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A - OPERATION AND ECONOMICS

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EXPERIMENTAL INVESTIGATION OF PERFORMANCE OF THE ROTORCRAFT DIRECTIONAL RUDDER

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Resume

The paper presents the results of gyrocopter fuselage experiment testing in a wind tunnel. The model subjected to testing was made in 1:8 scale by 3D printing. The tests included the measurement of forces and aerodynamic moments acting on the model, for a variable fuselage sideslip angle β (-20º to 20º), and for three different positions of the rudder setting (0º, +5º, +10º). The measurement was carried out at an airspeed of 25 to 26 m/s. Based on the measured values, aerodynamic drag coefficients, lift coefficient and aerodynamic moment coefficients with respect to all axes of the reference system, were determined. The measurements carried out have facilitated the derivation of diverse characteristics, validating our conclusions. The results and conclusions drawn from these experiments can be valuable in enhancing the design and functionality of rotorcraft rudders.

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1 Introduction

Aircraft designs, prior to flight testing, must be subjected to numerous simulation tests [1] and in wind tunnel [2-3]. In the case of studies conducted on pre-prepared test stands, even at the CAD (computer aided design) design stage, it is crucial to evaluate the adequacy of the applied design solutions in terms of reliability [4]. To enhance the safety of the conducted research, it is also worthwhile to continuously monitor the technical condition of the research setup, for example, by utilizing thermography [5]. As a result of these tests, the aerodynamic properties of the aircraft are determined, as well as the values of forces and moments acting on the structure [6]. It is also possible to determine the behavior of structures that may occur during flight [7]. Strength tests of fuselage covering samples [8] and computational simulations of the main rotor spar beams [9] are also being conducted to assess their load-carrying capacity during aerial operations. There are also solutions aimed at analyzing stresses in shape memory materials, which are also used in aviation [10]. This is crucial in terms of evaluating both the strength and the controllability and in-flight behavior of the structure. At the design stage, tests are conducted in a simulation environment. The development of computer programs has contributed to the use of advanced calculations of the means of transport design using the finite element method (FEM) [11]. The development of advanced simulation techniques has increased the popularity of simulation fluid dynamics in the form of CFD (computational fluid dynamics) simulations for the construction of unmanned aircraft prototypes [12-13] and aircraft propulsion systems [14]. Simulation studies of the lifting rotor [15-16] and the thrust propeller in the case of rotorcraft [17] also play a special role in rotorcraft

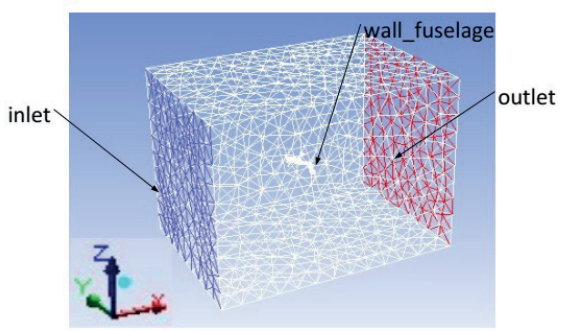

Figure 1 *Boundary conditions [25]*

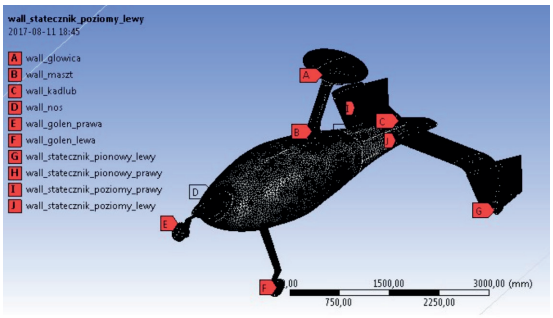

Figure 2 *Mesh of the gyrocopter model - isometric view [25]*

Table 1 *Parameters used in CFD simulation*

Parameter	Symbol	Value	Unit
Radius of the main rotor blade	R	5	m
Flight velocity	V	28	m/s
Air density	ρ	1.226	kg/m^3
Ambient temperature	T	288	K

design. Computer simulations are also used for research aimed at improving flight safety [18]. Once the physical prototype of the UAV (unmanned aerial vehicle) is built, the bench tests are conducted for the model, which is made at a reduced scale if necessary [19]. Tests conducted on the model allow for a significant reduction in the costs associated with making any changes to the design. In the case of an aircraft, one of the most common methods for conducting bench tests is tunnel testing. The wind tunnel allows determining the three-dimensional system of aerodynamic forces and moments acting on the model [20]. It is also possible to determine aerodynamic characteristics for different airflow velocities, varying angles of the model's orientation with respect to the airflow, or different configurations of the tailplane's orientation [21]. In recent times, one can see a trend toward the growing importance of unmanned aircraft [19], as well as ultralight aircraft [22] in the entire field of aviation. The wind-rotor, which is the subject of the described tunnel tests, is a very specific type of aircraft. It is a short takeoff and landing machine. The lifting force is generated by a lifting rotor, as in the case of helicopters, but it is put into rotary motion by the phenomenon of autorotation [23]. Control surfaces that operate similarly to aircraft are used to control altitude and direction. They are located on the tail boom, within the aerodynamic footprint of both the lifting rotor and the propeller, which means they must have relatively large surfaces [24].

2 Research object and methodology

2.1 The CFD calculations

Figure 1 shows that the research object's measurement zone takes the form of a cuboid with its sides positioned at a distance of 20 meters along the X-axis, 15 meters along the Y-axis, and 15 meters along the Z-axis, on both sides. The dimensions of gyrocopter are 6 348 mm in length, 2 802 mm in width, and 3 148 mm in height.

Within this specified computational domain, velocity inlet and pressure outlet conditions were defined. The other boundaries, which encompass the surfaces of the fuselage, have been designated as walls, but they are individually identified and referred to as integral components of the gyrocopter structure. These include the head, left leg, right leg, fuselage, mast, nose, left vertical stabilizer, right vertical stabilizer, left horizontal stabilizer, and right horizontal stabilizer.

To prepare the geometry of the gyrocopter for the CFD simulations, it was essential to make certain adjustments. Initially, the geometric model underwent refinement in CATIA v5, involving tasks such as connecting individual components, addressing specific deficiencies, discontinuities, and openings. Subsequently, the model was imported into the Ansys Workbench's Design Modeler. Here, further simplification occurred, primarily aimed at reducing the prevalence of fragmented surfaces, correcting any anomalies like acute angles, and smoothing out disjointed edges. Various tools were employed for these repair tasks, including Repair, Hard Edges, Edges, Sems, Holes, Silvers, Spikes, and Faces. Fragmented surfaces were fused together using the Merge tool. Following the necessary geometry simplifications, a fluid domain, or the research area, was created using the Enclosure tool. This step involved enclosing the research object within a cuboid. Figure 2 shows the created mesh of the research model of the gyrocopter.

This is the mesh created by the Tetrahedrons method with an advanced function of the curvature dimension. The inflation with the smooth transition

Table 2 *Technical data of the wind tunnel*

Description	Parameters
Measurement space diameter	1.05 m
Power of the driving motor	55 kW
Maximum air velocity	50 m/s
Working range: angles of attack	-35º to 35º
Sideslip angles	-20º to 20º

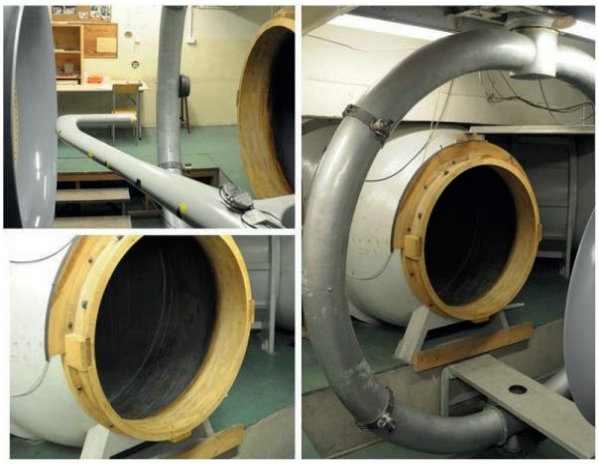

Figure 3 *The wind tunnel in which the study was conducted*

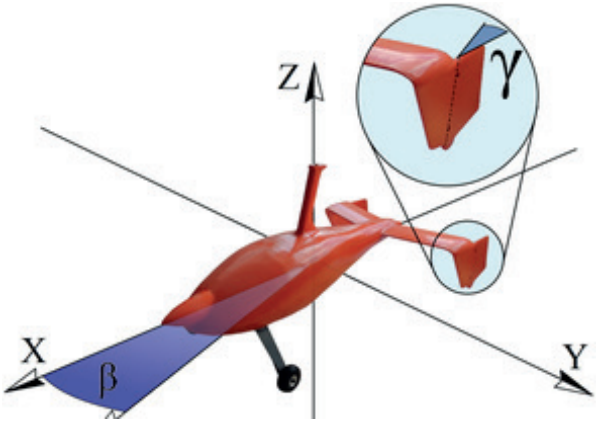

Figure 4 *Aduster gyrocopter model in 1:8 scale with variable angles β and γ*

with 7 layers and a growth rate of 1.15 was applied on the fuselage surface. The mesh was about 6.7 million cells in total. Table 1 presents the basic parameters used to perform CFD calculations [25].

2.2 Wind tunel

The research was carried out in a wind tunnel. The tunnel is used for weight measurements of aircraft models, airfoils or load-bearing airfoils. Its technical data are shown in Table 2.

The tunnel operates in closed air circulation. It has a wooden body and an open measuring space. The direction of air circulation is counterclockwise. The internal (stinger) and external (Witoshinsky scale) scales enable the weight measurements. Proprietary measurement software made in LabView allows automatic measurement and recording of the obtained results. Figure 3 shows the appearance of the wind tunnel.

Most often, the tunnel is used to conduct weight tests to determine aerodynamic characteristics. Both the whole structures and their components are tested.

2.3 Tested model

A model of the Aduster gyrocopter was tested. The solid model of the aircraft's fuselage was designed using the CATIA V5 software. The individual elements of the fuselage were made by 3D printing from PLA (polylactide) material. The model was made at a scale of 1:8. Figure 4 shows the appearance of the tested gyrocopter aircraft. Measurements were carried out for the fuselage model without the lifting rotor mounted.

Table 3 *Characteristic dimensions of the model [own development]*

Parameter	The actual gyrocopter	The model
r	5 m	0.625 m
$A = \varpi r^2$	78.5398 m^2	1.22718 m^2
$Ar = \varpi r^3$	392.699 m^3	0.766999 m^3

Figure 5 *Tested configuration with contraption, landing gear and nacelle*

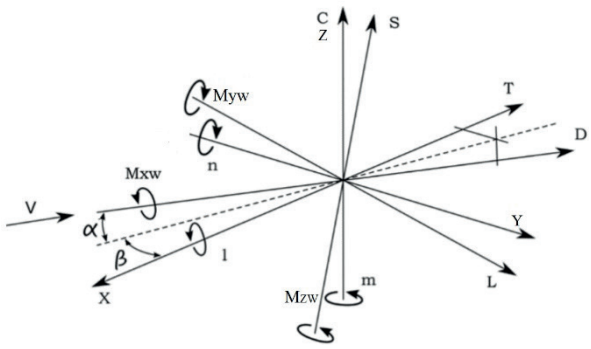

Figure 6 *The adopted coordinate system*

Table 3 shows a comparison of the dimensions of the actual aircraft with the made model.

2.4 Research methodology

The gyrocopter model was tested in several configurations and at different sideslip angles. For the purpose of this analysis, we considered the results obtained at an airspeed in the range of 25 to 26 m/s in the full configuration, i.e., with nacelle, landing gear, contrail, and a fixed fuselage angle of attack $\alpha = 0^{\circ}$.

The wind tunnel model of the gyrocopter was mounted on a measuring strain gauge scale. It was attached to the scale's boom by the rear tailplane, as shown in Figure 5. The measurement was carried out in the coordinate system associated with the model (body) F_b = [*T C N*], to move to the reference system associated with the velocity vector (wind) F_w = [*D S L*], rotation matrices by angle α and β were used according to Figure 6.

Figure 6 shows the direction of the velocity vector from which the system was deviated by an angle β. For all measurement points, the angle $\alpha = 0$. The local coordinate system of the model is the system [*x,y,z*] and the force system F_b is rotated about the *y* axis where the *C* axis and *y* axis are congruent. The local system of moments [*l,m,n*] is consistent with the [*x,y,z*] system.

Rotation matrices by angles α and β are:

$$R_\alpha = \begin{bmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{bmatrix} \quad (1)$$

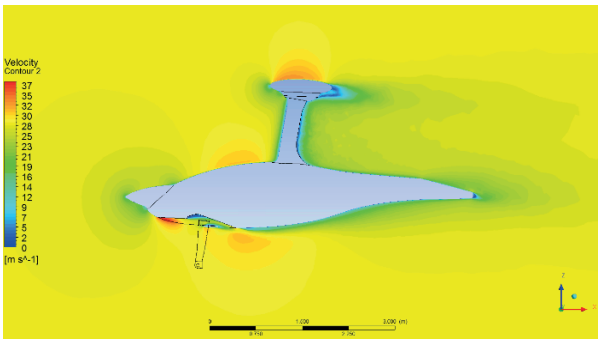

Figure 7 *Velocity distribution in the computational domain*

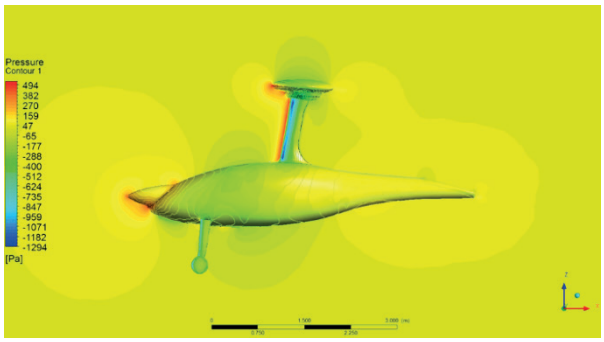

Figure 8 *Pressure distribution in the computational domain*

$$R_\beta = \begin{bmatrix} \cos\alpha & -\sin\beta & 0 \\ \sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{2}$$

Determining the force vector in the velocity vector system F_w, from the force vector in the model input F_b, requires the product:

$$F_W = R_\alpha R_\beta F_b\,. \tag{3}$$

The obtained matrix is binding in the rotation of the vector of moments. Force vectors in the coordinate system were determined. With respect to the set angles of attack and glide, the force vector takes the form:

$$\begin{bmatrix} D \\ S \\ L \end{bmatrix}(\alpha,\beta) = \begin{bmatrix} (T\cos\alpha + N\sin\alpha)\cos\beta - C\sin\beta \\ (T\cos\alpha + N\sin\alpha)\sin\beta - C\cos\beta \\ N\cos\alpha - T\sin\alpha \end{bmatrix}. \tag{4}$$

When determining the forces in the velocity system, the vector of moments takes the form:

$$\begin{bmatrix} Mx_w \\ My_w \\ Mz_w \end{bmatrix}(\alpha,\beta) = \begin{bmatrix} (l\cos\alpha + n\sin\alpha)\cos\beta - m\sin\beta \\ n\cos\alpha - l\sin\alpha \\ (l\cos\alpha + n\sin\alpha)\sin\beta + m\cos\beta \end{bmatrix}. \tag{5}$$

When changing the reference point from the point of the center of aerodynamic weight to the point of the center of gravity, relations occur:

$$F_2 = F_1\,, \tag{6}$$

$$M_2 = M_1 - r_{12}F_1\,, \tag{7}$$

$$\begin{bmatrix} l_2 \\ m_2 \\ n_2 \end{bmatrix} = \begin{bmatrix} l_1 \\ m_1 \\ n_1 \end{bmatrix} - \begin{bmatrix} 0 & -\Delta z & 0 \\ -\Delta z & 0 & \Delta x \\ 0 & \Delta x & 0 \end{bmatrix} \cdot \begin{bmatrix} T \\ S \\ N \end{bmatrix}, \tag{8}$$

where in the model used during the study:

$$\Delta x = 110\,mm\,, \tag{9}$$

$$\Delta z = 51\,mm\,. \tag{10}$$

Before each measurement series, a measurement of the reference signal *"tare"*, corresponding to signals in an aerodynamically unloaded system, was carried out. The measured values are subtracted from the measured signal.

3 Test results

3.1 The CFD results

Based on the CFD calculations carried out under the conditions described in section 2.1, air velocity and pressure distributions were obtained in the computational domain containing the gyrocopter model. The results were visualized on a plane symmetrically intersecting the model along the longitudinal axis. Calculations were carried out for measurement points including the variable: *sideslip angle* β in the range from -20° to 20°. The *angle of attack* α and the *rudder angle* γ were not variable and were 0° at all the measurement points of the CFD simulations. The numerical simulations generated numerical data containing the coefficients of forces and moments acting on the virtual gyrocopter model. Graphs of selected coefficients, determined by the numerical calculations, were compared to graphs representing the data acquired during the wind tunnel testing, presented in section 3.2. Figures 7 and 8 show the distribution of velocity and pressure in the computational domain for the measurement point α = 0°, β = 0°, respectively.

3.2 The tunnel results

The results were obtained in the form of measured values of forces and moments with respect to the three axes of the coordinate system. Measurements were made at a constant air velocity 25.5 (±0.5) m/s. For the conditions under which the measurements were carried out, the Reynolds number Re = $2.15{\cdot}10^6$ was determined. The measurements were made for three different configurations of the position of the γ-stay. Measurements were made in the neutral position, and with the directional rudder tilted by +5º and +10º. For each configuration the measurements were made for 13 different fuselage sideslip angles β (-20, -16, -12, -8,

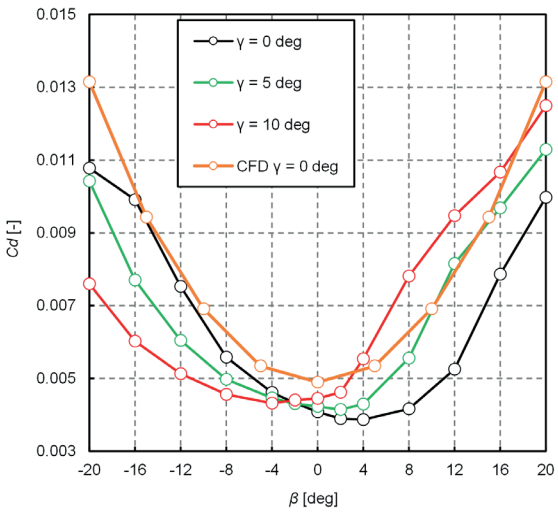

Figure 9 *Characteristics of aerodynamic drag coefficient C_d as a function of sideslip angle β*

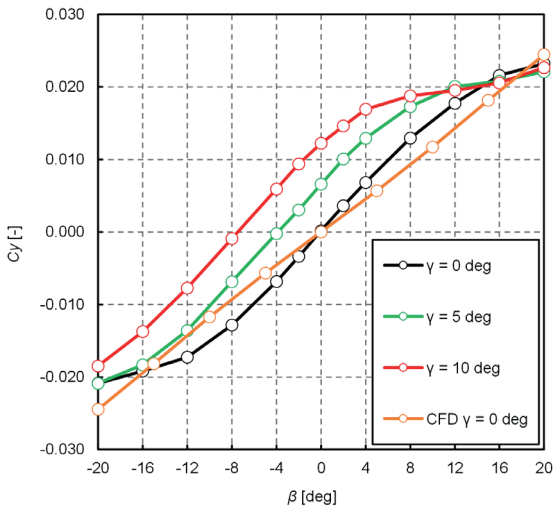

Figure 10 *Characteristics of the lateral force coefficient C_y as a function of fuselage sideslip angle β*

-4, -2, 0, 2, 4, 8, 12, 16, 20°). A total of 39 measurement points were taken.

Figure 9 shows the course of the aerodynamic drag coefficient of the fuselage, as a function of the fuselage sideslip angle β, for three different rudder deflections wedging height. The smallest aerodynamic drag coefficient was obtained at $\alpha = 4°$, when the rudder was set at $\gamma = 0°$. The coefficient of drag force was approximately $C_x = 0.004$. For the analyzed gyrocopter design, the deflection of the rudder in the range of 0 to 10°, with the fuselage positioned at an angle of $\beta = -2°$ does not significantly affect the value of the aerodynamic drag coefficient. The results obtained from the numerical simulations are represented by an orange line on the graph. The line is symmetrical about the vertical axis passing through the point $\beta = 0°$. The smallest drag force coefficient is $C_x = 0.005$ for $\alpha = 0°$. The simulation results of the drag force coefficient take values on average 25 % larger than the experimental results. This is due to differences between the physical model and the virtual model, which had an additional element on the mast to simulate the aerodynamic effect of the rotor. The additional surface caused the aerodynamic drag to increase.

Figure 10 shows the course of the lateral force coefficient as a function of the angle of lateral deflection of the fuselage. The results show that in the yaw range up to $\beta = 8°$, the lateral force is approximately linearly proportional to the angle of deflection of the directional rudder. Swinging the rudder in the direction of fuselage yaw, for angles $\beta > 12°$, does not significantly increase the lateral force. In the case of deflecting the directional rudder opposite to the direction of fuselage deflection, the limit of rudder effectiveness is reached at $\beta = -20°$. The course of the transverse force coefficient determined numerically intersects with the corresponding experimental course at $C_y = 0°$, $\beta = 0°$. The numerical characteristics in the whole range have a linear course. The results obtained during the tests show that after exceeding the value of the angle $\beta = \pm 12°$, the characteristics of the lateral force coefficient become nonlinear, and further increasing the inclination has less and less effect on further increasing the C_y coefficient. The characteristics of the effectiveness of the directional rudder is an important parameter in the design of automatic aircraft control systems and allows maximum effective use of aerodynamic properties.

An important parameter, when analyzing the performance of an aircraft's directional rudder is the torque coefficient with respect to the vertical axis (C_{mz}). The course of the obtained characteristics is shown in Figure 11. The shape of the vertical torque curves indicates a properly constructed rudder. The torque increment is proportional to the rudder deflection angle. At the same time, it is possible to indicate the angle $\beta = 16°$ as the limit of the effectiveness of the directional rudder, above which a change in the rudder angle will not affect the vertical aerodynamic moment of the gyrocopter. Simulations showed a smaller effect of fuselage angle on the value of lateral forces than during the wind tunnel tests.

