosen to point out the possible shortcomings of the set requirements following the next phase of experimental testing.

4 Discussion

The need to test alarm systems has long been recognized in the circles of experts and scholars of literature and should be given due consideration. The importance of experimental tests affects many people, such as security managers, private security operators, installers, academics and, finally, end-users [10].

In addition to users of individual systems, the results of experimental tests are also needed for simulation programs designed to evaluate the proposed systems. Those results could influence design of the system at an early stage, focusing on design efficiency and cost-effectiveness of the solution [11-12].

Experimental testing was focused on an innovative way of testing alarm systems using the simple programmable circuits. Indeed, this type of testing can also be used for designing the critical infrastructure elements in different types of alarm systems. In addition to critical infrastructure, the results of experimental tests can be used to ensure the continuity of road traffic, particularly in the case of video surveillance systems testing against extreme weather conditions [13-14].

The results of the experimental tests can be understood from several perspectives as it is an overlap of industry interest. In terms of data transmission and capabilities, one can talk about the quality of the transmission service through a non-post channel. From the aforementioned definition of the availability of an alarm transmission system, it can be stated that it is precisely it from alarm transmission systems. In this statement one assumes that the whole testing methodology was designed and based on the issue of alarm transmission systems.

The ten-day cycle that this paper is dedicated to was the initial phase of testing that was needed to create the necessary image of the functionality of the whole, presented alarm transmission system and testing equipment. Currently, the second phase of testing is under way, which monitors the data transmission in the long term, while removing the identified shortcomings from the first phase. The data obtained so far are of a higher value in terms of value and the expected completion of the second phase is in February 2020.

Intruder alarm systems, video surveillance systems and alarm transmission systems have been tested at the Faculty of Security Engineering. In terms of the effectiveness of obtaining the data needed to evaluate the object protection system, it would be necessary to focus on experimental testing of the input control system and reliability of human factors to automate the object protection rating system even more accurately.

5 Conclusion

The paper is aimed to point out a new possibility of obtaining the data necessary to re-evaluate the system of object protection, which is formed by a combination of subsystems. The main topic was alarm systems, namely alarm transmission systems, in which the first experimental testing, focused on the availability of the transmission system using a testing device, was performed. When designing and creating the test equipment, the simple programmable circuits were used to simulate the connection of the protected object to the alarm transmission system center.

Using the long-term testing, 10 days, it was possible to determine the availability of the transmission system, as well as the alarm transmission path, with minimal attention to it. Experimental testing is based on the need to obtain the data needed for simulation programs to evaluate the object protection system. With selection of the alarm transmission systems, the long-term scientific intention of the Faculty of Security Engineering was followed upon, which, within its scientific and publishing activities, devotes itself to the evaluation of object protection systems comprehensively.

From individual parts of the object protection systems, it is necessary to pay due attention to experimental testing and to repeat it at regular intervals, focusing on analysis of the reliability development of individual end parts. From the comprehensive approach to evaluation of the object protection system, the representatives of the Faculty of Security Engineering will deal with the systems of access control.

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