In Figure 12, the characteristics of the lateral force coefficient C_y as a function of the drag force coefficient C_d is presented. From the polar plot below, it can be observed that an increase in the rudder deflection angle $\gamma = 5°$ and $\gamma = 10°$ does not significantly affect the change in C_d within the range of negative sideslip angles $\beta = -20°$, $\beta = -16°$. However, within the range of angles $\beta = -16°$, $\beta = 4°$, an influence of increasing rudder deflection angle γ can be seen on the increase in the lateral force coefficient C_z and the aerodynamic drag force C_d. Within the range of $\beta = 4°$, $\beta = 20°$, there is a sharp decline in the effectiveness of the rudder with an increase in the deflection angle γ. From the numerically calculated course of polar characteristics, it can be seen that the virtual model is affected by smaller

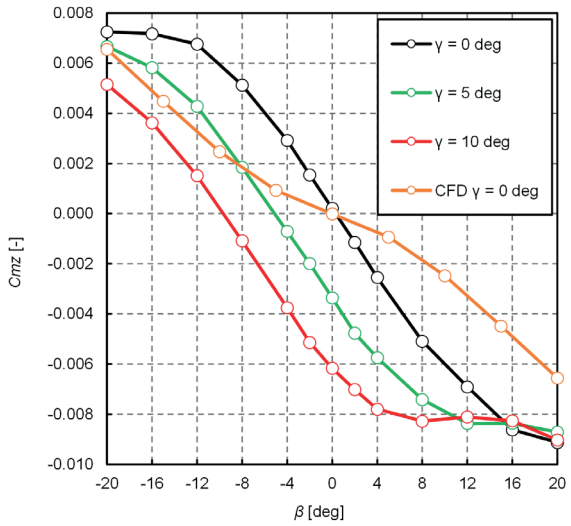

Figure 11 *Characteristics of the moment coefficient C_{mz} as a function of fuselage sideslip angle β*

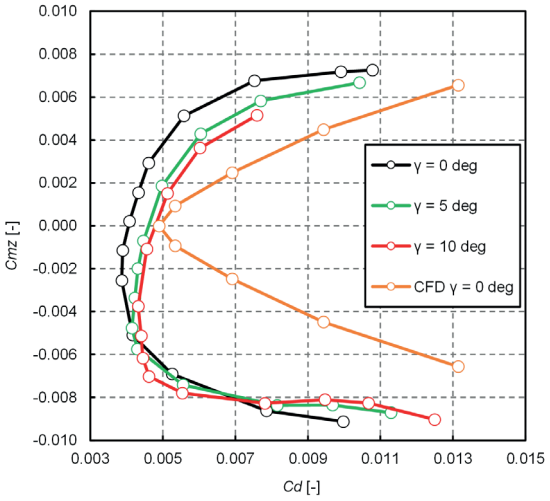

Figure 13 *The characteristics of the moment coefficient C_{mz} to drag force coefficient C_d*

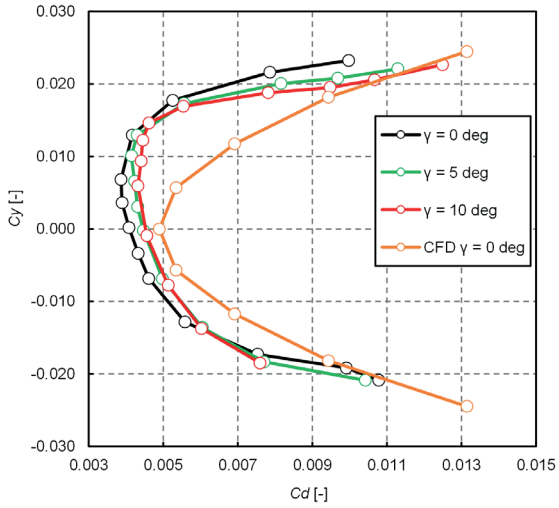

Figure 12 *The characteristics of the lateral force coefficient C_y as a function of drag force coefficient C_d*

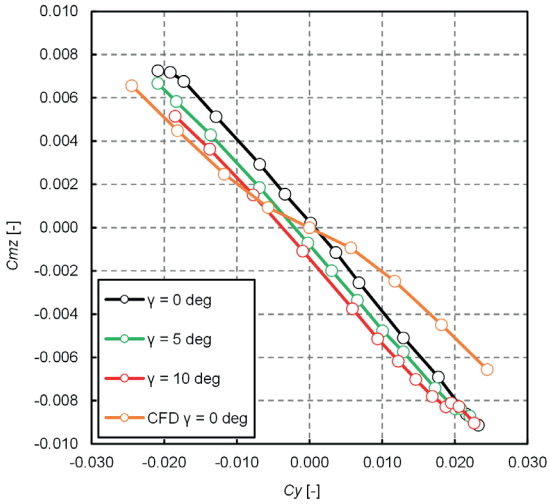

Figure 14 *The characteristics of the moment coefficient C_{mz} as a function of lateral force coefficient C_y*

lateral forces, which makes it less prone to drift. In the range of sideslip angles β from -15° + 15°, the side force coefficients C_z take values from -0.018 to 0.018. They are on average 50 the % lower than the values of C_z coefficients for experimental results.

Figure 13 presents a similar plot for the vertical moment coefficient C_{mz}. The resulting polar curves illustrate the relationship between the increase in the rudder deflection angle γ and the effectiveness of its operation, as determined by the value of C_{mz}. The black line shows the experimental results of the yaw moment coefficient value as a function of the aerodynamic drag force coefficient. The smallest value is 0.0045 for the yaw torque coefficient C_{mz} = -0.0025. The numerical simulation shows the smallest value of C_d = 0.005 corresponding to the torque coefficient C_{my} = 0. In the CFD simulation, increasing the angle β linearly affects the value of the torque coefficient C_{mz}.

Figure 14 presents the characteristics of the rotating moment coefficient C_{mz} as a function of the lateral force coefficient C_y. The graph illustrates how the lateral force coefficient varies with the aircraft sideslip angle. A clear difference can be seen between the experimental and simulation characteristics for a directional rudder angle γ = 0°. The moment curve of the simulation model intersects with the experimental curve at the point (0,0) of the adopted coordinate system. The simulation plot is characterized by a smaller than experimental C_{mz} coefficient by about 0.002 on average in the intervals β = (-20°, -5°) and β = (5°, 20°).

Figure 15 illustrates the characteristics providing information about the variation of the C_d/C_y ratio as a function of the sideslip angle of the fuselage. The curve's profile is consistent with theoretical assumptions. Depending on the angle β, forces along the Y-axis act in such a way that, at negative sideslip angles, the

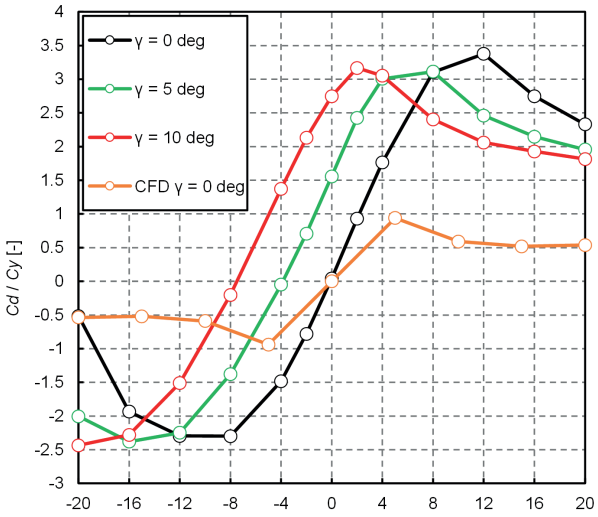

Figure 15 *The characteristics of the ratio of coefficients C_d/C_y as a function of the fuselage sideslip angle β*

fuselage operates in the opposite direction to the Y-axis. For positive values of the sideslip angle β, the aircraft operates in alignment with the Y-axis.

4 Conclusions

The construction of the full-scale aircraft is always a subject to certain discrepancies between the analytical aerodynamics calculations and the actual parameters of the fluid flowing around the aircraft. Therefore, it is necessary to conduct tests in a wind tunnel using a realistic model that replicates the aerodynamic parameters of the aircraft. Due to the high costs of creating a full-scale fuselage model, a favorable solution is to create a scaled-down replica to verify the accuracy of the analytical calculations and the behavior of the aircraft during the flight with less time, effort, and costs. A series of measurements conducted on the wind tunnel model of the aircraft allows for the analysis of the rudder's operation and its impact on flight mechanics. The conducted measurements have enabled the generation of various characteristics, based on which the following conclusions have been verified:

The variation of the drag coefficient C_d as a function of the sideslip angle has a parabolic shape. Depending on the set value of the sideslip angle β and the deflection angle of the rudder γ, the lowest values of the drag coefficient are within the range of -4° to 4°. The increase in the drag coefficient with the rudder deflection is related to the appearance of an additional surface area in the Y-Z plane on which the dynamic pressure acts. The shape of the characteristic for all the three rudder deflection angles γ is symmetrical with respect to the points of lowest C_d values and has a smooth profile, indicating that the measurement was conducted correctly.

The lateral force coefficient C_y as a function of the sideslip angle β, with zero deflection angle of the elevator $\gamma = 0$, has a linear trend within the range of -12° to 16°. In this range of angles, increasing the rudder deflection angle results in a proportional increase in the value of the lateral force coefficient C_y.

Deflecting the rudder by an angle γ results in a proportional increase in the yawing moment coefficient C_{mz} in the direction of the rudder deflection. This indicates that the rudder has been correctly designed.

The polar characteristics of the lateral force to drag force indicates that as the rudder deflection angle increases, the aerodynamic drag, represented by the C_d coefficient, increases as well.

From the characteristics in Figure 7, the effectiveness threshold of the rudder can be determined. It can be observed that for a sideslip angle of 16°, the rudder ceases to be effective.

The aerodynamic characteristics of the tested model exhibit profiles consistent with literature values. It can be concluded that the rudder in the presented aircraft fulfills its function properly.

The results of numerical simulations of the developed gyrocopter model differ from the experimental results. This is probably due to the additional component that simulated the aerodynamic drag of the rotor during CFD simulations. For the design reasons, the nacelle was not used in the tunnel tests.

Some discrepancies between the numerical and simulation results are due to the mounting of the tested model in the wind tunnel. The experimentally tested gyrocopter was fixed on the measuring scale with a beam that lowered the aerodynamic drag, which covered the rear of the fuselage, where under the normal conditions a vacuum is created that increases aerodynamic drag. For this reason, the aerodynamic drag coefficient for the CFD tests obtained a higher value than for the bench tests.

The study made it possible to assess the effect of

the sideslip angle γ on the aerodynamic properties of the entire aircraft fuselage, especially in the context of the relationship with the sideslip angle β. As a rule, a large value of sideslip angle results in a decrease in the lifting force generated on the lifting surfaces, an increase in the drag force and a change in the aerodynamic moment. An increase in the angle γ results in a decrease in the sideslip angle at which the minimum drag occurs. However, as expected, the minimum drag value corresponds to zero γ angle.

The conducted research allowed to formulate the following conclusions:

The sideslip force increases with an increase in the γ angle over the entire sideslip angle range. The value of the sideslip angle, corresponding to zero lateral force, decreases with an increase in the angle of the ballast. For a large value of γ angle (10°), the zero value of aerodynamic moment with respect to the Z-axis occurs at smaller values of sideslip angle. The developed C_y-C_d and C_{mz}-C_d polar characteristics allowed analysis of situations where there is a minimum aerodynamic drag and a maximum ratio of drag to side force or moment with respect to the Z - axis (yaw moment). This is important for analyzing the lateral stability of the aircraft and optimizing the geometry to minimize the drag.

The analysis carried out is important from the point of view of assessing the impact of the alignment of the applied contraption on the characteristics of the aircraft when performing maneuvers with a change in sideslip angle, i.e. when performing a turn. In a special case, there may be a simultaneous change in sideslip angle causing the aircraft to yaw with a simultaneous change in the aircraft's roll (a coordinated turn may then occur). The analysis carried out is a prelude to evaluation of the effect of the sideslip positioning on the characteristics of the aircraft during the execution of the turn maneuver.

The publication adds the results obtained from numerical tests. However, they differ to some extent from the results obtained from wind tunnel tests, as pointed out in the discussion. The probable reasons for the observed differences are also explained. The resulting data allows to illustrate the effect of flight conditions on the flight stability and behavior of the gyrocopter at different sideslip angles, and can also be used in flight control systems, such as fly by wire or autopilot systems. The paper adds the CFD simulation results that show the same configuration of the gyrocopter as in the wind tunnel tests. The results obtained can be used to better configure the simulation parameters, as well as provide knowledge on the behavior of the gyrocopter under certain flight conditions. Gyrocopters are a specific type of aircraft and their controls are different from those of airplanes and helicopters, so this type of data is very important.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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BIBLIOMETRIC OVERVIEW OF CURRENT TRENDS IN MARITIME TRANSPORT: THE ISSUE OF A SPECIAL INTEREST IN DELIVERY OF A CONSIGNMENT AS A TOOL TO ACHIEVE SUSTAINABILITY OF INTERNATIONAL TRANSPORT

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Resume

The sustainability of international transport remains a critical topic of concern in both theory and practice. Ideally, scientific literature should align with practical needs, but such concurrence is not always present. This disparity is also evident in the specific issue of consignment delivery, which is currently of a great practical importance but lacks sufficient coverage in scientific literature. This paper aims to analyse current trends in maritime transport and their relevance to achieving global sustainability in international transportation. Additionally, it seeks to compare these findings with the practical needs and requirements of the industry, in order to provide constructive recommendations for further research. To accomplish this objective, a bibliometric analysis was conducted using scientific databases, including Web of Science and/or SCOPUS.

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1 Introduction

The basic construct of liability of contracting parties in maritime transport is included in the United Nations Convention on Contracts for the International Carriage of Goods (Wholly or Partly) by Sea, the so-called the Rotterdam Rules, which establish the liability mostly for the carrier in cargo transportation. The period of the carrier's liability starts at the moment when the carrier, or the performing party, accepts the cargo for transportation, and it ends at the moment when the cargo is delivered to its recipient. To determine the indemnification amount in the case of a loss or damage of the cargo, the value of the cargo in the place, and the time of delivery is crucial. The value of the cargo is bound to its exchange value; if the cargo (goods) does not have an exchange value, then the value is bound to its market value; if none of these values can be identified the value of the cargo represents a common value of goods of the same kind and quality at the place of delivery. As for a delay in delivery, the claim to get the indemnification ceases if no complaint due to delay in delivery of the cargo is filed within 21 days from the cargo distribution. In the case the complaints are raised in relation to the performing party, which delivered the cargo, they have the same effect as if they were raised to the carrier themselves. This is true the other way around, too. The amount of the carrier's liability is restricted with this Convention to 875 SDR (a unit of special drawing rights) for a carried unit, or 3 SDR for

a kilogram of gross weight, depending on which amount is higher. The carrier has the ability to agree on a higher liability limit with the shipper; the shipper also has the right to declare a higher value of the consignment in the contract of carriage. The carrier‘s liability for losses due to delay in delivery of the cargo is limited to 2.5-times of the freightage. The issue of a special interest in delivery of a consignment does relate to this issue immanently. In modern times, the carriage of goods, mostly the international one, is built on a principle of restricting the carrier's liability, otherwise the carrier would not be willing to assume a risk related to the consignment carriage since the value of the consignment usually exceeds the value of the reward for providing this service several times. To carry a consignment of a certain mined raw material across a heavy sea presents a riskier activity than mining of the raw material itself. Without the carriage of goods to the shipper on the other side of the world there would no development of the world trade or general growth happen at all. Almost all international treaties on carriage of goods by any type of transport means, as well as national legislations of many countries do contain provisions restricting the carrier's liability for damages, which have occasioned due to a common and predictable risk related to the international carriage, the nature of the consignment and the transport means used, too. Even despite an indubitable practical relevance of this issue, the state of its working out is not satisfactory in the current scientific literature. The legal regulations themselves are paid only a partial attention within broader constructs of thoughts. This can be assumed from a pre-research realised in the environment of Web of Science, or SCOPUS platforms. Thus, it is relevant to analyse the current trends in the area of maritime transport in the context of their importance in more details, while achieving the global sustainability of international transport, and comparing the found state to needs and requirements of the practice, to constructively formulate recommendations in the area of a further orientation of the research so there occurs a synergic effect of the theory and the practice for the sake of achieving a sustainable development of the society in a long-term horizon. This also happens to become a goal of the paper introduced; to fulfil it a bibliometric analysis was realised with application of VOSviewer software support. It is a progressive scientific approach, featuring a postpositive character, based on the application of the best practices from other fields of study. The origins of a citation analysis development, as a separate discipline, are closely associated with the bibliometrics. In the beginning of the 20th century F. J. Cole and N. B. Eales published a paper for a research in anatomy, named "A Statistical Analysis of the Literature". The work aimed to map the interest in the discipline in different countries, using the methods of a statistical distribution. The citation analysis is one of the bibliometrics methods, which studies and quantifies relations among documents, authors, scientific institutions, or scientific branches based on the bibliographic citations and bibliographic references. The citation analysis has its importance not only for the profiling of library's collections, but it is also a base for the citation mapping of the science with the construction of the so-called citation networks. Bibliometrics is a discipline, which is devoted to a quantitative analysis and measurement of documents used to spread the scientific knowledge. A mutual relation of bibliometrics, infometrics and scientometrics (which are related disciplines) comes out from relations between the system of science, the library science and the scientific communication. The field of study of these disciplines overlaps since all of them consider a document an important object of their own measurements. The citation analysis is closely associated with the "citation mapping" term. This term serves to indicate the visualisation of the citation analysis. A citation map is a graphical representation, which depicts relations built with citation references and cited articles. The most important data sources for the citation mapping are citation indices. The result of the citation mapping is the graphical representation of citation relations. The citation mapping has its significant place in the context of information representation. A complex and effective mapping of a certain scientific field is possible only based on the data generated from the citations usage. The mapping of the science is based on the formation of the so-called citation network, which best describes how specific areas of science and research are structured.

2 Theoretical background of research itself

International trade and shipping play crucial roles in fostering economic growth, job opportunities, innovation, and cultural interchange. They contribute to cooperation and stability between nations, promoting effective resource utilization and diversification [1].

Nowadays, cargo is transported from one place to another in various ways, taking into account the conditions of the countries of origin and destination. The existence of transport contracts and relevant transport legislation is crucial. Legislators seek to organize relations between the transport entities through applicable legislation. Transportation contract, among other things, determine the mutual rights and obligations of the contract parties, i.e., the sender of goods and the transport operator. There is often a case of human failure during transport. This is the case, for example, when an operator, responsible for the safe transport and delivery of cargo, makes a mistake and the goods do not arrive at the place of delivery or are delivered damaged. There are certain rights and obligations associated with the performance of transport. One of the rights of the sender of goods, that are expected to be observed by the transport operator,

refers to loss and restitution of goods. This restitution includes all the costs of the sender.

Globally, there is a noticeable surge in the dynamic evolution of intermodal transportation. This progression is intricately linked to the rising demands for enhanced transport efficiency and sustainability. The heightened level of efficiency poses a challenge for participants in intermodal transport systems, necessitating a thorough examination of the factors that impact both efficiency and sustainability in this mode of transportation [2].

Transportation of goods are handled by the international transportation companies and organizations, with the bill of lading issued in all the cases. International maritime companies owned by the government must develop the culture of cooperation and share the interests achieved via activity with their staff. Moreover, international transportation companies owned by government, which have taken into economic emergencies, must be managed as the administrative arms based on the principle of cost and benefit [3].

There are inconsistencies in legal regulations for the issue of a special interest in delivery of a consignment, and even despite its practical relevance in the current scientific literature, it has not been worked out comprehensively [4]. At the same time we may state that the question of particularities of legal regulations disharmony in international transport can be characterised with an appropriate meaning from the point of view of practical needs. The issue of the legal regulations variance itself is coincidently ascertained even from several aspects: 1) a threat of special-purpose manipulation in the context of a special-purpose suitable legislation; 2) the rigidity and absence of legal regulations for current issues; 3) a risk of bureaucracy and continual increase of the administrative severity of international transport; 4) a barrier to achieve goals of a global environmental policy.

According to DeSombre, the impact of globalization on international standards for environment, safety and labour, has reflected into the decisions of shipowners about the register their ships. Shipowners have moved registration of ships to low-standard states, while traditional national registries relaxed standards in an effort to keep ship registrations. As a result, recent successes in increasing standards have come from mechanisms of exclusion - ships that remain out of the international regulatory process are prevented from benefiting from their free riding by the imposition of trade restrictions, dockworker boycotts, and also by the inspection and detention processes [5].

In September 1959, the Nineteenth Conference of the International Maritime Committee (Comité Maritime International) was held in Rijeka, Croatia (former Yugoslavia). The Conference adopted a draft of a convention that aimed to address the issue of liability of the operators of nuclear ships (mainly in the terms of use nuclear reactors as a source of transportation both civil and military ships). The draft convention reflected the fact that liability issues arising from the nuclear ships considerably differ from those issues, arising from the operation of land-based nuclear reactors. The draft of convention reflected the fact that issues of liability, arising from nuclear ships, considerably differ from those issues arising from the operation of land-based nuclear reactors. The Rijeka Draft became crucial for the later developments in the field of international nuclear law, in particular for the adoption of the Brussels Convention on the Liability of Nuclear Ships at the Eleventh Session of the Diplomatic Conference on Maritime Law in 1962. However, it also influences the content of another bilateral agreements.

The 60th anniversary of the Rijeka Draft represents significant opportunities - to revisit the principles provided by the draft convention, and to reconsider the impact of this draft on further development of international nuclear law, [6]. According to Yang et al., the issue of safety and environmental pollution liability insurance (SEPLI) is crucial in this case, too [7]. This new insurance product - SEPLI - has been recently developed as an important supplement to the current safety and environmental risk prevention and control system. In comparison with other common insurances, SEPLI extends the function of insurance - from the simple compensation function to the "process management + compensation" function [8].

Based on the work of Storkersen et al., and the analysis of empirical data from Norwegian fish farming and coastal transport, the paradoxical relationship between the governmental deregulatory measures and organizational overregulation have been revealed. The data confirms a rapid growh of number of internal rules and protocols, ill-fitting procedures, and pervasive, exaggerated safety management. Three basic mechanisms are detected that have driven internal overregulation: work auditability; managerial insecurity and liability; and audit practices. These mechanisms show how functional regulation can have unintended consequences when it meets other accountability expectations. Expectations of market doctrine, bureaucratic entrepreneurism and control can lead a company to transforming current simple governmental regulations into overcomplicated safety management systems [9-10].

Until the 20th century, most countries have focused on developing the benefits of maritime transport and paid little attention to oil pollution from ships. The development of marine transportation was the main trigger of marine pollution. Nowadays, marine pollution in general is considered to be a dangerous source of contamination of the marine environment, but the threat of oil pollution from ships draws the greatest concern. This concern is clearly felt by the BRICS countries, that are keenly interested in preserving and protecting the marine environment against pollution, including marine pollution caused by oil from ships.

The BRICS members are countries with extensive economies and significant influence on regional and global issues. In recent years, the BRICS countries represent a significant role in the world economy (in terms of total production, destinations for investment capital and potential consumer markets). Therefore, the improvement of legal framework, relating to civil liability for marine pollution damage, have a significant importance for the ensuring of environmental safety of these countries.

This paper explores the legal regime relating to civil liability for marine pollution damage at the international level and in the terms of BRICS member states. It compares the differences in the domestic legislation of the BRICS countries, pertaining to civil liability for marine pollution damage and results in recommendations for better implementation [11]. This paper follows the Fabriz and Quiroga Obregon research, that alanyzes the current state of the marine environment, which is polluted by maritime transport in both national and international waters.

Addressing the inconsistencies in the regulation of international transport is dynamic and evident, especially in recent times. Moreover, Naevestad et al. have detected a considerable difference between the formal and and informal aspects of safety by analyzing a significant report of coastal freight sector [12]. The research of regulatory inconsistencies in international transport will focus primarily on regional specificities, thus waiving the global reach of the issue. One of the most important issues in transportation is determination of the basis for determination of liability for each transportation body. In this regard, several theories have been proffered, such as the theory of fault, the theory of default in guarding objects, theory of guarantee, the theory of damage and the theory of risk or liability. Based on a critical evaluation of these theories and analysis of relevant legal provisions, particularly in the French, UAE and Egyptian jurisdictions, this paper argues that the theory of damage, as a basis for liability, is the most applicable to contracts for the passenger transportation. Its content is clear, specific and consistent with the general rules of guarantee adopted in domestic laws, such as the UAE Civil Transactions Law. Above all, it offers handicapped passengers the quickest access to justice and the opportunity to receive due compensation [13].

Although such an approach does often occur in the current scientific literature, it does not suit the particularities of the issue solved here [14].

In the scope of the above mentioned, the following research questions have been set:

(1) What are the current trends in the scientific literature?
(2) Do the current trends in the scientific literature reflect real needs of the practice in the context of the issue of a special interest in delivery of a consignment?

3 Methodological background

The individual formulated research questions can be answered primarily with the implementation of the bibliometric analysis into available secondary data included in reputable scientific databases of Web of Science, or SCOPUS. To realise such selected investigation methodology, the VOSviewer software platform has been selected. It is a freely available computing program, primarily designed for analysis of bibliometric networks. This program is standardly used to create citation maps of publications, authors and citation networks. A citation network is a guided chart usually of a big scope; it shows how researchers publish their works, or how they cooperate, and it points out works of outstanding authors. Objects in the citation map are the most frequently depicted as parts of the chart or the network. Citations networks can also be defined as a cluster of documents, which is linked through relations between its elements. The workflow of a scientific mapping comprises the following steps: 1) data search; 2) data pre-processing; 3) extraction of the citation map; 4) data standardisation; 5) citation mapping; 6) data analysis, and 7) data visualisation. The following is true: the quality of results and the relevance of the following interpretation are directly proportional to the quality of the processed data.

This tool can be used to analyse records and to create clusters, which are then visualised. The cluster analysis belongs to methods, which deal with a similarity of multi-dimensional objects and a classification of these objects into clusters [15]. Generally, a cluster analysis can be defined as a general logical method formulated as a procedure; it is used to merge objects into groups - clusters, based on their similarity and difference [16]. The cluster analysis can also be used to radically decrease the dimension of a task; the variables under consideration are replaced with a single variable, expressing the affiliation to such a defined cluster [17]. A cluster is a group of objects whose distance (dissimilarity) is less than the distance between objects not belonging to the cluster. A similarity measure of objects x_i and x_j is denoted as $S(x_i, x_j)$, or S_{ij} in its short form, and it is true that $S_{ij} = S_{ji}$. In an ideal case, the similarity measures take values from an interval, where 0 means the maximum dissimilarity of objects, and 1 means the maximum identity. A dissimilarity measure of objects xi and xj is noted as $D(x_i, x_j)$, or D_{ij} in its short form, and the following is true: 1) $D_{ij} \geq 0$; 2) $D_{ii} = 0$; 3) $D_{ij} = Dji$ [18-19]. The similarity of objects can be measured with different methods, which can usually be categorised into the following basic groups: 1) association measures; 2) distance measures (metrics); and 3) correlation measures, where the coefficients of association and correlation represent measures of the object's similarity, and the metrics represent measures of the object's dissimilarity [20-21].

The observed records can be represented with

Table 1 *Overview of relevant journals listed in Web of Science*

Journal Title	JCR Category	Quartile in Category	Impact Factor	Publication Years	Papers Totally
Journal of Maritime Law and Commerce	International Relations	Q4	0.244 (2010)	1974-2011	1,427
	Law	Q4			
Maritime Economics and Logistics	Transportation	Q3	1.703 (2019)	2009-2020	333
Maritime Policy and Management	Transportation	Q2	3.152 (2019)	2009-2020	657
Polish Maritime Research	Engineering, Marine	Q3	1.263 (2019)	2007-2020	945

Table 2 *Overview of relevant journals listed in SCOPUS*

Journal Title	JCR Category	Cite Score	H index	Publication Years	Papers Totally
Journal of Maritime Law and Commerce	Social Sciences: Law Social Sciences: Political Science and International Relations	0.5 (2019)	10	1996-2020	504
Maritime Economics and Logistics	Economics, Econometrics and Finance: Economics, Econometrics and Finance (miscellaneous) Social Sciences: Transportation Engineering: Ocean Engineering	3.3 (2019)	45	2003-2020	487
Maritime Policy and Management	Social Sciences: Geography, Planning and Development Environmental Science: Management, Monitoring, Policy and Law	5.8 (2019)	53	1976-2020	1,598
Polish Maritime Research	Social Sciences: Transportation Engineering: Ocean Engineering Engineering: Mechanical Engineering	2.4 (2019)	18	2007-2020	923
Maritime Studies and Management	-	-	-	1973-1976	87
Maritime Business Review	Business, Management and Accounting: Management of Technology and Innovation Business, Management and Accounting: Business and International Management Social Sciences: Transportation	0.6 (2019)	3	2018-2020	72

journals concentrating on the issue of maritime transport, registered in reputable databases of Web of Science, or SCOPUS. An overview of relevant journals, listed in Web of Science, is summarised in Table 1.

Not all the journals, appearing in the Web of Science database, can be included into the analysis of trends in the studied field. Journal of Maritime Law and Commerce is excluded because it has been inactive in the database since 2011, which is in conflict with the research objective to identify the actual trends. Likewise, Polish Maritime Research journal is excluded due to its orientation towards the technical connections of the issue. With regard to the facts above the following Web of Science database journals come into consideration: Maritime Economics and Logistics, and Maritime Policy and Management; they focus on transport and they imply economic-managerial aspects of maritime transport. An overview of relevant journals listed in SCOPUS is summarised in Table 2.

Similarly, as in the case of Web of Science database, not all the journals appearing in SCOPUS database can be included into the analysis of trends in the studied field. Moreover, we can observe a duplicate evidence of journals in the studied databases, which would cause distorted results if the data is simply downloaded. In the case that a particular journal is present in both databases, the input analysis data will be taken from the database, containing a greater volume of articles in given journals. In particular, these are Maritime Economics and Logistics, and Maritime Policy and Management journals, which identically contain more articles indexed in SCOPUS database (487, or 1,598). Polish Maritime Research journal is excluded due to the same reason as in the case of Web of Science database. Due to the non-actual data, Maritime Studies and Management journal must be excluded, as well. This reason, however, is no truer in the case of SCOPUS database, when speaking about Journal of Maritime Law and Commerce. It has

still been a part of SCOPUS database (in contrast to Web of Science database, which it was excluded from in 2011). In the context of SCOPUS database, also Maritime Business Review journal can be taken into account as well besides the already identified journals. Ten appearances of a keyword in investigated records create a threshold for it being displayed. The following journals have been considered within the bibliometric analysis: 1) Journal of Maritime Law and Commerce; 2) Maritime Economics and Logistics; 3) Maritime Policy and Management; 4) Maritime Business Review. To ensure a more robust input data set, all these journals have been considered with their articles appearing in the SCOPUS database.

4 Results and discussion

The realised bibliometric analysis detected five basic trends in maritime transport, which are graphically represented in Figure 1.

The bibliometric map implies that there are the following current trends in the scientific literature in the field of maritime transport:

1) logistic optimisation (represented in purple colour);
2) economic efficiency (represented in blue colour);
3) ecologic severity (represented in red colour);
4) legislative-organisational security (represented in green colour), and
5) regional particularities (represented in yellow colour).

An interesting fact is that the issues of economic efficiency and ecologic severity are mutually related. A similar situation occurs in the case of legislative-organisational security and regional particularities. The issue of logistic optimisation forms a relatively autonomous cluster without any apparent relations to the other identified ones. The information mentioned above implies that the issue of legal regulations is one of the current trends in the study of international transport, but when compared to other identified trends it is a relatively incoherent cluster, which de facto comprises categories not classified into the other ones. Thus, it can be stated that, contrary to the needs of the practice, the issue of a special interest in delivery of a consignment is not paid any attention in the scientific literature; the ambition of the authors of this article was to eliminate that shortfall and to fill the identified gap in the scientific literature. Moreover, addressing this gap is crucial for a comprehensive understanding of the multifaceted challenges within the realm of international transport. This is the outcome of Figure 2.

The restrictions, which usually arise from the consignment's weight (in kg) and the value of the carried unit, bring a peace of mind to the carrier; provided the standard and carrier-required processes are observed during the carriage, then any potential damage, destroy and loss of the consignment, will not have any fatal consequences for the carrier in the form of a liquidation of their business and financial liquidation. Carriers may insure the liability risk and

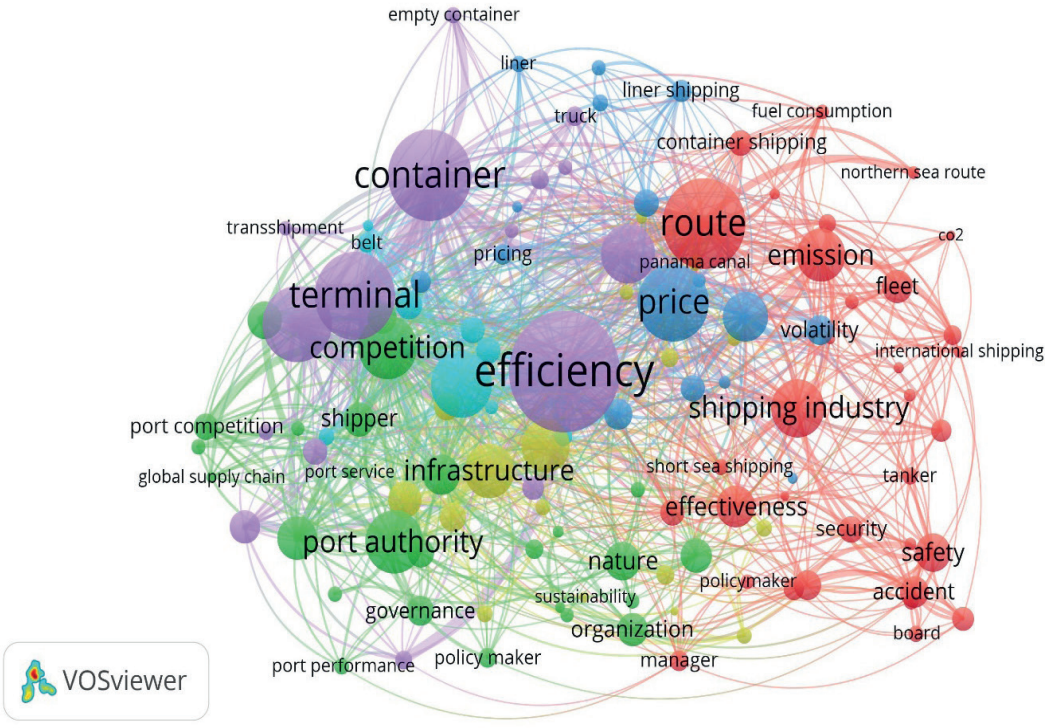

Figure 1 *A bibliometric map identifying clusters of trends in maritime transport*

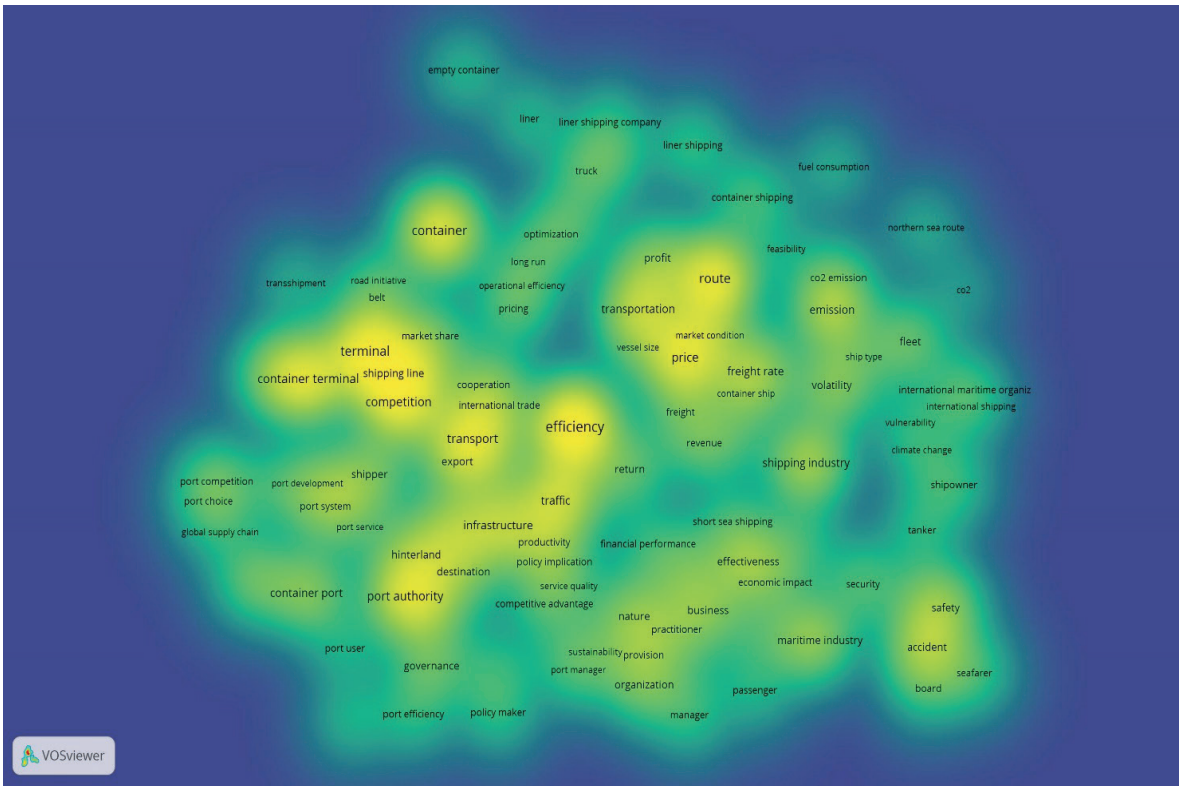

Figure 2 *A bibliometric map identifying relevant partial issues within clusters of trends in maritime transport*

thus create a sufficient protection against a potential indemnification, which arises in a direct relation to the carriage performance. Despite that, it can happen that the principle of the carrier's restricted liability is broken; the reason may lie in their non-standard behaviour, while handling the consignment during the carriage, or the carrier may decide to assume a higher liability than they are committed to under the current legislation. An example of an extended carrier's liability is first of all their intentional act, which leads to damage of the consignment, or their gross negligence, recklessness, gross organisation misconduct, etc.

An optional extension of the carrier's liability, based on an agreement between the carrier and the shipper, lies in determination of higher limits of liability in the case a certain event happens during the carriage; the carrier may also commit themselves to compensate bigger harm related to damage, destroy or loss of the consignment. A special interest in delivery of the consignment is expressed by the shipper towards the carrier in the case that loss, damage or exceeding the delivery time represents such a severe consequence for the shipper that they are willing to provide enhanced fulfilment for the carrier's services to ensure a better carrier's care of the consignment and its timely delivery, too. This interest may be evoked with the uniqueness of the carried goods, its irreplaceability, the commitment to timely delivery for the purpose of its usage in the place of destination, but also some prestigious reasons related to keeping awareness of a high reliability of the shipper's products and ability to deliver them within the agreed time. However, it must be stated that agreements on a special interest in delivery of the consignment, as well as related agreements on the price of the consignment, are not overly prevalent and used by shippers in real life.

4.1 Agreement on a special interest in delivery

A significant number of international conventions on carriage of goods requires that the agreements between a shipper and a carrier on a special shipper's interest in delivery of the consignment in the case of loss, damage or exceeding the delivery time, should be made in writing, entered into the consignment note and that the carrier is paid a surcharge against the freightage (usually prior to the carriage). The entry into the consignment note on accepting the agreement on a special interest in delivery of the consignment, functions as a caution, not only for the carrier but for other subjects participating in the carriage and coming into contact with the consignment, as well. If applicable regulations (international conventions) require the acceptance of the agreement on a particular interest in delivery to be entered into the consignment note, then the agreement between the shipper and the carrier, mentioned for example in the contract of carriage, or e-mail communication, should be considered inadequate, thus invalid. Furthermore, there is much discussion about the question if the surcharge against the freightage

must be paid unconditionally, or if only the consent to its amount is sufficient. In addition, in this case it may be stated that the failure to pay the surcharge for a special interest in delivery of the consignment can be considered as a non-fulfilment of the fundamental prerequisite of the agreement, and such a breach does not allow for the shipper to demand a higher compensation from the carrier. The agreement, which would mean an unreasonably low surcharge against the freightage, in relation to possible consequences, could also be considered invalid. However, it cannot be ruled out for the surcharge to be included in an increased freightage. As a result of agreeing on a special interest in delivery, no value limits, set in individual conventions on carriage of goods, will be applied, but the carrier will be obliged to compensate the shipper for the damage up to the negotiated amount of the interest in delivery, usually declared in the consignment note (as already mentioned above). If damage of the consignment occasions or the delivery time is exceeded, it does not automatically mean that the carrier is liable to pay the amount negotiated as the (maximum) special interest in delivery of the consignment. In that case, the shipper would have to declare that the actual damage has arisen due to the consignment's carriage and the carrier would be obliged to compensate it up to the maximum amount of the interest agreed upon. Some international conventions, however, allow that the carrier themselves must prove that the claim made by the shipper is higher than their actual interest in delivery of the consignment, and thus they have impacted the amount of their compensation duty. For completeness' sake it must be stressed that insurance companies do not usually cover either the carrier's risk in relation to the agreement on a special interest in delivery of the consignment, or the related value agreements on the price of the consignment. Therefore, the fulfilment of the risk, resulting from the carriage of goods, and the agreement on a special interest in delivery of the consignment, will present a direct intervention into the carrier's financial stability.

4.2 Amendment of international conventions

To become more familiar with amendments of a special interest in delivery, and conditions for its arrangement, individual types of the international carriage were considered in more detail.

The Hague Rules, in the provision of Article 4 Paragraph 5, allow an extended liability of the carrier in the case of any loss or damage to or in connection with the goods if the nature and price of the goods have been declared by the shipper before shipment and inserted in the bill of lading. At the same time, the Hague Rules allow that by agreement between the carrier, captain or agent of the carrier and the shipper, another maximum amount different from that given as the limit of the carrier's liability, may be fixed, provided that no maximum amount so fixed shall be less than the appropriate maximum set under the Hague Rules. That is, the Hague Rules rule out a reduction in the limit of the carrier's liability, however, they allow for the shipper to declare and enter into the bill of lading the nature of the consignment and its increased price in the case of its loss, damage or "damage related to the goods", hence for example damage resulting from delay in delivery of the consignment, prior to the shipment. Like the more recent Hague-Visby Rules, drafted in 1968, in their Article 2, which amends the provision of Article 4 Paragraph 5 of the Hague Rules, allow that the nature and value of the goods will be declared by the shipper before shipment and inserted in the bill of lading, which will result in the carrier's liability extended again over the limited threshold of liability.

Under the Hamburg Rules, the liability limit of the carrier for damage resulting from any loss, damage or delay in delivery of the consignment, may also be extended in compliance with the provision of Article 6 Paragraph 4 of the Hamburg Rules. The character of this agreement is, however, not determined under the Hamburg Rules, and the provision of Article 6 Paragraph 4 thus rather tends to a higher limit of the carrier's liability in connection with the consignment itself, than to the special interest in delivery of the consignment.

Under Article 59 Paragraph 1 of the Rotterdam Rules, the shipper may declare and include in the contract particulars a higher amount than the limited compensation up to which the carrier is liable for breaching their contractual duties.

Under the CMNI, a higher amount of liability may be agreed between the carrier and the shipper, though the CMNI misses a direct provision on the so-called special interest in delivery of the consignment. Pursuant to Article 20 Paragraph 4, the maximum amounts of the carrier's liability, set in the CMNI, do not apply where the higher value of the goods or transport equipment have been expressly specified in the transport document and the carrier has not refuted those specifications, or where the parties have expressly agreed to a higher amount of liability.

The Warsaw Convention on the international carriage by air enables to make the so-called "special declaration of interest in delivery at destination", in compliance with Article 22 Paragraph 2a. This declaration of interest in delivery at destination must be made by the shipper at the time when the consignment is handed over to the carrier, and a supplementary sum must be paid. Whether the sum is required depends on the carrier who decides if the sum is collected either immediately or later on. In this case, the carrier is obliged to reimburse any damage up to the set amount, if not declared that this amount is higher than the actual interest of the shipper in delivery of the consignment at destination. It is undeniable that the carrier will declare the so-called "actual interest of the shipper"

in delivery at destination in the case they will dispute the indemnification amount required by the shipper, resulting from a special declaration of interest in delivery. In addition, in this case, the carrier is liable not only for the damage, which has occasioned on the consignment itself, but for the delays in carriage by air as well.

The Montreal Protocol for the unification of certain rules for the international carriage by air, in its Article 22, allows for the shipper to make, at the time when the goods are handed over to the carrier, a special declaration of interest in delivery at destination and pay a supplementary sum if the case requires so. In that case, the carrier is liable for any damage occasioned to the shipper, up to the set amount, unless they prove that the sum is greater than the shipper's actual interest in delivery of the consignment at destination. The Montreal Protocol also applies the declaration of interest in delivery of the consignment at destination, not only to cases of destruction, loss, and damage of the consignment, but to delays in carriage by air, as well.

A special interest in delivery of the consignment is regulated in Convention on the Contract for the International Carriage of Goods by Road (CMR), in Article 26. Pursuant to this regulation, the shipper may, against the payment of the surcharge sum agreed upon for the freightage, fix the amount of a special interest in delivery of the consignment in the case of loss or damage or exceeding the delivery time, by entering such an amount in the consignment note. Thus, the CMR requires entering the value of the special interest in delivery directly into the consignment note, and paying the surcharge sum to the freightage, otherwise the agreement on higher liability of the carrier is invalid. If a declaration of a special interest in delivery has been made, compensation for the additional damage proved may be claimed from the carrier, up to the total amount of the interest in delivery declared. Under this regulation the limited compensation for damage, provided for in articles 23, 24 and 25 of the CMR, is exceeded. The term "additional damage proved" may be understood as a loss of profit, a compensatory purchase of a destroyed or lost machine, paid taxes and charges related to the destroy and loss of the goods, and to carriage, production outage, provision of compensatory fulfilment, exchange rate differences, etc. Furthermore, compensation for any damage in connection with the consignment's carriage, mainly if it means loss, delay in delivery of the consignment and resulting factual and legal consequences, may be claimed up to the amount of the interest in delivery of the consignment agreed upon. It is questionable whether in the case of application of a relevant national system of law, the claims to reimburse damage representing the so-called sentiment factors (a destroy of a favourite object, a unique object or an equipment), and the claims to reimburse price of "involvement" (death of a beloved animal during carriage, etc.), would be legally sustainable. Pursuant to Article 6 Paragraph 1 of the CMR Convention, the consignment note shall contain basic data, and pursuant to Article 4 Paragraph 2, if needed, the contractors shall include the following particulars: the price of the consignment and the amount representing the special interest in delivery. The consignment note shall be the evidence of making the contract of carriage, and, at the same time, the receipt of the goods by the carrier. The loss, destroy or irregularity of the consignment note of the CMR, shall not affect the existence or the validity of the contract of carriage, which shall remain subject to provisions of the CMR Convention. It may be stated that the consignment note confirms the contract of carriage, however, it does not make it. The CMR Convention allows for contracting parties to increase the set limit if there, in the consignment note, the value of the goods has been fixed or if the special interest in delivery of the consignment requires so. A counter value for extending the carrier's liability is usually represented with the surcharge against the freightage.

Under the Convention Concerning International Carriage by Rail (COTIF/CIM), the carrier may be requested the indemnity beyond the limited compensation for damage. Under the provision of Article 35 of the CIM, the shipper may enter into agreement with the carrier that the shipper will record the calculated amount of their special interest in delivery of the goods in the consignment note, for the case of any loss, damage or exceeding the delivery time agreed upon. Thus, the COTIF/CIM does not directly require paying both the increased freightage and the surcharge sum against the freightage. If a declaration of interest in delivery of the goods is made, then, besides indemnities predicted in Articles 30, 32 and 33 of the CIM, it is possible to demand compensation for additional damage proved, up to the amount of the declared sum. It is necessary to highlight that the eligible party is obliged to prove the damage occasioned, thus the claim to a higher indemnity is not made automatically. If the consignment note is lost, then the shipper must prove that they have recorded a calculated amount of their special interest in delivery of the goods, in the note. Pursuant to Article 44 Paragraph 5 of the CIM the burden of proof, i.e., the obligation to prove the consignment note is missing or lost, lies on the shipper.

5 Conclusions

The goal of the paper was to analyse the current trends in the area of maritime transport in the context of their importance, while achieving global sustainability of international transport, and comparing the found state to needs and requirements of the practice, to constructively formulate recommendations in the area of a further orientation of the research, so there occurs a synergic effect of the theory and the practice for the sake of achieving a sustainable development of

the society in a long-term horizon. By employing the bibliometric analysis to identify trends, it was observed that the issue of legal regulations stands out as a current trend in the field of international transport studies. However, in comparison to other identified trends, it forms a relatively disjointed cluster, encompassing categories not classified elsewhere. Consequently, it can be asserted that, despite the practical significance, the specialized interest in consignment delivery lacks attention in the scientific literature. The intent of the collective authorship of this article was to address this gap and contribute to the existing body of knowledge.

The primary source of complications in international goods carriage lies in the fact that the relationships involved extend beyond the borders of a single state, introducing an element connected to another state. This "international element" shifts the regulation of goods carriage from domestic legal systems to the realm of international law. The imperative to coordinate, integrate, and unify principles governing international carriage is not a novel concern. Despite the significant disparities in the original sources of private law, regulating carriage between countries, with continental and Anglo-American legal systems, the international unification process in the field of carriage can be deemed successful. The international carriage of goods belongs to the most unified areas from the normative aspect. It must, however, be stated that one must remain critical in evaluation of individual conventions and treaties and one must not settle for their current form, since definitely they are not the perfect tools for the regulation of complex processes, accompanying the international carriage of goods. When we look at the carriage of goods in different parts of the world, we can see noticeable differences. While the carriage by sea is still dominant world-wide, while within the European Union the carriage by road is the number one. However, there exist certain characteristics or concepts, which are identical, despite the efforts to specialise individual contracts of carriage across the entire typological sector of the carriage. An effective application of rules regulating the carriers' liability is one of the pillars the entire structure of carriage law depends on. The liability of the carrier for destroying, loss, damage or delay, is perhaps the most pressing problem not only from the point of view of the customer, but of the carrier themselves, as well. There, in the analysis of the legislation, the primary aim was to find out the group of issues, which can be resolved generally, regardless of particularities of individual systems of law and types of carriage. Costs of carriage represent one of the most significant expense items of business entities. The higher these costs are, the more they are reflected, either into a decreased profit of businessmen, or into increased consumer prices, which under standard conditions naturally evokes a fall of demand for such goods of a higher price.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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THE EXPERIENCE ECONOMY IN THE SYSTEMS OF URBAN AND REGIONAL TRANSPORT - FROM A CHANGE OF LOCATION TO POSITIVE EMOTIONAL IMPRESSIONS DURING MOVEMENTS

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Resume

The achievements of the experience economy show that, when using services, not only their useful value is important, i.e., changing the location in the case of transport, but also related positive experiences and impressions are of increasingly great importance. Hence, the aim of the research was to assess and indicate the directions of application possibilities of the experience economy in the urban and regional transport. There were used methods of analysis of the current theoretical achievements of the experience economy and the social studies into the use of cars, as well as the methods of analogy, brainstorming, synthesis, and modelling. The personalization of services should be pursued, in the field of passenger information, travel planning, and tariff solutions, as well as solutions increasing the possibility of using the travel time for the professional matters, education, and entertainment.

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1 Introduction

The ensuring of sustainable development of the transport system is related to such a division of transport tasks in which the public transport will play an important role in movements, in particular in the intensively developed areas. However, even though the policy of car traffic limitation in cities has been pursued for many years, and that substantial public funds are spent to co-finance the provision of services and investments in the public transport, it does not always provide the expected results. For many years, the number of cars and the car traffic have been increasing in cities, and the urban, suburban, and regional public transport have been recording declines in the transport volumes, or in the share of the transport service of the city. The situations of growing volumes of movements by the public transport are usually related to the covering by the service of new areas, to a general increase in the population of a specific urbanised centre, or to the implementation of solutions forcing the limitation of private cars usage, e.g., through the enlargement of the city centre areas closed for traffic, or the implementation or expansion of the paid parking zones. Unfortunately, a trend is not universally observed, in which the services of the urban public transport, due to the users' attachment, and due to other features, would effectively compete with the movement by cars, leading thereby to a change in the division of transport tasks in favour of the public transport. The public transport services can offer everything, which could seem necessary: punctuality, modern vehicles, information, and competitive prices with respect to cars; they are also promoted in a standard way; however, this is now not something unusual, the punctual provision of services is already a standard. People expect something more, something additional, which will delight, will increase the attractiveness, will cause that people will start talking about these services, which will become fashionable and well perceived, and not, like it is in numerous cases, that the sole

encouragement to use these services will consist in the limitations or difficulties for cars, restricted traffic zones, the charges for entering the city centre, for parking, and others. The actions related to the traffic limitation, such as closing city centres for the traffic, charging for the entering, limitation of the number of parking places and the paid parking, may be positively assessed, however, they associate with the administrative compulsion, which is not willingly accepted. It is much better, when the travellers, of their own free will and without any enforcement, will change the way of travelling and to a larger extent will start using the public transport, and this means that special attention shall be paid to the whole of supporting actions and resulting in choices in the field of using the public transport.

The balancing of transport requires many actions [1], obviously the spatial development itself is very important [2], however, in the situation of competition with movements by cars it is necessary to ensure not only a transport offer and attractive prices of the public transport. It is necessary to direct the public transport towards the service users, not only by the adaptation to the needs and a high quality of the transport services, but also by facilitating and improving the attractiveness of the public transport use by passengers at all stages, starting from the route planning, tickets purchasing, waiting at the stops, and moving by a vehicle of the public transport. Positive experience and assessment related to the use of public transport can result from the very solutions on-board vehicles and at stops and stations, the use of applications related to the passenger information, the travel planning and payments for the services [3], the experience from contacts with the staff, including the drivers, with other passengers, and various solutions, not used so far, which allow to use the time of travelling for education, entertainment, or in another way preferred by the passenger.

2 The objective and research methods (methods and materials)

The objective of the research consists of the analysis and assessment of application possibilities of the experience economy in the urban and regional transport, so as to cause, in particular through various types of accompanying services, additional to the service of movement itself, an increase in the attractiveness of the services of urban and regional public transport, and hence the increase in the number of transported passengers. Specific suggestions for the urban and regional public transport will be formulated, directed towards the strengthening of the positive impressions and experiences of passengers, to encourage or strengthen their attachment and the habit of using this form of movements.

In the concept of experience economy, acquired by consumers, it is not that tangible objects or services are the goods, considering only their practical properties, while positive experiences, impressions, emotions, or feelings, accompanying the purchases or the use of services, play an increasingly great role, in certain cases a crucial role, at consumer decisions. In addition, they significantly affect the choices and purchasing decisions made, and this applies to the objects or services, original purpose of which was not related to the creation of positive experience. The purchasing process itself, the environment, in which it takes place, the service, the emotions and impressions can have a greater value for the buyer than the purchased object or service.

The experience and emotions obviously always accompanied people, this is nothing new; for example, it was related to the exchange of products on the markets, characteristic negotiations, bargaining or just arguing about the price, and later on the satisfaction and pleasure from the successful transactions. Already in the ancient times numerous experiences and emotions were provided by the theatre performances or various types of competitions and sport games, hence the events directed towards impressions. However, for many years the consumers were treated as individuals making rational choices, paying attention primarily to the practical values of the purchased objects or services, comparing the practical properties and the price paid for the good. The producers also focused on that in their offers, to meet such assessment criteria. However, for many of them this has turned out a road nowhere, which required cutting the costs, and thereby the funds for the development. The competition on the markets, and the growing consumer requirements and expectations, also resulted in many actions of the producers, intended to increase the sales, to cause the attachment to a given product, the feeling that it is indispensable and thereby to obtain a premium due to that, and in order to ensure the attachment to a specific company/brand there was a widespread influence on the emotions and sentiments. The experience economy plays an increasingly great role in the countries with a high level of socio-economic development; a part of researchers assume that it will be the next stage of socio-economic development after the agriculture, industry, and services, that the increasing demand for positive impressions and experiences will be maintained, not only in sectors directed towards their provision (tourism, sport events, cultural events, cinema, theatre, musical concerts, and others), but in those where attention was not paid to them so far, as well.

The conducted review of databases, indexing the scientific publications, allowed to state that the use of experience economy in the systems of urban and regional public transport was not a subject of studies in Poland, Slovakia, nor worldwide. There are papers on the very trend of experience economy, and on the possibilities of using it in the sectors oriented most generally at the provision of experiences, like the tourism, entertainment, and media. The application of

solutions, directed towards experiences in the shops of selected brands and in selected services, is also visible. The lack of research in the field of public transport limits the use of the subject literature only to the theoretical foundations of the experience economy itself, and to the identified premises, experiences, and emotions connected with the use of cars. In this case the studies were carried out by the sociologists. The paper uses the theoretical achievements of the experience economy, the results of studies conducted in sectors other than the urban transport, and the social studies into the use of cars, as well as the methods of analogy, brainstorming, synthesis, and modelling. The basic sources of information, used during the research, comprise scientific papers, books, articles, and reports related to the experience economy, as well as the behaviour and expectations of people using cars and the public transport.

3 The hitherto state of research

3.1 The experience economy - creation of positive experience as the direction to make tangible products and services more attractive

The emotional experiences and impressions during the purchases planning, the purchases themselves, and the later use of the purchased products or services, are not something new for the people. They were accompanying people already many years ago, for instance during exchanges made in the marketplaces. Obviously, with the division of work and smaller self-sufficiency of households, and the development of goods and money economy, the understanding of principles describing these processes was increasingly important. The science describes the processes of economic behaviour and making choices by the people, where the starting point was the classical economy and works of A. Smith and D. Ricardo, which assumed the rationality of people economic behaviour and the maximisation of achieved benefits at the possessed funds. Over time, it is visible that the principle of rational behaviour, adopted under the classical economy, is not always confirmed in the actual consumer behaviour, new trends originate in the research in the field of economy, providing a new look at the usefulness and the choices made. It is worth drawing attention here that already in the ancient Greece the doctrine of hedonism was functioning, which considered the pleasure as the only motif and goal of the human life.

In recent decades many publications have expressed the opinion that on competitive markets it is not enough to produce and deliver a useful product or service to succeed and gain a group of permanent and faithful customers. Positive experiences and related impressions become increasingly important during the purchase or service use, apart from the usefulness itself. They can differentiate the goods of various suppliers, and also be a factor decisive for purchasing. The impressions can occur both during the purchase planning itself, or the service use, e.g., during a visit to the shop or a place, where the service is being provided, and later on, when the purchased good is used. Persons involved in various scientific disciplines, both sciences related to the economy, management started to notice that, as well as those involved in the sociology, psychology, philosophy, or futurology.

The transformations in the society expectations are related to the economic growth, which occurred in many countries since the end of the World War II. The economic growth and the increase in income over time resulted in the reduction of poverty, privations, daily problems related to the survival; with time more and more social groups had a possibility of convenient and comfortable life, availability of many services, personal development, and the orientation to survive was replaced with a possibility of an attractive life, in which the universal accessibility of medical services, education, and various types of tangible goods and services is obvious. More and more free time adds to that, which is related not only to the growing labour productivity, and thereby possibilities of shortening the working time, but also with the fact that the time, which in the past was devoted to various household activities, has been reduced. The free time exists not only during holidays, or on weekends and official holidays, but on the working, days as well, [4-5].

The increased accessibility of tangible goods, and the satisfying of needs in that respect to a large extent in the situation of material well-being, caused actions both of their manufacturers and sellers, and the buyers themselves. The tangible goods were started to be related to various impressions, which were aimed at increasing their attractiveness; at the same time the consumers, being aware of that or not, started to look for positive experiences and impressions. Already in the 1950s the publications appeared, which drew attention to the emotional aspects of consumer experience/impression; following this way in the next years people were obviously encouraged to look in a broader way on the human behaviour, and to recognise the emotional aspects of decisions making [6-8]. According to Carbone and Haeckel, a product or service is always connected with the experience, which consists of certain impressions created by, e.g., meetings, or when the people consolidate the sensational information. Such impressions can be very subtle, even subliminal, or extremely obvious. They can occur by chance or on purpose, individual sections can exist, or altogether as some set. They can refer to the function of a product or service, the staff behaviour, the outfit of the interior, the smell, the cleanness and privacy of location, the legibility of print on the receipt, or a number of other elements [9]. These publications, and many others [10-11], have shown a direction, but also in a way have contributed to creation later of the concept of the experience economy by Pine and Gilmore.

The experiences and impressions, as an additional

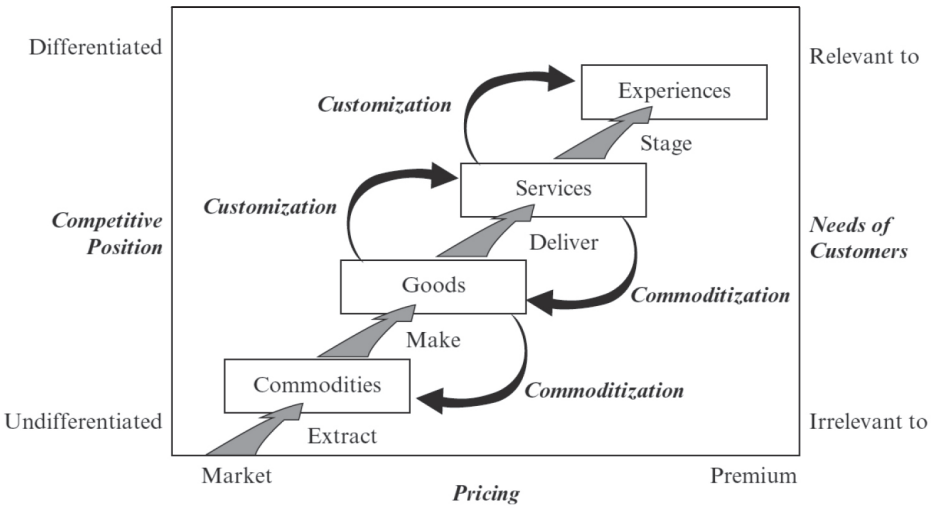

Figure 1 *The progression of Economic Value, [20]*

factor increasing the attractiveness of tangible products or services, or as a separate market offer, which gains an increasingly big share in the market in societies with a high level of socio-economic development, were presented by Pine and Gilmore [12-13]. Snell also made a big contribution [14]. The links between the experience economy and development of creative sectors and post-industrial cities are also perceived. Creative employees (creative class) are the employees, who seek innovative and novel solutions in various sectors, who creatively resolve problems, using for that the knowledge and certain unconventional approach. In that respect the scientific staff, intellectuals, IT specialists, architects, as well as artists, are most frequently mentioned. Creative employees tend to settle and work in cities, and the capability of cities to attract and retain the creative class employees will decide about their future economic growth [15-16]. The experience economy becomes a development policy of urban and regional authorities; it may be proved by the strategies, which promote the experience economy, and by the reports showing the economic influence and the growth potential offered by the experience economy [16].

Publications about entities delivering emotions create a trend in the theory of economy, but they also exist in strategies of entities, in particular in marketing; in general, the consumers are treated as rational persons, but at the same time operating under the influence of emotions and waiting for pleasant impressions. So, we can refer to the maximisation of usefulness, however, from a broader perspective, which considers positive impressions as well. The combination of those two areas of usefulness, resulting from the performance of the original function of the good or service (e.g., movement in transport) and of the emotional area, may be defined using a concept of experiential marketing [17]. It is also possible to find opinions, according to which in rich societies the possibility of satisfying an emotional need becomes the main objective; the linking of the labour productivity with the development, self-realisation, pleasure, and even with fun [18]. Referring to cars, it becomes obvious that they are purchased to symbolise the style of life, and to realise the dreams [18]. It is necessary to draw attention that if the experience is to ensure a significant usefulness, it should be personally perceived as significant, and it should contain elements of novelty, surprise, learning, and involvement [19].

Of course, it is also possible to meet opinions drawing attention to the fact that the better utilisation of resources should be the basis for action, including the rare resources and an increase in productivity, and not various additional functions or solutions, which create emotions and, in a way, hide the basic usefulness of a given good. It is difficult to deny them logic, however, numerous decisions are related to the human personality, emotions, pursuit of the adopted goals, and it is difficult to negate that. The reference to those opinions exceeds the framework of this paper; those are studies in the field of psychology, sociology and, in the context of economy, it is related to the regulatory activity of the public administration, and to determination of the scope of freedom in the business activities.

National economies of highly developed countries feature now a high share of the services sector, both in terms of the GDP growth, and the area of employment. The recent decades of the socio-economic development may be also looked at as a broadly understood third wave of Alvin Toffler, which is characterised by the growing role of information, knowledge, and skills. They are considered the wealth, which is not consumed in the processes of their use, providing a great potential for the productivity growth, and thereby further expectations and changes resulting from a greater amount of free time, and possibilities of having a pleasant and attractive life. Pine and Gilmore [20] have shown that the tangible goods and services, which provide positive experience,

and affect the buyers' emotions, will be playing an increasingly great role, which justifies the separation of another stage - the stage of socio-economic development of the experience economy (Figure 1).

They draw attention to the necessity, wherever possible, of products and services adaptation to individual customer needs, to distinguish the product, and to better satisfy the buyers needs and wishes. The customer experiences in this case are internal individual impressions, hence there is a need for personalisation and even creation of special offers for individual customers [20]. In addition, the authenticity is important here, understood as the compliance of the given product, conditions of selling, or provision of service with the buyers' imaginations, both of who they are, and to what values and assessments they aspire [20].

The experiences may be classified in different ways; the division from the point of view of participating in them is one of approaches; a passive one may be mentioned, hence we experience such, but we do not participate in its creation, as well as an active one, in which the interested person participates in its creation. A relationship or an environmental relation, which links customers with the event or performance, is the second dimension. The absorption is one of the spectrum's ends, the other is the immersion. As a result, this allows to divide the experience into four broad categories, i.e., entertainment, education, escape (escapism, distraction, active participation resulting in the detachment form the real world), and aesthetic [13]. The attention is drawn here to the fact that the categories are not separate; for example, the education and entertainment, depending on the participating person's involvement, may be at the same time a smaller or greater detachment from the reality, these can be aesthetic experiences as well. That depends not only on the event itself and its staging, but also on the consumer him/her-self, who can perceive and react differently. The experiences and emotional impressions exist more and more frequently as the offer itself on the market, and in combination with other tangible products or services. Pine II and Gilmore express a far-reaching opinion that the experiences or even a series of related experiences, which result one from another, can and should be treated by entities as a separate economic offer, which can generate additional revenues from the participation fees, and at the same time increase the sales of the basic product range [21-22]. In a way they distance themselves from the experience marketing itself, or usual marketing campaigns, stating that the method to reach customers consists in creating just a separate economic offer of attractive experiences, involving customers, and creating their unforgettable recollections. It is not necessary to limit to the physical domain, the virtual experiences may and should be used as well for example through diverse Internet portals. Referring to the public transport, such experiences may comprise a possibility of visiting historical facilities, e.g., an urban transport depot, where not only historical means of transport will be gathered, but also their equipment (e.g., mechanical ticket machines, validators), ticket patterns, staff uniforms, and many other exhibits, which will make visitors to travel in time. Another experience may consist in the participation in computer games, in which, for example, the environment and the visualisation correspond to the city, where we move, and the lines run in accordance with the current routes of the lines, and the challenge may be the virtual management of the public transport or even the urban transport, where the player takes decisions, e.g., in the field of the transport offer, ticket prices, and others. According to the Pine II and Gilmore suggestions, such an offer may be paid, and at the same time it will create experiences related to the use of public transport. It is necessary to add, at the same time, that the very measurement of experiences is a major problem, a big difficulty with it, or even the assessment of the overall experience. The range of experiences is large, starting from cognitive, emotional, physical, sensory, and social, which still requires the research. The knowledge and measurements are indispensable to explain, in particular in the situations, where the designed experiences are not attractive and exceptional [23].

3.2 Movements by cars in cities as a source of positive impressions, experiences, and emotions

From the point of users' view, the movements by cars have many advantages; the car, when commuting to work, in a way may be an extension of spending the time in a similar way as at home [24-26]. It is the driver or the car user who decides, whether (s)he will travel alone, or commute in a company of another person, e.g., a colleague, friend, person travelling in the same direction; it is like the apartment or house owners, who live there on their own, with the family, or invite friends. The travelling by car with another person can create certain bond, the feeling of closeness, common objectives, impressions, and emotions, which are pleasant for humans and necessary for them. The car segment (class), its additional equipment, also may be the analogy to the place of residence, its size, spaciousness, materials used for the interior outfit (e.g., leather armchairs) and its equipment. Finally, moving by car it is possible to take many actions, the same, which are made at home - to deliberate in loneliness, talk to the co-traveller (for example, a colleague, family member), talk on the phone, listen to music or to other contents [24]. The car, like the home, in a way insulates from the surroundings, physically by closing the doors (which is important, e.g., during movements at the night-time), as well as from the outside noise, protects against unpleasant temperature, heat or cold, rain, dust, and unpleasant smells [27], e.g., on hot days in the crowded means of public transport. It protects against taunts and

provocative looks of others, if any. The car is considered a method to create a mobile environmental bubble, to reduce unpleasant impressions, related to the city life [28-31]. Movements by passenger cars may increase safety during the pandemic, for example during Covid-19 many people have decided to switch to individual means of transport, such as bicycles or cars, to avoid the risk of infection in public transport. This trend has increased the interest in bicycles, electric scooters, and other alternative modes of transportation [32]. The car traffic is related to accidents, but it paradoxically increases the safety of the person moving by car, in a limited way (s)he moves on foot, does not wait at stops, less often crosses the street, does not use a two-wheeled vehicle, and at the same time cars are designed and manufactured with numerous systems of active and passive safety.

The car allows the driver to abandon the adopted social etiquette, observed when using other forms of travelling. When driving the car, the driver can talk aloud on the phone, sing, comment on the behaviour of others, shout, or even swear, not worrying about the opinions of other people [28, 33]. The solutions in the form of garages and car parks in residential houses, office blocks, or other places of work, which are opened and closed by remote controllers, enable moving by car without walking to it through the generally accessible and public zones [28, 34-35].

When moving by car, if it ensures a faster reaching of the destination, the time devoted to travelling is shortened, at the same time having a feeling of some extension of the stay at home or at work; by the reproduction of once static home [28, 36] or professional spaces [28, 37], it shortens the feeling of time spent on travelling, which a part of people equate with the lost time. It is also possible to encounter the argumentation, in which the possession of a car brings increasing expectations that it will enable getting to a larger number of places in a shorter and shorter time [26]. The cars expand the range of people's movements, hence a possibility of their activity. Many things, which people consider a social life, could not be obtained without the car's flexibility and access to it 24 hours a day [38]. The car enables better time management, flexible adaptation to the schedules of the day, related to the work and to various duties and activities. In fact, the purchase and use of a car in many cases means the acquisition and purchase of time. This obviously does not apply to big cities with the metro systems, which in intensively developed city centres offer very short travel times. Moreover, the additional functionality of cars in the form of a possibility of using the boot allows for, e.g., bigger single shopping and related time saving, and the transport of bigger objects (e.g., purchased in the building or furniture shops), which can also save time and improve the purchasing of a good, because it is not necessary to order a separate transport service.

A car gives a possibility of fast moving, nearly without the distance limitations, and also without any additional formalities. It is not necessary to learn the network of the urban public transport, tariff regulations, and to purchase a ticket; the car with the navigation practically ensures easy moving to the destination, without the knowledge of a given area topography. The car also gives a greater possibility of choosing the place of residence and the place of work, expands the spatial range of searching, it is also easier to realise the desire for living in green areas, to have a house with a garden, in silence, and not in the city hubbub, and at the same time to use the possibilities provided by the city, driving there if necessary. As a result, the choice of a place of residence in numerous cases takes into account the possibility of using a car, in suburban districts or areas with a low-rise development and small population; as a rule, there is no offer of the public transport, characterised by a high frequency of journeys and a short time of getting to the city centre [39].

The use of a car may be related to many positive impressions, resulting from the feeling of comfort, luxury, prestige, success, material status, realisation of dreams, independence, freedom, and simply power. This applies not only to the luxury and premium brands; the impressions are individual perceptions of the users, and the very value of the car, which realises the dreams, gives the feeling of comfort and independence, depends, inter alia, on the material status of the person. It should be added that the impressions are received not only by the car owners, but also by the environment, neighbours, friends, counterparts - sometimes the used car in a way may fail to meet the expectation related to the held position or to the profession. In addition, the feelings of admiration, satisfaction of someone's success can appear, as well as for example, of jealousy. The behaviour and situations are not rare, in which the change of a used car make into a newer and better one results not from the needs of the car user, but just from the opinions expressed by the environment, or the place of work; in entities making vehicles available to the managerial staff, it is a standard practice that the vehicle class depends on the ranking in the entity's positions hierarchy.

Such impressions frequently result from very grand and individualised additional equipment; this applies not only to the quality of seats and the internal upholstery, but also to such systems as navigation, multimedia stations, multi-zone air conditioning, heated and ventilated seats, and many various devices supporting the car driving, and thereby providing the feeling of comfort and safety. A paradox appears here; the car driving may be a great impression, where the driver has a limited contact with senses (the sight prevails), and also a limited social and environmental contact [27]. People refer to the lack of sensory involvement between the drivers and a broadly understood environment [40]. The car ensures total mobility, and minimum movements are required from the driver and passengers, people travel being fastened with a safety belt to the seat

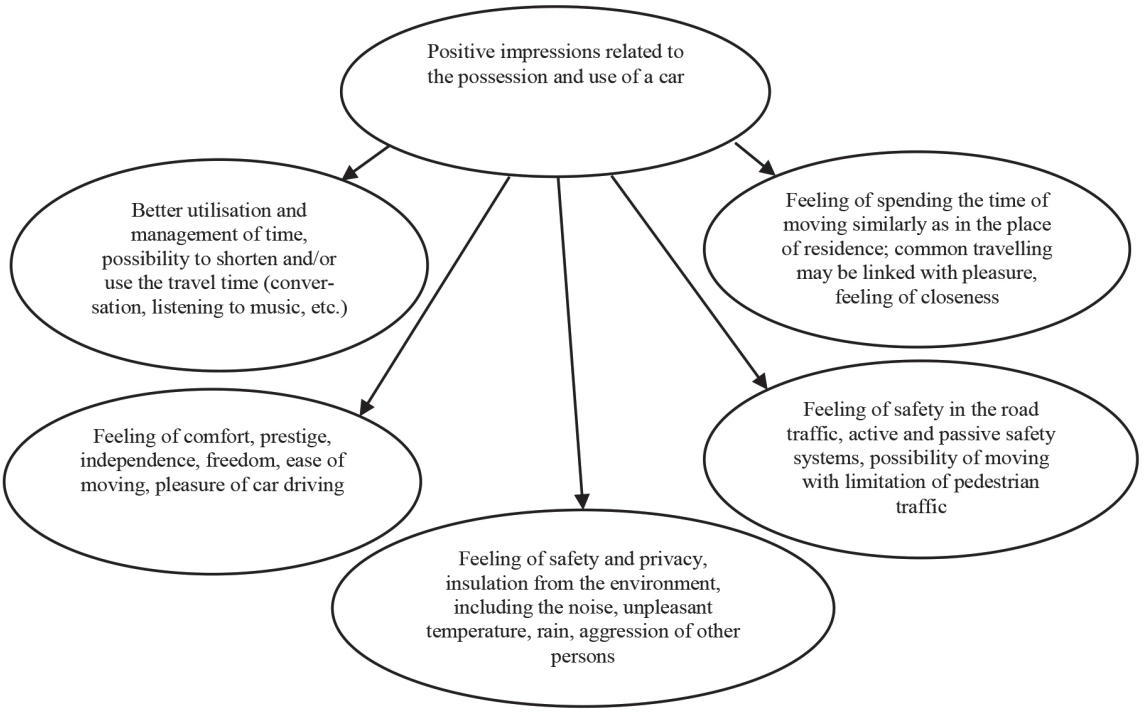

Figure 2 *Possible positive impressions related to the possession and use of a car*

[26-27]. There are definitely more such paradoxes now; on the one hand the criticism of cars, on the other hand it is common that bigger cars are purchased, with engines of higher power (frequently unnecessary in the context of the maximum speed limits) and high own weight, with the drive on more than one axle, or off-roads, which practically never leave the asphalt pavements. Figure 2 presents possible positive impressions related to the possession and use of a car.

The travelling, in particular in the field of the means of transport choice, is not only the issue of the duration, even though the time is very important. This is also the issue of friendliness and attractiveness of the conditions of travelling; the manufacturers of cars are aware of that, and the car interior equipment was substantially enhanced as compared to the solutions a few decades before, and the cars themselves and travelling by them in many cases is related to positive emotional impressions [41]. This does not apply to the public transport within such a scope; in this case the significant changes introduced in recent decades, important from the passenger point of view during travelling, include the low-floor vehicles and solutions related to the IT technologies - applications for travel planning, information, and purchasing of e-tickets. The decline in the bus occupancy has not caused significant changes in the number of seats; after all, their increased number, especially on lines with low occupancy, could improve the comfort of travelling by bus. The transport organisers assume that the low-floor vehicles, the real-time information, and the applications for travel planning and tickets purchasing are sufficient for passengers; however, competing with movements by private cars it is necessary to go further, to ensure positive impressions, the feeling of well spent time during the ride, and thereby to create a fashion for the use of the public transport.

There are many reasons to use cars; certainly, they are used to cover a distance, but this need in many cases may be also satisfied in another way. The end of the 19th century and the beginning of the 20th is the beginning of the automotive industry, manufacturing of cars on a large scale, related numerous innovations in technical and technological solutions, as well as in the field of management and organisation of the production and sales. A huge automotive industry originated, providing employment and affecting the implemented social and economic policy. The spatial planning of cities and the construction of transport infrastructure was related to that, cars allowed for daily commuting to work from longer distances, which enabled cities to develop spatially, the processes of urbanisation, and later on, also suburbanisation. Over the years, it created the organisation and style of life, and simply a mobility culture based on a car. Private cars are now, after a house or apartment, the second major expenditure of a household [33], where in part of situations even a greater weight is applied to the car.

The automotive industry is one of the main industrial sectors of the global economy, it is strongly linked with other sectors, e.g., of the steel, rubber, glass production, and with the crude oil consumption. Apart from that, the manufacture and use of cars is related to construction of the transport infrastructure, in particular roads and

car parks. Cars have also a significant impact on the environmental issues, especially CO_2, as well as on the land take [42]. Attention should also be drawn to many petty offences and crimes related to the possession and usage of cars; one can mention thefts (cars are frequently high-value objects, and their mobility makes them relatively easy objects of theft), speeding, drunken driving [43], and as a result accidents and related fatalities or injured persons, personal tragedies of many people, and social losses.

The usage of a car also means other inconveniences for the users. The travel time in certain cases may be longer than in the public transport, especially in the centres of cities, which have implemented systems to privilege vehicles of the public transport, and if the time necessary to find a parking place is added. In addition, because of frequent closing of strict city centres for traffic, it may be necessary to leave the car at some distance from the destination. The necessity to drive the vehicle may be another inconvenience, especially in the situations of a high traffic volume, and for drivers with poorer skills, it may mean additional stress, fear of collisions or accidents, and related procedures and responsibility. When driving a car on your own, the possibility of being involved in other activities is limited as well, which are possible in the means of public transport; one can mention the reading of press, books, or - what is now more and more frequent - of e-mails, social portals, and giving answers, and the autonomous vehicles in the urban traffic are still a pretty distant future. In addition, the problem with finding a parking place is against the usage of cars; it may require a lot of time, and is also related with the uncertainty, whether in an acceptable distance from the destination such a place may be found. The possession and usage of cars means also costs higher than in the case of using only the public transport [44-45]. Frequently, car users, when comparing the costs, compare the marginal costs of the car usage, i.e., the costs of fuel and parking charges related to a given travel, and do not consider the costs of purchase - depreciation of the value, insurance, services and repairs, and possibly a parking place, car park, or a garage for a vehicle.

4 Results and discussion - how to increase the competitiveness of the urban and regional public transport

4.1 Travel time utilisation and making it more attractive

Movements may be carried out individually, within individual households, then the demand for means of transport, fuel, service and repair activities, and parking services is made. The demand for transport services may also be satisfied by entities, which provide such services; these may be the services by taxies or by means of public transport. These two systems of individual transport and collective transport, differ from each other; the individual transport is substantially personalised to the user needs, and this personalisation starts already at the stage of purchasing or another form of vehicle's acquisition; the user makes a choice from among numerous brands and makes, and also different equipment versions. The use of a car considers only the needs of a specific user or users; this applies to the moment of starting the travel, route choice, decisions about breaks, if any. In the case of using a car there is no need to wait at a stop nor to stop at intermediate stops - this is quite important, because the time of waiting at a stop and at intermediate stops is particularly perceived as lost, and subjectively it flows slower, because during that time the traveller does not approach the destination. The planning of the transport offer itself in the public transport is based on macrosimulation models, which consider passenger flows generated in transport regions, and the direct connections and great frequencies, by nature, are created for the biggest of them. The considering of links and destinations of incidental travels is possible to a limited extent.

Despite the existing limitation of possibilities for individualisation of the public transport offer, this method of movement, apart from external benefits connected with the lower emissions, land take, and energy consumption, as well as higher safety calculated per one transported passenger, has, or can also have other benefits, from the persons using the public transport point of view. This is a possibility of using the travel time for other purposes, which, due to the car driving, is substantially limited in the case of a private car use. The issue of time becomes crucial with the economic development and higher peoples' income, this results from a higher value of time; in each unit of time, allocating it for work, the nominal and real income is higher than in the past in addition, there are numerous possibilities of spending the time, frequently in a very attractive way for the given person. Simplifying, one can assume that the time, which is not a travel for a given purpose, is usefully utilised in specific locations, like the work, sleep and rest, or various types of interests. It is necessary to assign a part of time to movements between locations; a large part of this time may be considered lost.

The criterion of time saving is considered at the assessment of benefits of the undertaken transport investments, starting from the roads, which enable faster movements, as well as various types of transport systems. However, in the case of transport in cities, the shortening of the travel time is substantially more difficult, and the intensive development of city areas, the increase in the number of persons staying in cities and of places of work, the increase in the traffic volume, and its calming at the same time, as well as the safety issues, will even be slowing the traffic down, which ultimately extends the time of moving, and hence of the

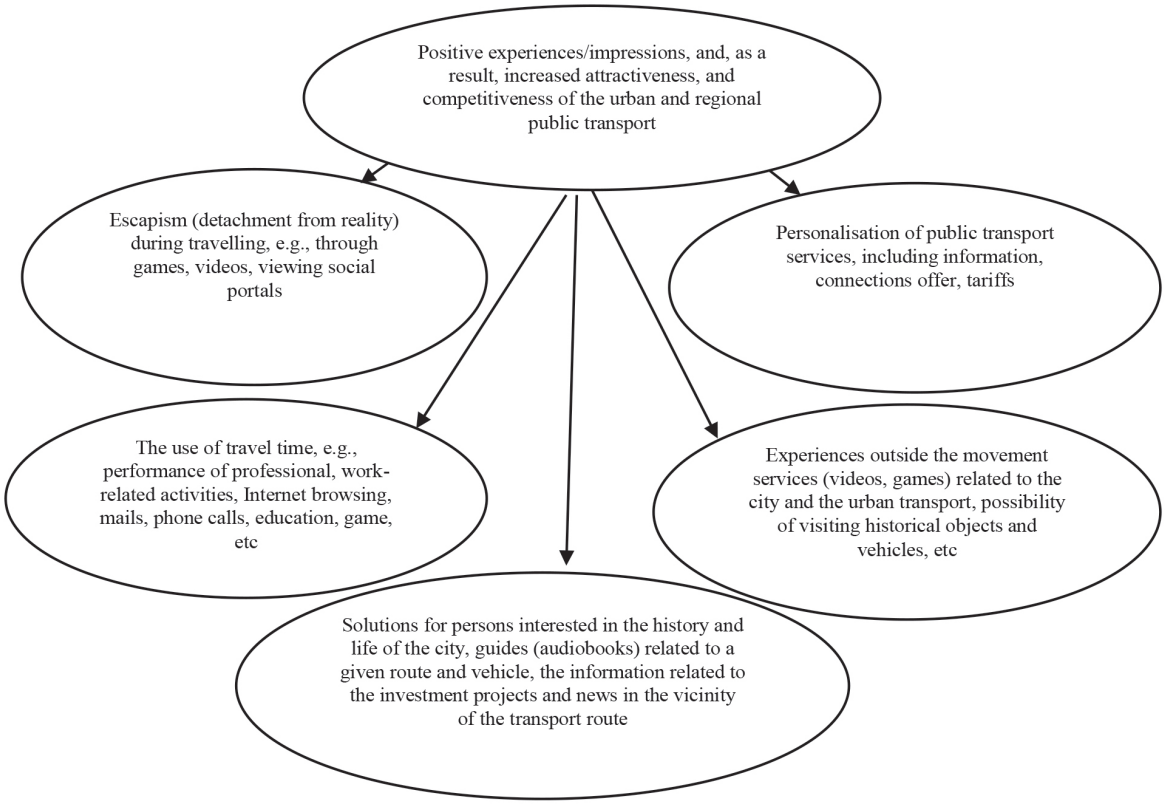

Figure 3 *Areas of activity and methods for obtaining positive impressions related to the urban and regional public transport*

travel. In the case of the public transport, during the travel, both at stops, stations, or in vehicles themselves, it is possible to perform selected actions, which allow for practical usage of this time. These may be the actions related to the work, education, maintenance of social relationships, rest, and relaxation; however, in part of the cases people get bored with the travel itself, have the feeling of lost time and a dragging on travel, and, as a result, additional tiredness. It is possible to use the time of travelling in the public transport for the reading of daily newspapers and books, or for thinking and mental preparation to work or other events of the day; such utilisation existed already many decades ago, practically from the begging of the public transport. However, the development and wireless accessibility to the Internet by means of mobile devices has significantly enhanced the possibilities of using the time, which can convert into a positive attitude to the public transport. Mobile devices with the Internet access provide very broad possibilities, phone calls, and on-line receiving and sending of e-mails or SMS-s, access to social portals, reading the contents of selected files, e-books, educational applications, e.g., learning of languages, various types of games, films, or music (headphones). For tourists or persons willing to learn something more about the history, interesting objects, and the current life of those areas of the city, through which a given line runs, information sets could be prepared (in several languages), which the passengers could listen to via headphones on the possessed mobile devices. All that allows to perform selected actions related to work, education, entertainment, or detaching from the feeling of losing the time for travelling and focusing on an interesting action. It also allows for a wide personalisation of services, including the information, the transport offer, and the tariffs. Vehicles can also display data about the means of transport, type of drive, and especially emission-free status. Figure 3 presents possible positive experience related to the public transport.

Obviously, the current and increasingly broad usage of mobile devices is the behaviour paving its way, more frequent in the young generation, which results from the fact that previously such possibilities did not exist, and this shaped the framework of behaviour, not only when travelling. There are no major difficulties in carrying out phone calls at stops or stations; in vehicles it depends on their size and occupancy, in the case of higher occupancy it is rather necessary to reduce to evasive and short replies to questions, to provide hints, without any excessive descriptions, not to disturb other passengers. The possibility of using the time for work to a large extent depends on the work nature. If someone runs his/her own business, holds managerial functions, employs people, it is possible to provide guidelines and instructions related to the selected aspects of work. Similarly, if the work requires reading selected

documents, this may be done in a means of transport. However, the studies show that not all the time will be used, and only a part of the travel time. The work may be equally productive, but we do not necessarily like the environment, or it is different from that to which we got used at work; the lack of access to certain materials, which are available only in the office, or the impossibility to contact the person, needed in a given case, may also be a problem. The performance of work-related actions is not possible for many types of work, most frequently of physical labour type, like the work on production lines, cleaning, security, building works, and others. Another approach to the travel time consists in getting involved with actions related to the education, interests, and entertainment, which results in the benefits in the form of positive impressions during those activities, and in the feeling of shortening - reducing the travel time. As a result, the travel time, and the travel itself by the public transport, is associated as less arduous, and even positively.

For the public transport users, the mobile devices created a possibility of widening the positive experiences and contributing to positive perception of the travel and reduction of the time loss feeling. One can mention information applications, available in the vehicles of the urban public transport, which are educational in nature (e.g., language learning, information from the indicated field), various types of games and competitions (games available in mobile applications, the next levels, so that their continuation would be possible only in the vehicles, during the next travels), listening to selected audio-books, videos in smartphones, meetings with interesting people. In addition, other possibilities to use the time when waiting for a vehicle and on-board vehicles of the public transport are to be considered, which, for example, is not possible when driving a car, and in this case, it may be the source of competitive advantage.

4.2 Personalisation of tariffs, passenger information and travel planning systems

The personalisation is a natural reaction of tangible goods manufacturers and service providers to the individuality and unrepeatability of individuals, and their pursuit of being noticed, separate, and standing out. At the same time, the personalisation allows for adaptation or increased functionality of a given good, facilitation in usage, and thereby, an increase in its attractiveness for the consumer, and his/her attachment to use the specific good. As a result, it translates into the financial results via the improvement in competitiveness, a significant number of loyal customers, and - if such a strategy is implemented - the acceptance of higher prices by the customers.

The personalisation may be implemented in various ways; that depends on the sector, as well as on the strategy of entities. The IT technologies are an important factor, which facilitated the personalisation itself and reduced its costs. They facilitated the gathering of information on customers, both this acquired automatically about the purchases or service usage, and on various features

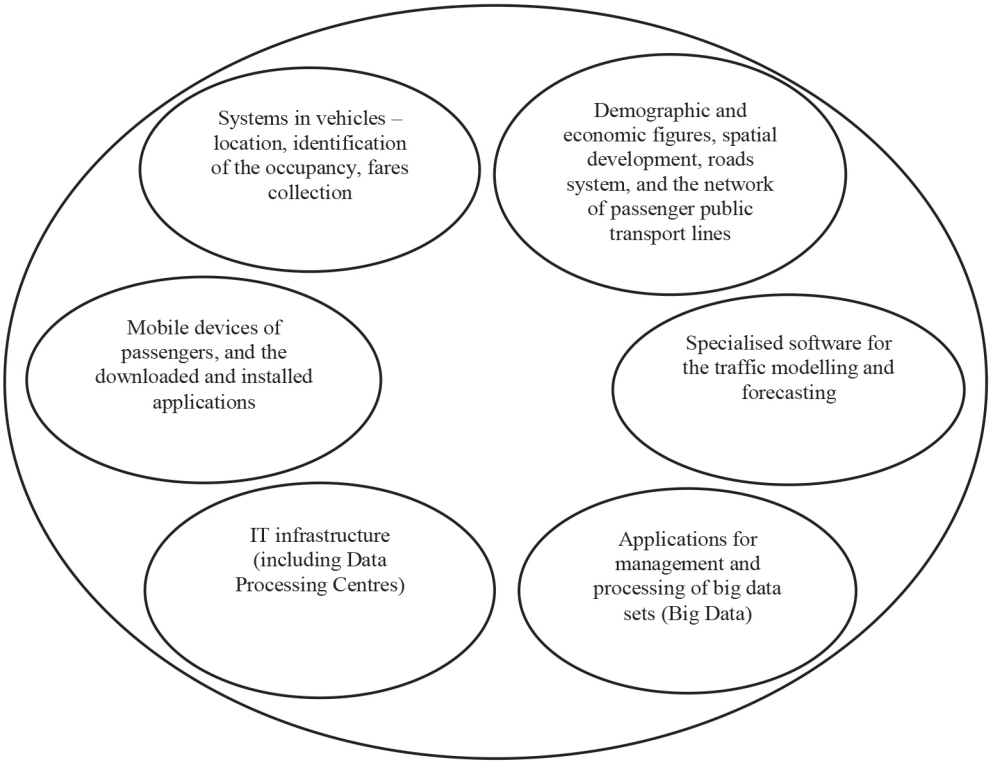

Figure 4 *Selected infrastructure and IT tools to create the personalisation of services, attractiveness and competitiveness of the urban public transport*

applicable to the given person, his/her expectations, and consumer preferences, introduced during the installation of dedicated applications, e.g., the loyalty ones, which allow to obtain information, facilitate the purchase of delivered goods or services, and also the making of payments. Applications installed on mobile devices became widespread, for the business entities it is a cheap solution; the device, installation, and payments for the Internet access are on the consumer side, and the entity ensures development, making the application available, and its updating. The applications are also a tool to build the identity and recognisability of a given entity, inter alia via the existence of the icon on the device desktop, reception of notifications, or using the application in connection with the service use. Figure 4 presents the selected infrastructure and IT tools to create the personalisation of services, attractiveness, and competitiveness of the urban public transport.

The universal nature of mobile devices (most frequently smartphones) and applications concerning various aspects of movements give a possibility of personalisation of the urban public transport services, despite that according to the assumption, this service, due to a high capacity of means of transport, is dedicated to the mass transport. The applications related to the urban public transport services are encountered now, which allow for the travel planning, including determination of possible routes and means of transport, which can be used, of the distance to be covered, travel time, and availability of means of transport - departure times. Moreover, the applications also allow for obtaining the information about the costs related to the movement; in various variants some of them also allow to practically make the payment, and in part of cases it is necessary to use another, application dedicated to that [3]. The applications also allow to obtain the current information on the operation of urban public transport vehicles or disturbances and difficulties in the traffic. The automatic location of a given smartphone (and thereby a potential passenger) means that it is only necessary to indicate the travel destination, and even that may be simplified by the possible saving of previous travels and selecting one of them, like it is the case in the navigation used in motor vehicles.

The personalisation of urban public transport services is possible through appropriate adaptation of the information, suggestions of the travel route, and the ticket price to the user's expectations, as well as to the policy of the service provider. It may allow to gain passengers, e.g., those who sporadically move in the given city (e.g., tourists, persons on business trips, visiting someone in the given district) and are not familiar with a frequently quite complex system of public transport lines and tariffs, which results in the choice of a taxi or an own car. In bigger cities, with a more developed network, it is also possible to create an offer of movement routes between the travel origin and destination, indicating for selection the fastest route, under the given conditions, or the cheapest one, and the route suggestion itself may also consider preferences of the means of transport and method of travelling, e.g., with a transfer, using the rail transport, or a direct movement by bus, or the lack of suggestions for the routes, on which vehicles are overcrowded and/or delayed. The information may also relate to the current occupancy of the means of transport, possibilities of transporting a bicycle, and many other parameters, which can be useful for passengers. The utilisation of mobile devices for tickets buying enables also the prices to be diversified, to the extent, which has not been used so far; for example, in the case of the first ride by the urban transport, the first purchase using a given mobile device, the application of a free or of reduced-price ticket, hence slightly differently than it has been applied so far, when the travel based on a single-ride ticket is much more expensive than based on season tickets. It is also possible to apply dynamic tariffs, charging the fare most favourable for the passenger, after the counting of the number of travels in a given period. There is possibility to implement solutions for disabled people as well, ensuring their accessibility and ease of using public transport, especially since the number of this social group is growing [46]. The personalisation may also comprise solutions in vehicles, for example, the temperature in the vehicle, as it is unfortunately the case, not necessarily must depend on the solutions and yield of the heating or air conditioning equipment. Like in private cars it was possible to create zones, it seems that also another principle may be applied that, for example, there will be three zones from the vehicle's front - warmer, intermediate, and cooler, and the travellers choosing the place in the vehicle will thereby be capable of choosing the preferred temperature.

In the urban transport, there is a relatively high variability of demand for services, depending on the hours, day of the week, as well as periods in the year [47]. In addition, various events of urban or local impact add to that in city districts, as sports and cultural events, markets, fairs, trade exchanges, and others. They are cyclical or sporadic in nature. Schedules of classes in secondary and higher schools have a major influence, as well. Days free of learning, before and after holiday periods, inter-semester breaks, examination sessions, or secondary school-leaving examinations, cause major changes in the number of passengers, using a specific transport line, even in the group of working days, or Saturdays or holidays. The number of passengers using the urban public transport is affected by a season of the year as well; in the wintertime the walking and the use of single-track vehicles is usually reduced, and, in the case of very unfavourable road conditions, the usage of private cars; the number of people using the public transport increases then, like in the case of rainy days. In this context, it is widely proposed to designate routes and create vehicle circulations based on multi-criteria analysis methods [48], as well as those used so far in the

case of optimization of cargo and shipment flows in cities [49], in which the transport routes, in the normal course of events, change frequently.

5 Conclusions

The theoretical achievements of the experience economy show that in societies with a higher degree of socio-economic development, increasingly great attention is paid not to the basic usefulness of a given tangible good or service, but to the positive and attractive impressions accompanying both before, during and also after the service use. The experiencing of impressions is an individual matter to a large degree; hence the personalisation is important, adjusting products or services to individual customer expectations. Referring that to the movements of urban, suburban, and regional range, apart from the covering of space and location change, which is related to a specified benefit, the impressions and feelings, related to the travel, are of considerable importance, as well. The offering of various additional services in the urban public transport, which provide a feeling of a better used travel time, education, knowledge enhancement, and attractive impressions, may lead to improvement in the public transport competitiveness in relation to private cars, and thereby an increase in the transport volume.

Cars, despite the mass production, since they are used only by the driver, or possibly a small number of passengers, ensure the personalisation of travelling. In recent decades cars experienced significant changes to adapt them to the buyers' expectations and to provide them emotions of driving. The multitude of makes, possibility of personalising the colour and interior materials, and the equipment itself, navigations, multimedia stations, multi-zone air conditioning, equipment for phone calls, increasingly great power generated by the engines, systems facilitating the driving and increasing the safety, all of that ensure not only a possibility of moving itself, but also a good mood, and increases the attractiveness of travelling.

Against a background of changes introduced in cars, those in the vehicles of public transport, aimed at improving the comfort and making the travel more attractive, cannot be considered significant. Obviously, major facilitations include the introduction of low-floor vehicles, passenger information systems, and utilisation of applications installed on mobile devices, which facilitate and allow for the travel planning, or its purchase and payment for it. The available IT technologies, the ease of automatic location, the possibility of wireless data transmission, and the widespread possession and use of smartphones, provide great possibilities of using these tools to increase the effectiveness in the processes of urban transport management, as well as to introduce many services and solutions, which provide a feeling of attractive, pleasant, and useful spending the time.

The public transport may provide, different from cars, possibilities of using the travel time. The development of IT technologies and related more and more universal possession and usage of mobile devices with the Internet connection, have incredibly expanded the possibility of using the travel time. That may be used for the purposes related to the professional work, but also for entertainment, education, and learning. Mobile devices can also personalise the use of public transport and adapt to the individual needs. Various persons, travelling by the means of public transport, can watch videos on the screens of their devices or play games, and using the headphones listen to various contents, in accordance with their wish. Mobile devices also enable personalisation, depending on the needs for the passenger information and the applied tariffs; various promotional campaigns may also be personalised.

A substantial part of the paper deals with attractive experiences and feelings of car users. This results from the objective adopted in the research, in which an assessment was made of a possibility of introducing at least a part of them in the urban and regional public transport, hence that should not be equated with the intention to support this form of travelling. A car is a competitive method of travelling for the urban public transport, therefore pursuing the increased share of travels by the public transport it is necessary to understand the foundations of choices of persons, who buy and use cars. Cars may be obviously linked to numerous negative events, which the owner or the driver can encounter, like vehicle's theft or damage, an accident or road collision, costly and/or long-lasting repairs, getting stuck in major road jams, stress, fears, significant risks during moving in difficult conditions on roads, snow, icing, and fog. The purchase and usage of a car means a significant expenditure, frequently higher than in the case of public transport services. However, the equipment and the very possession and usage of cars ensure positive impressions, which is proved by their widespread presence almost worldwide, hence one of actions (apart from others), aimed at increasing the volume of the public transport, should be the ensuring of attractive impressions, better use of the travel time and the personalisation of services.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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THE IMPACT OF THE SAFE FOLLOWING DISTANCE ONTO THE TRAFFIC SAFETY

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Resume
This paper provides an analysis of the values of safety distance between the two moving vehicles, based on the parameters of the behaviour of young drivers. The main objective of this research was to determine the driver's response time for braking manoeuvre (BRT) in car-following situations. The test results were used to verify certain recommendations for the vehicle driving parameters, the principles of driver's performance to increase road traffic safety, etc. The driver's response times, determined during the testing in the simulator, were used to assess the recommended values of the safe following distance under different road conditions and various ways of driver behaviour. In the paper, for different values of BRT a safety distance in emergency traffic situations was determined.

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1 Introduction

The behaviour of the driver's in different road situations is very varied because it can depend, on many factors. In the car-following situations, the drivers must correctly maintain an adequate distance between vehicles, to ensure safety in traffic. Different factors can determine the values of a driver's response time and the way of performance of the driver in various emergency situations. Researchers were, for many years, from many countries, trying to determine how various factors can affect the driver's behaviour in these situations. The driver's tests can be conducted under different conditions and road situations, i.e., on a test track, in a simulator, or using special test devices. Both healthy and sick, young or older drivers, with or without experience, can participate in the tests. Since the driver's behaviour may depend on many factors, so the variety of research in this area is understandable. Studies in the driving simulator are very popular in this field, although known are limited to use of this research method. In the simulators, the tests were performed a many tests e.g., to analyse the performance of the old drivers [1-2], drivers with various chronic diseases, e.g., Parkinson's or Alzheimer's disease [3], or other disabilities. A fairly large number of researchers were concerned with influence the complex orthopaedic surgeries that adversely affect driver's physical fitness [4-5] restrictions, which can be important during various road situations [6]. For example, in the work [7], the authors describe an attempt to evaluate the behaviour of drivers for 5 different variants related to the limitation of limb mobility. Many of the tests analysed the influence of other factors on driver's behaviour [8]. In tests of driver's behaviour, such factors can be analysed: tiredness [9], experience [10], age [11-13] stress [14], the influence of environmental factors [15-16] and others.

Drivers' behaviour is also influenced by factors such as alcohol [17], used medicine, or drugs [18]. In the currently manufactured vehicles, the driver can use many devices such as: multimedia stations, GPS navigation, and control systems of various systems that can distract drivers and negatively affect, among others, his reaction times. Hence, many studies analyse this aspect as well. Many drivers use mobile phones while driving, including hands - free sets. The way the use of such devices, perhaps negatively affects the behaviour of drivers. These tests are described in many publications [19-22]. Many numbers of papers described analyses,

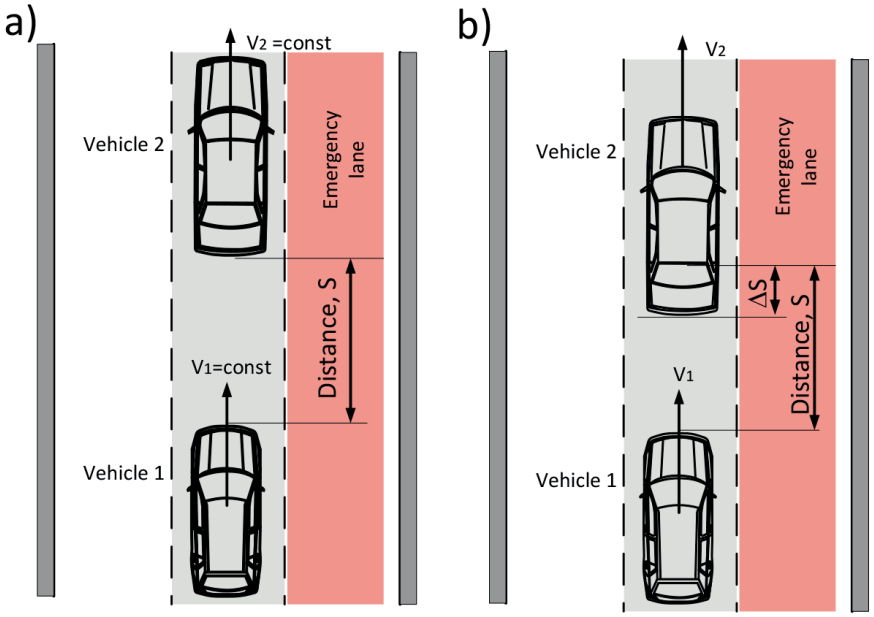

Figure 1 *Diagram of the road situation; a) in the initial phase, b) when vehicle 2 braking*

which determine the influence of various roadway factors on driver behaviour [23].

Now, because the vehicles are equipped with different systems supporting the driver, much research has been undertaken to determine the influence on the driver's behaviour [24- 26].

Some studies focus on the construction details of control systems [27], for example, analysed the influence of the type of keyboard interface (touch screen keyboard vs. numeric keypad) on driving performance and eyeball movements.

Test with the use of a mobile phone carried out on motorway driving in a car-following situation has been realised on younger and older drivers [28]. Muttard analysed the influence of chosen factors on the driver's behaviour, such as the driver's age, fatigue, dispersion of attention, road lighting level, and the free space around the car [29]. The investigations carried out in the simulator have some advantages and disadvantages. A main argument for conducting investigations in a virtual environment is to perform identical, pre-defined situations [30]. Many virtually created road situations can be impossible or dangerous to perform under real conditions. The road tests realised for these situations, may generate high risk to the participants and damage to the used measurement devices [31]. In a simulator is possible to check the driver's performance under specific psychophysical conditions such as great fatigue, driving after consumption of alcohol, medications, or drugs, etc. Driving simulators can be used to simulate the following various situations [32]. These road situations can be very dangerous since the motion of vehicles is realised at a high speed. For this reason, the implementation of research in the simulator does not cause hazardous situations in the traffic [33]. Issues related to the car following movement were analysed in publications [34-37]. Threat factors affecting the behaviour of drivers [38-39], and possible risks occurring during the traffic [40-42], the impact of road shaping [43] in this intersection [44-45], may cause drivers' response times to change [46-49]. The response time may change when one has to be activated with time pressure [50].

To simulate various dangerous road situations driving simulators can be often used. In most of them, the possibility of their reproduction in real conditions would be associated with great danger. Hence, the high popularity of using this way of testing, which, ensures repeatability and stability of measurement conditions. One of the quite dangerous situations is driving in a column. In this situation, vehicles move on the road at quite high speeds with various (sometimes small) distances between them. For all the moving vehicles, any movement stability disorder can cause dangerous consequences. Such disorders include, for example, rapid braking of a preceding vehicle or a sudden appearance of an obstacle. Many publications recommend ensuring a high level of safety, and in this car-following situation, appropriate distance should be maintained [51]. In the paper [52] Bradstone et al. described the studies, in which the distance between vehicles on motorways was determined by use of specially equipped vehicle. Problems related to different road situations, and the values of safety distance between them, have been discussed by numerous researchers [53].

The paper describes the safety distance on a motorway from the aspect of the behaviour of young drivers in an often encountered road situation. The values of the driver's response time for braking manoeuvre (BRT) to determine the safe distance were measured and analysed in the test. In this paper were analysed influences of chosen factors for calculating values of the safety distance.

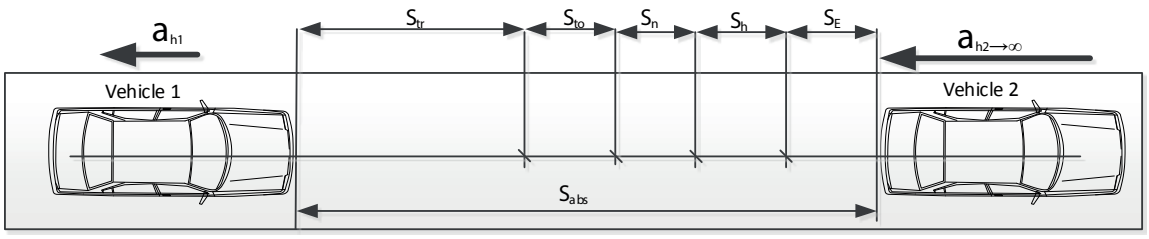

Figure 2 *Diagram for determining the absolutely safe distance*

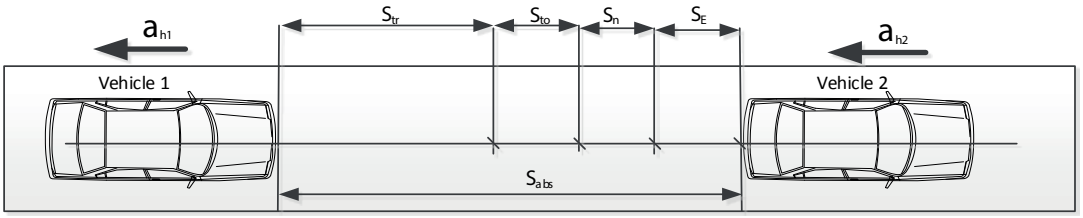

Figure 3 *Diagram for determining the relatively safe distance*

2 Definitions of the safe distance

The aim of the tests realised in the driving simulator was to determine the behaviour of young drivers in situations of sudden braking by the preceding vehicle. The test was realised on a straight section of the road on a motorway. The test road had two traffic lanes and an emergency lane. The road situation is shown in the diagram in Figure 1. Between these vehicles was a safety distance S.

In the literature on this subject [54-57] we come across different terms characterizing the safe following distance. Two terms are considered here: absolutely, and relatively safe distance.

The absolutely safe distance is defined as the gap between one vehicle and the next that enables the following vehicle to decelerate (a_{h1}) and avoid a collision with the preceding vehicle that suddenly stops ($a_{h2} \rightarrow \infty$). The situation may take place, for example, when the lead vehicle approaches the scene of a multi-vehicle collision, or there is a sudden intrusion of another vehicle or a wild animal into the roadway. The value of the safe distance can be determined from the following:

$$S_{abs} = S_E + Vp_1\left(t_r + t_o + \frac{t_n}{2}\right) + \frac{V_{p1}^2}{2a_{h1}} = S_E + Vp_1 T_R + \frac{V_{p1}^2}{2a_{h1}}, \quad (1)$$

where: S_{abs} - absolutely safe distance, S_E - minimum distance between the vehicles when stopped; we can assume e.g., S_E=2 m, V_{p1} - initial driving speed of the following vehicle (vehicle 1), a_{h1} - deceleration of vehicle 1, t_r - driver response time, t_o - brake system activation delay time (0.2 to 0.6 s), t_n - pressure build-up time (0.2 s), T_R - non-braking time.

The value of the time T_R is:

$$T_R = t_r + t_o + \frac{t_n}{2}, S.. \quad (2)$$

It is possible to determine the absolutely safe distance according to:

$$S_{abs} = S_E + S_{tr} + S_{to} + S_n + S_h, \quad (3)$$

where: S_{abs} - absolutely safe distance, S_E - minimum distance between the vehicles when stopped, S_{tr} - driver reaction distance, S_{to} - brake activation delay distance, S_n - pressure build-up distance, S_h - braking distance for value of a_{h1}.

The diagram for determining the absolutely safe distance is shown in Figure 2.

The relatively safe distance is defined as the gap between one vehicle and the next that enables the following vehicle to brake and avoid a collision when the preceding vehicle decelerates (a_{h2}) to stop:

$$S_{rel} = S_E + V_p\left(t_r + t_o + \frac{t_n}{2}\right) + \left(\frac{V_p^2}{2a_{h1}} - \frac{V_p^2}{2a_{h2}}\right), \quad (4)$$

where: V_p - initial driving speeds of vehicles 1 and 2, a_{h1} - deceleration of the following vehicle (vehicle 1), a_{h2} - deceleration of the preceding vehicle (vehicle 2).

If assumed that the both analysed vehicles can obtain identical deceleration during braking ($a_{h1} = a_{h2}$), one obtains:

$$S_{rel} = S_E + V_p\left(t_r + t_o + \frac{t_n}{2}\right) = S_E + V_p T_R. \quad (5)$$

The diagram for determining the relatively safe distance is shown in Figure 3.

Using the results of tests conducted earlier by the authors, for a similar road situation [8, 58], one can assume that the average value of braking response time determined for tested drivers is about 1.1 s. There was a large diversity of results of driver response time for braking, ranging from 0.74 to 1.99 s, depending on the driving behaviour.

As described in previous publications of the first author, the driver's response time used for the

Table 1 *Vehicle traffic parameters in subsequent phases*

Time of phase (Growing time) (s)	Vehicle 1 (subject vehicle)			Vehicle 2 (preceding vehicle)			Reduction in the distance between vehicles, ΔS (m)
	Description	Speed (km/h)	Distance (m)	Description	Speed (km/h)	Distance (m)	
0	Car-following situation Vehicle move at a constant speed	100	-50	Car-following situation Vehicle move at a constant speed, time brake lights	100	0	0
(+0.5) 0.5	Driver reaction time to brake lights 0.9 s	100	-36.10	Brake system activation delay time 0.5 s and pressure build-up come on,	100	13.90	0
(+0.2) 0.7		100	-30.55	Pressure build-up time brake lights come on, deceleration increases from 0 to a_{h2} = 9 m/s^2	96.8	19.40	0.05
(+0.2) 0.9		100	-25.00	Constant deceleration a_{h2} = 9 m/s^2	90.3	24.60	0.4
(+0.5) 1.4	Brake system activation delay time 0.5 s	100	-11.10		74.1	36.00	2.9
(+0.2) 1.6	Pressure build-up time 0.2 s for vehicle 1, deceleration increases from 0 to a_{h1} = 9 m/s^2	100	-5.60	Constant deceleration a_{h2} = 9 m/s^2	67.6	39.95	4.45
(+2.09) 3.69	Constant deceleration a_{h1} = 9 m/s^2	V_1 = 29	30.9	Constant deceleration to stop a_{h2} = 9 m/s^2	0	59.50	21.4
(+0.9) 4.59	Constant deceleration a_{h1} = 9 m/s^2 to the Vehicle stops	V_1 = 0	34.5	Vehicle stops			25

reconstruction of accidents should be assumed based on investigations conducted under very similar conditions [58-59].

The used value of the braking response time for a very "good driver" of 0.9 s may turn out to be either a little shorter or longer than that obtained on the test track [31].

Based on the many tests realised in both research environments by the Author, may say, that the values of the driver's response time for identical situations, determined during tests on the track and tests in the simulator, are different but correlated [59-60].

This paper analyses a hypothetical road situation, the diagram of which is presented in Figure 2. Vehicle 1 and Vehicle 2 at initial moment, move with constant speeds, e.g., 100 km/h at a certain distance from each other, e.g., 50 m.

This paper analyses a hypothetical road situation, the diagram of which is presented in Figure 2. Vehicle 1 and Vehicle 2 at initial moment, move with constant speeds, e.g., 100 km/h at a distance between them, e.g., 50 m.

At some point, suddenly, the driver of Vehicle 2 - begins to brake with deceleration a_{h2}. The driver of Vehicle 1, at the sight of the stop light, begins to react. From the moment when the brake lights come on in vehicle 2, to the moment when the braking by the driver of vehicle 1 is initiated with a predetermined deceleration, e.g., 9 m/s^2, a certain time passes (for this analysis it was assumed about 0.5 s). This time is a sum of the brake system activation delay time and the pressure build-up time. During this time, the driver of Vehicle 1 begins to respond after the driver response time, for instance, 0.9 s.

In the next step, after e.g., 0.5 s, vehicle 2 begins to brake with deceleration a_{h2}. During these manoeuvres, the distance between Vehicle 1 to Vehicle 2 is decreased

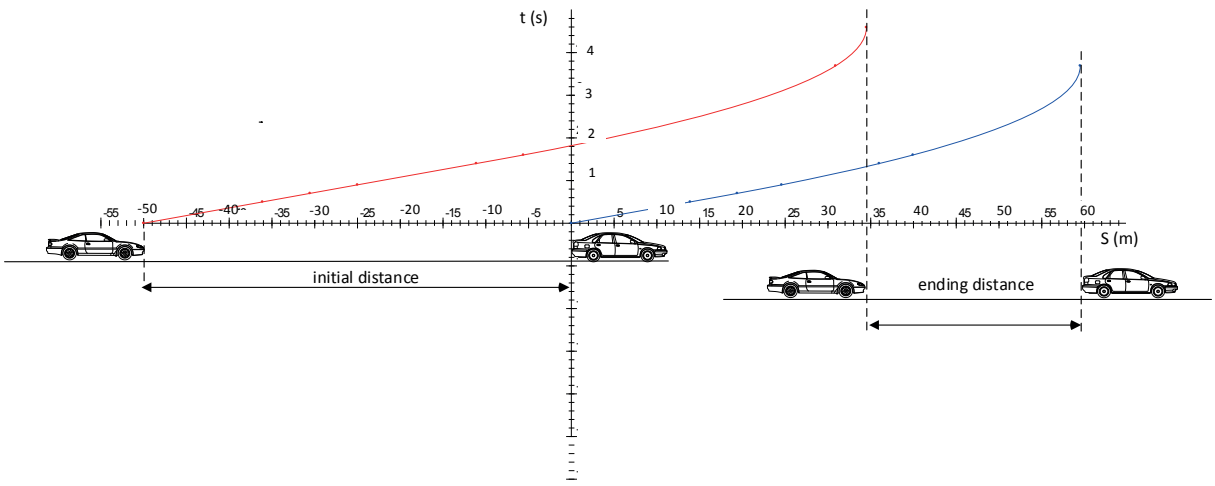

Figure 4 *Result of the time-space analysis for vehicles driving at an initial distance of 50 m*

and if an appropriate distance between vehicles is maintained, a collision does not occur.

In the analysed road situation, the distance between vehicles is equivalent to the relatively safe distance defined above. The driving parameters of both vehicles are shown in Table 1. The decrease in the distance between vehicles is significant, and it is 25 m. It should be noted that the safe distance between vehicles is still maintained. In this situation, the Vehicle 1 moving between the initial moment to the moment when the vehicle stops distance is about 84.5 m.

The Titan Cybid® software for the time-space analysis may show, that if the initial distance between vehicles is decreased, while the other simulation parameters are kept constant, a collision may occur - Figure 4. For situation presented in Table 1, the value of the minimum distance between the vehicles is about 25 m.

When the initial speed of the vehicles is increased to a value of, for example, 120 km/h (at the same value of the braking response time of 0.9 s), the minimum relatively safe distance should be longer. These values of the distance between vehicles can be considered sufficient, assuming that all the other parameters are constant.

If deceleration used by vehicle 1 (a_{h1}) is smaller than the deceleration reached by vehicle 2 (a_{h2}), then there is a dangerous decrease in the distance between them. This situation may occur when one of the vehicles (Vehicle 1) taking part in the event is not equipped with modern safety systems, e.g., the brake assist system (BAS). What would have happened if the driver response time had been different - shorter or longer - than the predetermined 0.9 s? The important question is: how does a change in the driver response time affect the minimum relatively safe distance between vehicles?

In some countries, there are certain recommendations for the distance between vehicles. They are the two-second distance (in time) or a 50 % distance (in space) calculated as half of the speed read from the speedometer. Can, however, these values be considered appropriate? Will the recommendations be sufficient in all the cases and, more importantly, for all drivers?

In this paper, the distance between vehicles is equivalent to the safe distance. The driver response time measured during the tests in the simulator, was one of the parameters used to determine the relatively safe following distance.

The simulation results were analysed to determine the distances at which it was possible to avoid a collision.

3 Tests in driving simulator

The testing of the driver was carried out at the Kielce University of Technology using a Oktal® dynamic driving simulator, shown in Figure 5. Its construction and main parameters were described in other papers by the authors [58]. The fragment fully equipped driver's cabin car the Hyundai Getz and three Full HD monitors, were placed on a 6 DOF mobile hybrid platform.

Identical to the real vehicle, the vibration of the steering wheel differs, depending on the surface type, and the driver feels resistance moments on the steering wheel. Additionally, 5.1 system speakers reproduce sounds related to cooperation of wheels with the road or behaviour of other participants of the traffic.

The system for visualizing the used road situation, while simultaneously controlling the platform motions, uses two computers with Scanner Studio® software. This software allows the modification of vehicle parameters based on the Callas® model of vehicle, the creation of a road profile, and the setting of the road environment for individual test scenarios on different types of roads. A user can create and modify a database that is easy to adjust to the needs of investigations.

It is also possible to develop a scenario through open sources (e.g., *Road XML*) by importing the 3D files with different roadway environments, comprising

Figure 5 *View of the Oktal® driving simulator*

Table 2 *Statistical parameters of the braking response time (BRT)*

Parameter of BRT	Values (s)
Mean values RT	1.16
SD	0.42
Median values	1.10
Quantile 0.10	0.74
Quantile 0.25	0.85
Quantile 0.75	1.41
Quantile 0.90	1.73
Quantile 0.99	1.99
Minimum value	0.5
Maximum value	2.7

buildings (e.g., 3DS, FLT, DAE, OBJ, DXF, OSG, and IVE formats).

Road type modification may involve changes in the pavement type, coefficient of grip, and road roughness. These parameters are very important for use by the model of vehicle dynamics in the software.

In the simulator, realised tests of 60 young drivers aged 22-23 drove on the right lane, as shown in Figure 6, with a speed of 100 km/h. In the tests a specified constant distance of 10 m to 50 m from the preceding vehicle was maintained. The research procedure has been described in the paper [58]. In the realised scenario, there were no other vehicles moving in around of the test vehicle. At a randomly selected moment, a vehicle moving in front of the research vehicle brakes with high deceleration 9 m/s^2.

Drivers of the tested vehicle were free to choose emergency manoeuvres: only braking, bypassing the braking vehicle, or both manoeuvres combined braking and steering. The tests involved registering the values of driver response time. The registered values of braking response time (BRT) in this test is the time, determined from the moment when the brake lights light up in the preceding vehicle, to the moment when the driver of the testing vehicle presses on the braking pedal.

4 Results

4.1 Driver response time for braking (BRT)

In the analysed scenario, there were no any limitations to the driver's behaviour. Authors analysed values of braking response time for all the tests for different distances between vehicles. To simplify, the further analysis in terms of safe spacing, the data collected in the study [58] were used and analysed as a single set. Statistical values, determined for them, are presented in Table 2. It can be seen, that the values of the mean and median braking response time are not equal, so it can be said that the distribution of the obtained values is asymmetrical. This is confirmed by the analysis of the normal distribution (Chi-Square test = 20.937, df = 4, p = 0.00042); a better fit applies to gamma distribution (Chi-Square test = 9.09, df = 4, p = 0.0588).

The values of the braking response time can significantly contribute to the driving safety in a road situation. A minimum safe distance between vehicles can be determined in two different ways: as a gap in space, when the distance is calculated as half of the speed expressed in km/h read from the vehicle

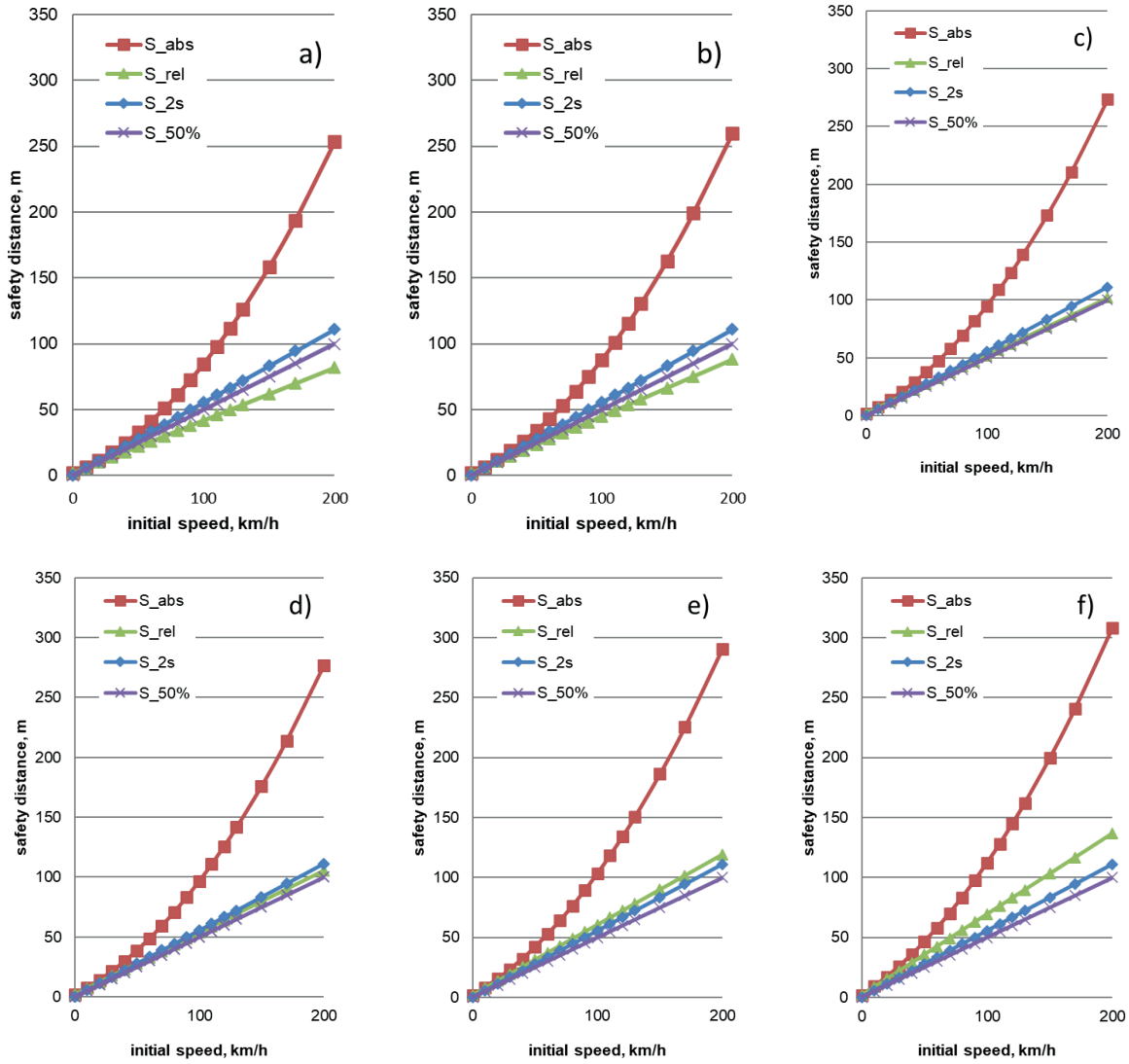

Figure 6 *Safety distance for various values of the BRT; a) the 0.1 Quantile, b) the 0.25 Quantile, c) median value; d); the 0.75 Quantile e) the 0.9 Quantile, f) the 0.99 Quantile*

speedometer (e.g., recommended in Germany or Poland) $S_{50\%}$, or as a gap in time, when the two-second rule is applied S_{2s} (e.g., in France).

When the two vehicles move one after another with identical speeds in the same direction, the distance between them is constant. In such a case, the required distance is equivalent to the relatively safe distance. Following the relevant recommendations, one can assume that the safe distance between vehicles moving, for example, with a speed of 100 km/h should be approximately 50-55 m. However, one can ask whether the large distance is not too large.

The driving safety in analysed situation is relatively high as long as the traffic flow is homogeneous. Some drivers, however, may want to decrease the distance between vehicles, which would result in a gradual decrease of the safety level. At smaller distances, a problem may occur in an emergency when the lead vehicle performs unexpected manoeuvres or just brakes suddenly. The driver in the vehicle behind starts to respond to the situation, most frequently to the brake lights coming on the preceding vehicle. Analysing the values of the braking response time in a car-following situation, one can notice a great diversity of results.

Comparing the response time for braking to that assumed in a hypothetical situation (see Table 1), one can question what distances ensuring safety are suitable for all drivers. What about people whose response time will, for some reason, be longer? Drivers with longer response times include not only people advanced in age, sick or physically disabled, but the young people as well who, for some reason, did not respond early enough.

The diagrams in Figure 6 show different values of distances between vehicles, based on the measured values of the BRT. The curves show the relatively safe distance S_{rel}, the absolutely safe distance S_{abs}, the two-second distance recommended for drivers in some countries, denoted as S_{2s}, and the 50% distance calculated as half of the speed read from the speedometer in km/h, denoted as $S_{50\%}$.

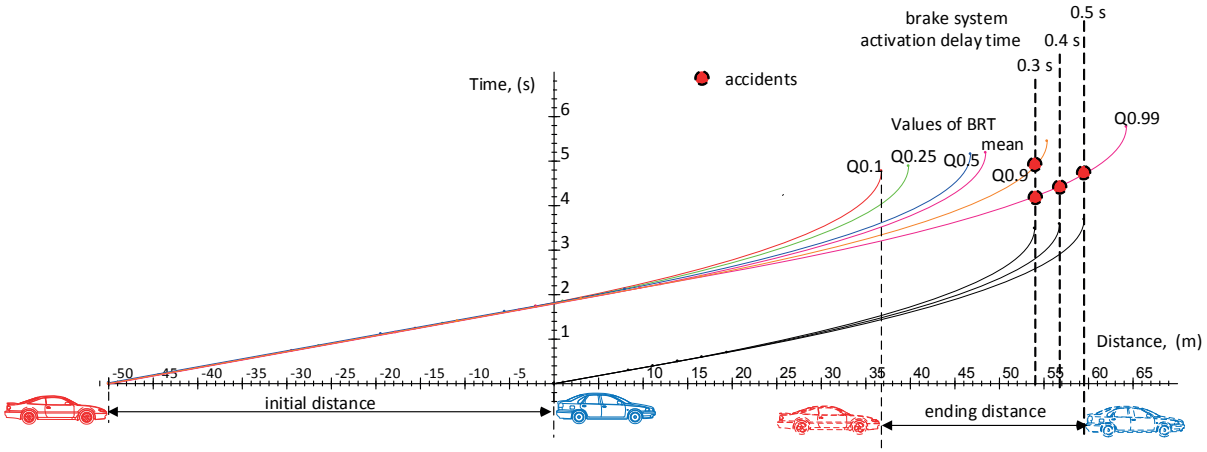

Figure 7 *Effect of changing the brake system pressure build-up time on the safe distance*

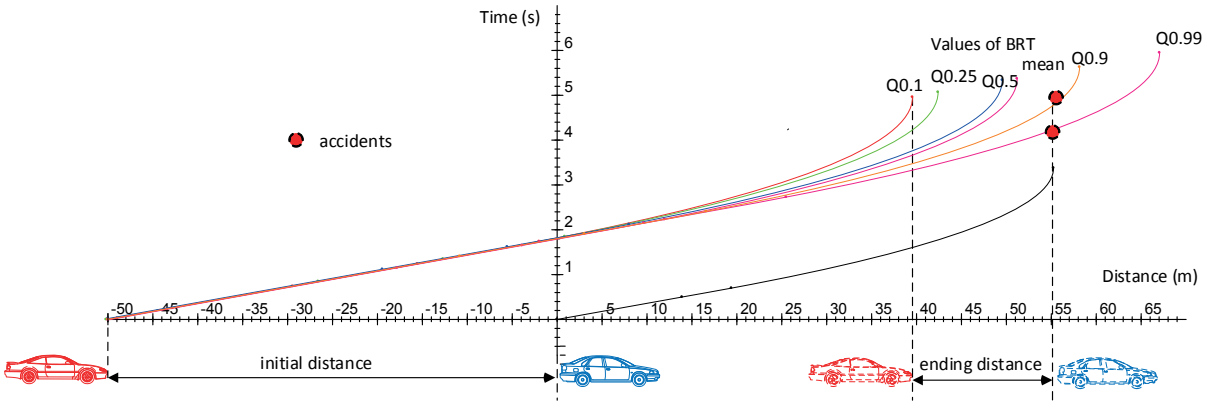

Figure 8 *Effect of changing the value of braking deceleration of vehicles on the safe distance*

Figure 6a shows the distance between vehicles for different driving speeds, assuming that the values of the BRT, recorded by the simulator, were at the level of the 0.1 Quantile. In this case, only 10 % of the tested drivers had shorter response times. This response time is determined for young, healthy, rested driver, with very good skill. From the analysis of the Figure 6a, one may notice, that the relatively safe following distance S_{rel} is smaller than the recommended S_{2s} and $S_{50\%}$ distances. The values of the S_{2s} and $S_{50\%}$ distances seem to be a certain trade-off between the absolutely safe distance S_{abs} and the relatively safe distance S_{rel}. The S_{2s} distance is slightly larger than the $S_{50\%}$ distance. At a driving speed of 120 km/h, the absolutely safe distance S_{abs} is nearly twice as long as the relatively safe distance S_{rel}. One can notice that above this value, the absolutely safe distance S_{abs} increases significantly.

Figure 6b presents a safety distance calculated for drivers, which have a response time of about 0.25 Quantiles. Interesting conclusions can be shown from the analysis of the distance between vehicles if one takes into account the average value of the *BRT* - see Figure 6c. The curve corresponding to the relatively safe distance S_{rel} shifts up and approaches the $S_{50\%}$ curve. It can thus be assumed that for drivers with an average braking response time, the relatively safe following distance S_{rel} is the same as the $S_{50\%}$ distance. This finding is particularly important because the $S_{50\%}$ distance is the easiest to calculate by the driver himself during driving. Figure 6c shows distances between vehicles assuming that the driver response time for vehicle 1 is equal to the median values. The distances were suitable for 50 % of the drivers tested. One can see that the S_{rel} distance is close to $S_{50\%}$ and slightly lower than S_{2s}.

However, if we look at Figure 6d, we can see that the distance S_{rel} should be slightly longer than $S_{50\%}$ and approaches S_{2s}. The curves in Figure 6e show the distances between vehicles for the braking response time of drivers equal to the 0.9 Quantile. The relatively safe distance S_{rel} is longer than the S_{2s} and $S_{50\%}$ distance. The relatively safe distance S_{rel} equivalent to the S_{2s} distance can be considered safe for 90 % of drivers. However, what about drivers whose response time is higher than the 0.9 Quantile? For them, the relatively safe distance, equivalent to the S_{2s} distance, may turn out to be insufficient. If the distances presented in Figure 6f were used in practice, they would ensure safe driving conditions in a car-following situation for 99 % of drivers. The relatively safe distance should be greater than the S_{2s} distance, and for 100 km/h speed is up to 140 m.

The analysed case concerns the case in which the main braking parameters of both cars are similar.

Interesting observations, regarding the safe distance can be made, when changing the assumed parameters of the braking process. An example of changes in the safe distance, in a situation when one of the vehicles (vehicle 2) will have a shorter brake pressure build-up time by 0.1 and 0.2 s, is shown in Figure 7. It may seem that such a small change cannot have a negative effect. However, it turns out that for the less capable drivers, whose BRT is equal to or greater than about 1.7 s (about 0.9 Quantile and above), combined with a very capable preceding vehicle, such a change makes it quite feasible for drivers to create an accident.

The next analysis was carried out for the situation where the driver from vehicle 1 is moving in a vehicle that is not fully operational and its braking deceleration is only 8 m/s^2, while the preceding vehicle brakes very effectively with a deceleration of about 10 m/s^2. The results of the spatial-temporal analysis in such a situation are shown in Figure 8. It can be seen, that even small changes in values of deceleration for analysed vehicles can cause an accident. Variations in deceleration can be caused by modern technology, as well as the technical condition of brakes, tyres, etc.

5 Conclusions

Drivers have a very large impact on the number of traffic accidents. Many factors are influenced by the behaviour of the driver's. To characterize the way the driver's behaviour a parameter that is often used, is the response time. The values of the BRT are of a great significance when emergency situations are analysed. Those are the values that can be used in simulation programs used to reconstruct a road accident.

From the analysis it is evident that the distances recommended in some countries, i.e., the distance equivalent to 50 % of the value read from the speedometer, $S_{50\%}$, and the two-second distance, S_{2s} ensure high safety for vehicles in the car-following mode, and therefore should be generally recommended. Unfortunately, for a certain group of drivers, whose braking response times are higher than the 0.9 Quantile, the recommended following distance may not provide full safety. The investigations conducted in a simulator confirm that for 10 % of drivers, the recommended value turned out to be insufficient. However, it should be remembered that this article analyzes the behaviour of young drivers, in the case of the elderly the response times are longer. For drivers with short response times, the recommended following distance seems too large. If, however, there is a risk of dynamic changes, e.g., due to fatigue, stress, disease or difficult driving conditions, it is not at all easy to assess whether the driver response time, corresponding to a safe following distance, is too short or too long.

In the analysed road scenario, the drivers were free to decide on the use of emergency manoeuvres [61]. Various studies show, that the safe distance is a relative value. It can change dynamically depending on circumstances on the road. The data is consistent with what drivers say, namely, that driving on a motorway is theoretically easier, but it does not mean that we should take less care.

The drivers perceive the safe following distance very subjectively, that may in practice lead to a dangerous traffic hazard. Using the results from various investigations, we can propose the following recommendations for the safe following distance. When the adjacent lane on motorway is clear and the vehicle is equipped with ABS and ESP systems, which suggests that, in an emergency, the manoeuvres of braking and steering away can be used, the minimum safety distance between the vehicles moving with a speed 100 km/h should be for the best drivers (level of the response time of drivers about 0.1 - 0.25 Quantiles) about 42 - 45 m. This value in smaller than the distance recommended in many countries, distance in time 2 s. In an identical situation, the minimum distance between the vehicles for the average driver (median or mean values of driver response time), amounts to 52 - 53 m. These values are slightly larger than the distance calculated for time equal 2 s. For drivers with a large driver response time about of 0.75 Quantiles, distance increases to about 60 m. These values for 0.9 Quantiles of BRT increases to 70 m. If we wanted the distance to be appropriate for 99 % of drivers in the analysed situation, the value could reach up to 77 m.

The article presents an analysis of situations in which the braking parameters of both cars are similar. Other variants were analysed, however, one still does not know, for example, how the safe following distance can be affected by the vehicle condition or the vehicle features (especially those related to the braking system), or what would happen if the brake system activation delay time and the pressure build-up time are much greater than those assumed in this study.

As such questions can be expanded, it is vital to continue the research on the subject, taking into account further factors.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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INCREASING THE RELIABILITY OF WATER TRANSPORT VIA THE USAGE OF MODIFIED EPOXY COATINGS

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Resume

In solving the problem of energy and resource conservation in transport, polymer composites are of paramount importance. Polymer composite using makes it possible to significantly improve the mechanical properties of the materials and simultaneously to increase the durability of the parts of transport machines. The authors of this article focus on the substantiation of introducing the modifier 4.4'-methylenebis(2-methoxyaniline) with low concentrations into the epoxy resin. Such materials are characterized by increased mechanical strength and the ability to withstand static, dynamic stresses, as well as impact loads, since the values of the properties are: bending stresses at bending - σ = 51.2 to 54.4 MPa, modulus of elasticity at bending - E = 3.0 to 3.2 GPa, impact toughness is W = 8.8 to 9.0 kJ/m^2. The obtained results of experimental studies of the composite materials properties are in good agreement with the results of testing samples by optical microscopy, which indicates their reliability.

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1 Introduction

The problem of energy and resources conservation, based on a great development of scientific and technological progress, especially in the recent decades has exceedingly drawn our attention. Polymer composite materials (CMs) and protective coatings based on CMs are the important things in this problem solving. Polymer coatings, especially epoxy-based ones, are used in various industries, including transport, for protecting metal parts from corrosion, which significantly increases their durability [1-5]. Moreover, protective coatings should be characterized in a complex manner, by the increased indicators of physical and mechanical properties. Only the latter determine the anti-corrosion characteristics of adhesive, which, in turn, provide the resource conservation of the process equipment [6-9].

It is well-known [10-11], that the protective coatings should be multifunctional. On the one hand, they should be characterized by increased adhesion and cohesion strength, and on the other hand, the shrinkage and residual stresses should be minimal in the protective coatings. Hence, the authors of [12-14] claim that for improving the properties of the polymeric materials in a complex manner, it is necessary to introduce the modifiers with low content into the epoxy binder. Moreover, the additives must be active before the physical and chemical interfacial interaction with the epoxy oligomer at crosslinking of compositions. Only such an approach will allow to obtain the materials

with a high content of gel fraction, and, in its turn, will provide the maximum increase of cohesive strength of the protective coatings.

Taking into account everything that has been mentioned above, the modifier 4.4'-methylenebis (2-methoxyaniline) at the homeopathic content is proposed to introduce into the epoxy binder. This additive contains active groups, which, in our opinion, activates the physical and chemical processes of crosslinking and will improve the increase of the physical and mechanical characteristics of the testing materials.

2 Materials and methods

The objective of the research is to investigate the effect of the modifier 4.4'-methylenebis (2-methoxyaniline) content on the physical and mechanical properties of epoxy composite materials.

The epoxy diane oligomer ED-20 (GOST 10587-84) was chosen as the main component for the binder in the formation of epoxy CMs. In this work, the structural formula of the epoxy diane oligomer ED-20 fragment is represented according to reference [12] and shown in Figure 1. The 4.4'-methylenebis (2-methoxyaniline) (MDMA) was used as a modifier [15]. As explained in [15], the modifier content 0.1 to 2.0 pts. wt. by 100 pts. wt. of epoxy oligomer ED-20 was introduced into the binder (hereinafter mass parts are given by 100 parts by mass of epoxy oligomer ED-20). The molecular weight of 4.4'-methylenebis (2-methoxyaniline) is 258.3 [15]. Chemical formula is $C_{15}H_{18}N_2O_2$. The modifier is soluble in benzene, ethanol, acetone, however, it is marginally soluble in water. The structural formula of the modifier is shown in Figure 2.

Polyethylene polyamine hardener PEPA (TS 6-05-241-202-78) was used for crosslinking of epoxy compositions that allow to harden the materials at normal and elevated temperatures [5, 10]. It is known [10] that PEPA is a low molecular weight substance that consists of the following interconnected components $[-CH_2-CH_2-NH-]_n$. The structural formula of the PEPA hardener fragment is shown in Figure 3. The hardener was introduced into the composition with a content of 10 pts. wt. on 100 pts. wt. of epoxy oligomer ED-20. The main characteristics of the epoxy diane oligomer are

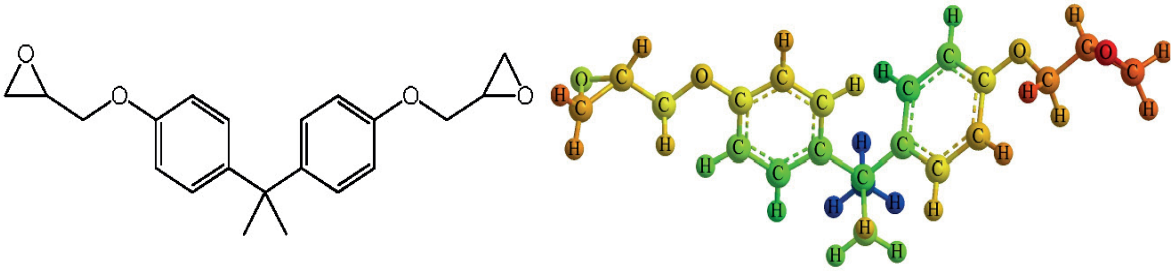


Figure 1 *Structural formula of the fragment of epoxy diane oligomer ED-20 [12]*

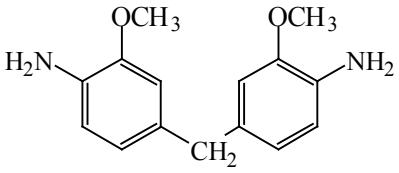


Figure 2 *General view of the chemical bonds of modifier 4.4'-methylenebis (2-methoxyaniline) (MDMA) [15]*

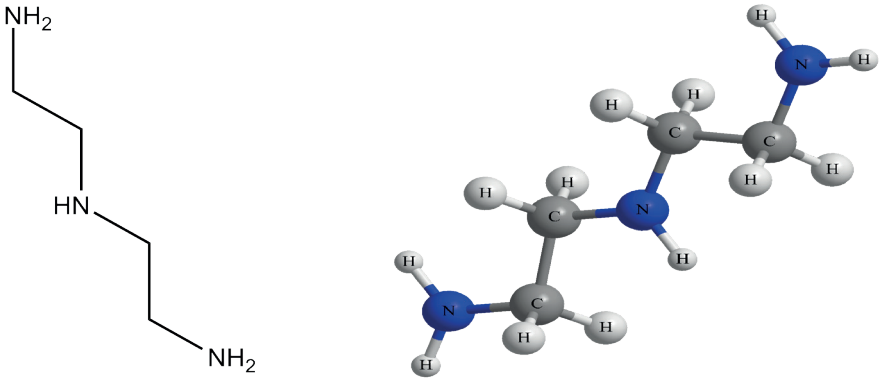


Figure 3 *Structural formula of the fragment of hardener PEPA [12]*

Table 1 *Characteristics of epoxy binder components [15]*

Characteristics	Epoxy oligomer ED-20	Modifier MDMA	Hardener PEPA
Molecular weight	390-430	258.3	230-250
The content of epoxy groups, [%]	20.0-22.5	-	-
The content of hydroxyl groups, [%]	1.25	-	-
Average functionality by epoxy groups, *fn*	2.0	-	-
Nitrogen content, [%]	-	10.84	19.5-22.0
Carbon content, [%]	-	69.74	-
Hydrogen content, [%]	-	7.02	-
Oxygen content, [%]	-	12.39	-
Toughness, η, [Pa s]	13-20	-	0.9
Density, ρ, [g/cm^3]	1.16	-	1.05

pointed in [15]. The characteristics of the epoxy diane oligomer, modifier and hardener are given in Table 1.

In the works [5, 12, 15], the main stages of the technology of forming and hardening of materials are given. Based on those studies, we were focused on the following. Epoxy composites were formed by the following technology: 1) heating of the resin up to the temperature T = 353 ± 2 K and exposure at this temperature during τ = 20 ± 0.1 min; 2) hydrodynamic combining of the oligomer and filler during τ = 1 ± 0.1 min; 3) ultrasonic processing (RCD) of the compositions during τ = 1.5 ± 0.1 min; 4) cooling the compositions to room temperature during τ = 60 ± 5 min; 5) introducing of the hardener and mixing of compositions during τ = 5 ± 0.1 min. Then the CM hardening was conducted under the experimentally determined mode: 1) formation of samples and their testing during τ = 12.0 ± 0.1 h at the temperature T = 293 ± 2 K; 2) heating with a rate of υ = 3 K/min up to the temperature T = 393 ± 2 K; 3) strengthening during τ = 2.0 ± 0.05 h; 4) slow cooling down to the temperature T = 293 ± 2 K. To stabilize the structural processes in the matrix, the samples were tested (strengthened) during τ = 24 h in the open air at the temperature T = 293 ± 2 K with further experimental testing.

In the studies [12, 15], the main methods of studying the mechanical properties of the materials are given. Those methods were taken as a principle in our work for the study of the following properties of CM: breaking stress and modulus of elasticity during bending, impact toughness.

Breaking stresses and modulus of elasticity in bending were determined in accordance with State standards GOST 4648-71 and GOST 9550-81 [16]. Sample parameters are the following: length l = 120 ± 2 mm, width b = 15 ± 0.5 mm, height h = 10 ± 0.5 mm [15].

According to State standard "GOST 4648-71" (ASTM D 790-03) the breaking stresses were determined as:

$$\sigma_3 = \frac{3F_{\max}L}{2bh^2}, \quad (1)$$

where ΔF_{max} - is the maximum load before breaking of the sample, N; L - is the distance between the props, mm; b - is a width, mm; h - is a thickness, mm.

According to the four-point bending loading scheme (GOST 9550-81) (ASTM D 790-03), the modulus elasticity was determined as:

$$E = \frac{0.185 \cdot L_v^3 \cdot \Delta F}{bh^3 \cdot \Delta z}, \quad (2)$$

where L_v - is the distance between props, mm; ΔF - is a load, N; b - is a width, mm; h - is a thickness, mm; Δz - is a deflection of the sample, mm [15].

Based on the method of research of impact viscosity of materials [5, 12, 15], in this study, the impact strength of CMs was measured by Charpy impact test without a notch (GOST 4647-80) [16] (ISO 179-1) by using a pendulum dill MK-30 at the temperature T = 298 ± 2 K and a relative humidity φ = 50 ± 5 %. The sizes of the samples are (65 × 12× 12) ± 0.5 mm. The distance between the props is 40 ± 0.5 mm. The impact strength of CMs was determined as:

$$W = \frac{A_n}{bs} \cdot 10^3, \quad (3)$$

where A_n - is the impact energy consumed for the fracture of the samples without notches; b - is a width, mm; s - is a thickness, mm.

Our study is based on the method of studying the strength of adhesive joints of materials to a metal substrate with uniform detachment and shear [12]. The scheme of sample formation for studying of the adhesive strength of composites in tearing and shearing is, respectively, shown in Figure 4 and Figure 5.

It should be noted, the diameter of the working part of the steel samples (St 3 grade) [17] during the tear-off and shearing was 25 ± 0.1 mm [12].

The study of adhesive strength in shear (Figure 5) was carried out similarly, measuring the tear-off force of adhesive joints of steel samples on the UM-5 automated tearing machine at the loading rate υ = 10 m/s.

Based on the method of studying materials by the method of optical microscopy [5, 12, 15], in this study,

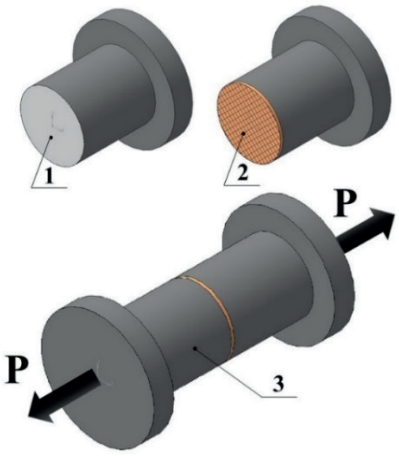


Figure 4. *The scheme of the sample formation for studying the adhesive strength of composites during the separation: 1 - the sample surface after cleaning (with the purpose of removing the oxide film) and degreasing; 2 - the sample surface after applying a uniform adhesive layer; 3 - adhesive samples that are subjected to the destructive load applied perpendicular to the plane of the contact surface contact*

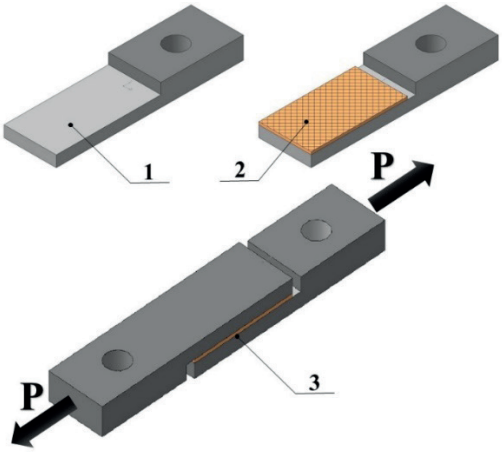


Figure 5. *The scheme of the sample formation for studying the adhesive strength of composites in shearing: 1 - the sample surface after cleaning (with the purpose of removing the oxide film) and degreasing; 2 - the sample surface after applying a uniform adhesive layer; 3 -adhesive samples subjected to a critical loading in the direction parallel to the plane of the contact surface*

the research of CM structure was also performed on XJL-17AT metallographic microscope, which is equipped with 130 UMD (1.3 Mega Pixels) camera. "Image Analyse" software was used for image processing.

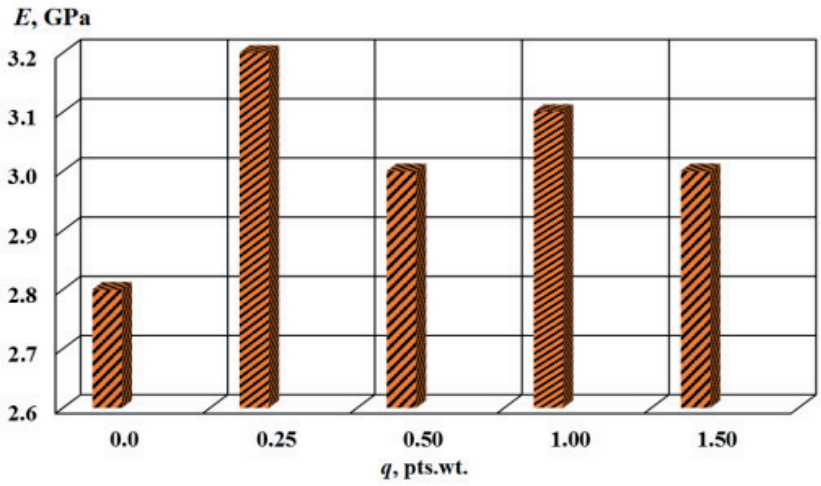
3 Discussion of the experimental results

To analyse the modifier impact on the cohesion properties of the matrix, the indicators of its physical and mechanical characteristics at different additive contents were investigated.

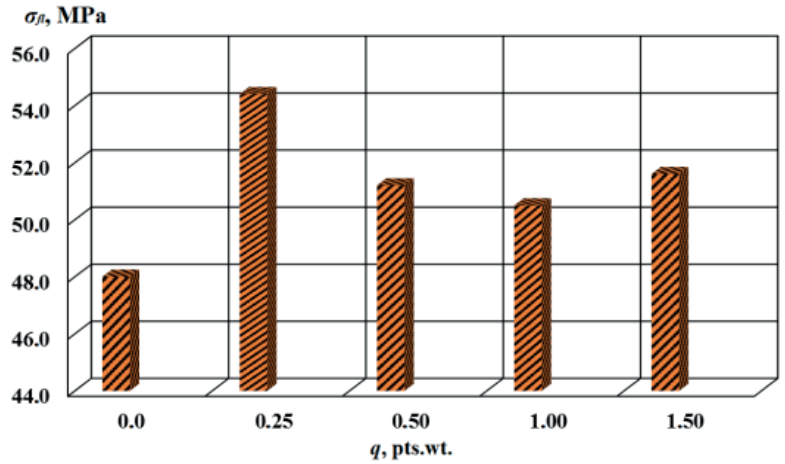
The physical and mechanical properties of the original epoxy matrix, modified by ultrasonic treatment, were previously experimentally established and represented in references [5, 15]. It is proved (Figure 6) that their characteristics are the following: modulus of elasticity in bending is E = 2.8 GPa; breaking stresses in bending is σ_{bn} = 48.0 MPa; impact strength is W = 7.4 kJ/m^2 [5, 15].

It is experimentally established (Figure 6a) that the introduction of the modifier at a low content (q = 0.25 pts. wt.) provides increasing of the CM modulus of elasticity from E = 2.8 GPa (for the original but ultrasonically modified epoxy matrix) to E = 3.2 GPa. These results of the study can be explained as follows [15].

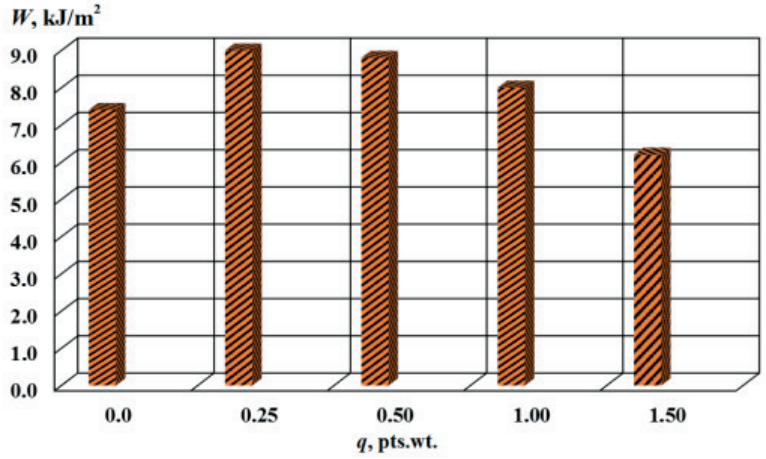
Firstly, it should be noted that the ultrasonic processing (US) of the compound was performed at the preliminary stage of the composition preparations (epoxy oligomer + modifier) after mixing of the ingredients. First of all, it provides uniform mixing of the components and degassing of the compositions. On the other hand, the formation of free radicals [14] was observed as a result of ultrasonic processing (US). In this case, free hydrogen ions and NH-, NH_2- or -CH-groups (in the modifier) and hydrogen ions and OH-groups (in the



a)



b)



c)

Figure 6 *Dependence of physico-mechanical properties and impact strength of epoxy matrix on the content of the modifier 4.4'-methylenebis (2-methoxyaniline): a - modulus of elasticity in bending (E); b - breaking stresses in bending (σ_{bn}); c -impact strength (W, kJ/m²)*

epoxy oligomer) are separated from both the modifier and the epoxy resin. Such ions and radicals are quite active in chemical interaction in crosslinking of epoxy compositions, which provides increasing of the modified matrix crosslinking degree.

Secondly, after ultrasonic processing (US), a significant percentage of macromolecules either of epoxy macromolecules or molecules of the modifier remain in the initial state. However, the presence of methyl CH_3-C, methylene - CH_2- groups and, especially, primary amines

- NH_2 in the structure of the additive provides the formation of additional chemical bonds with hydroxyl and epoxy side groups of the resin macromolecules.

Taking into account everything that has been already mentioned, including additional physical interaction of epoxy resin macromolecules either with each other or with the modifier, the authors considered that such a mechanism of structure formation of modified epoxy compositions is the most apprehended, and therefore it provides the improve of CM cohesive characteristics [18-22].

Increasing of the modifier content does not lead to the increase of the elastic modulus of epoxy matrix, which is confirmed by the study results given in Figure 6a. On the contrary, the introduction of additive in the range of 0.5 to 1.5 pts. wt. into the binder causes a decrease of the elastic modulus in the range of 2.9 to 3.1 pts. wt. in the whole investigated range of concentrations which indicates that the concentration of the modifier 0.25 pts. wt. for this investigated characteristic is critical, and its further increasing in the binder causes the incomplete crosslinking of the matrix during the polymerization. In our opinion, it is caused by the excessive number of molecules of the modifier in the compositions, so such materials are characterized by a high content of sol fraction that provides the decrease of physical and mechanical characteristics of the developed matrices.

The next stage of our research was focused on the study of the breaking stresses in CM bending dependence on the modifier content of MDMA. It was experimentally established (Figure 6b) that the introduction of additive with a low content (0.25 pts. wt.) into the binder provides the increase of the breaking stresses in bending of the modified matrix compared to the original one from σ_{bn} = 48.0 MPa to 54.4 MPa. Further MDMA introduction in the amount of 0.5 to 1.5 pts. wt. causes the deterioration of the composite cohesive properties, since the values of the breaking stresses are in the range of 50.5 to 51.6 MPa. According to the results of the study, the obtained properties are practically similar and are within the limits of the experiment deviation, and therefore further testing to improve the characteristics of the materials by increasing the content of the additive is not advisable. At the same time, it should be noted that the obtained data correlate with a similar dependence of the modulus of elasticity in bending on the modifier content (Figure 4), and the maximum values of E, at the same amount of introduced additive, were similarly revealed. Based on this, we can confirm the critical content of the modifier in the epoxy binder, which is 0.25 pts. wt. by 100 pts. wt. of epoxy oligomer ED-20.

The authors of [4, 12] defined that, from a practical point of view, the resistance of protective coatings to the impact is important during the operation of equipment under the dynamic loads. Based on this, the impact strength of the developed materials, depending on the content of MDMA modifier, was studied. As shown in Figure 6, c the maximum on the curve of dependence "impact strength - modifier content" was observed for the CM that contains MDMA in the amount of 0.25 pts. wt. For such a material, the impact strength increases from W = 7.4 kJ / m^2 to 9.0 kJ / m^2 in comparison with the original matrix. Further increasing of the modifier content from 0.5 pts. wt. to 1.5 pts. wt. causes a monotonic decreasing of the impact of the developed CM. The obtained data are correlated and coordinated well with the investigation results of the elastic modulus dependence and breaking stresses in bending that indicate the reliability of the obtained indicators based on the test results of the complex of physical and mechanical properties of the materials.

In addition, to confirm the abovementioned results of the physical and mechanical CM properties, the analysis of the surface of their fraction after testing on the pendulum dill by optical microscopy method was carried out. As shown in Figure 5a, the fracture surface of the sample based on the original epoxy matrix is heterogeneous. The crack propagation front is displaced during the impact loads that points out the presence of a stress state in the polymerized material.

The analysis of the image of the fracture of CM filled with the modifier in the amount of 0.25 pts. wt. (as shown in the Figure 7b) indicates the following: the trajectory of crack propagation during the impact is in a zigzag form. The formation of a high residual stress material can be established, on the one hand, as well as its increased cohesive properties on the other hand. That is, the sufficient number of physical and, especially, chemical bonds in the material resists the cracks propagation. As a result, the front of their distribution changes in the direction of the least resistance. Hence, it can be stated that the formation of a three-dimensional polymer net in the polymerization process with a high intermolecular distribution by volume implies a high degree of this CM crosslinking.

As shown in Figures 7c and 7d, the character of the fractures of the samples with CM filled with a modifier in the amount of 0.5 pts. wt. and 1.0 pts. wt. is approximately the same. The trajectory of the crack propagation is straight, but the area of CM destruction is slightly offset from the point of the impact at the final stage. That confirms the presence of the net with a sufficiently high degree of crosslinking and the density of physical and chemical bonds in CM, although it is not in the same amount as in the material of the modifier content of 0.25 pts. wt. It can be confirmed that such CMs have slightly lower cohesion strength. The obtained data are correlated well with the testing results of physical and mechanical properties of the materials. It is proved that the matrix with the modifier 0.25 pts. wt. is characterised by maximum values of the elastic modulus, breaking stresses in bending and impact strength.

Macroanalysis of the samples containing the modifier at the amount of 1.5 pts. wt. allows to state the following: the trajectory of crack propagation that

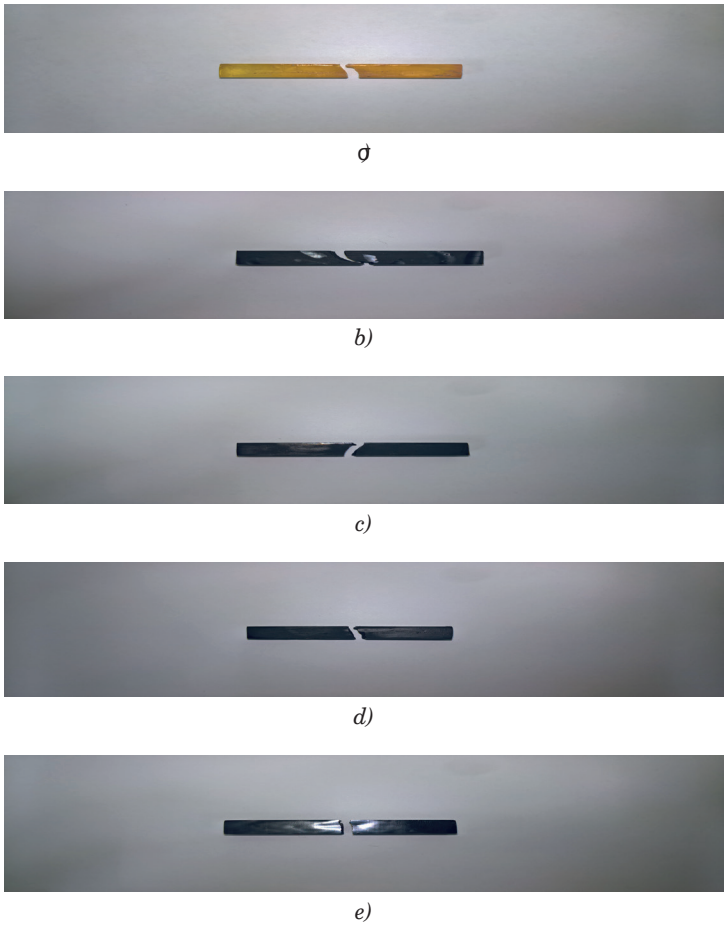


***Figure** 7 Micrographs of fracture of the original and modified 4.4'-methylene-bis (2-methoxyaniline) epoxy matrices (Range 1:2): a) the original epoxy matrix (control sample); b) q = 0.25 pts. wt. modifier; c) q = 0.50 pts. wt. modifier; d) q = 1.0 pts. wt. modifier; e) q = 1.50 pts. wt. modifier*

was perpendicular to the longitudinal axis of the sample (Figure 7e) was observed. We can state that there is a small intermolecular distribution of physical and chemical bonds in the volume of modified matrix on the one hand, and there is a significant content of sol fraction in the CM due to the excessive amount of the additive on the other hand. It is obvious that a net structure with an even distribution of the chemical bonds but with a low density in volume of the material is formed in these CMs that does not allow to provide sufficient resistance to fracture under shock loads.

Thus, it has been established that for the formation of materials with improved cohesion properties, it is necessary to use a binder of the following content: epoxy oligomer ED-20 (100 pts. wt.), hardener polyethylene polyamine PEPA (10 pts. wt.), 4.4'-methylenebis (2-methoxyaniline) modifier (0.25 pts. wt.). Formation of such a material provides a significant improvement of physical and mechanical properties in comparison to the original ultrasonically modified epoxy matrix.

Furthermore, the adhesive properties of the developed materials were investigated in this study. As shown in Figure 8, the strength of the adhesive joints is 24.8 MPa (the matrix is peeled), and it is 8.5 MPa (the matrix is sheared). Introduction of additives into the epoxy resin increases the strength of the adhesive joints of the samples (Figure 8). That is, the introduction of additives into the epoxy resin at a concentration of 0.1 to 0.2 pts. wt. provides an improvement in the strength of adhesive joints at the separation of CM from 24 MPa to 26.8 to 31.4 MPa. The subsequent increase in the concentration of the additive (up to 0.4 pts. wt.) ensures the deterioration of the strength of the adhesive joints of CM to 28.9 MPa. Further increasing in the amount of additive active to interphase interaction from 0.7 wt. h. up to 2 wt. h. causes decreasing in the adhesion of the protective coatings to the metal substrate. The value of the strength of the adhesive joints materials was observed to be 26.5 to 28.5 MPa.

Hence, it was pointed out that the maximum on the curve of dependence of adhesion on the concentration of the modifier (28.7 to 31.4 MPa) is in the range of additive concentrations of 0.2 to 0.6 wt. (Figure 8). At this concentration of additives, the physico-chemical processes of interphase interaction are improved. As a result, additional bonds are formed in the structural network of the polymer.

In addition, the effect of the modifier on the shear

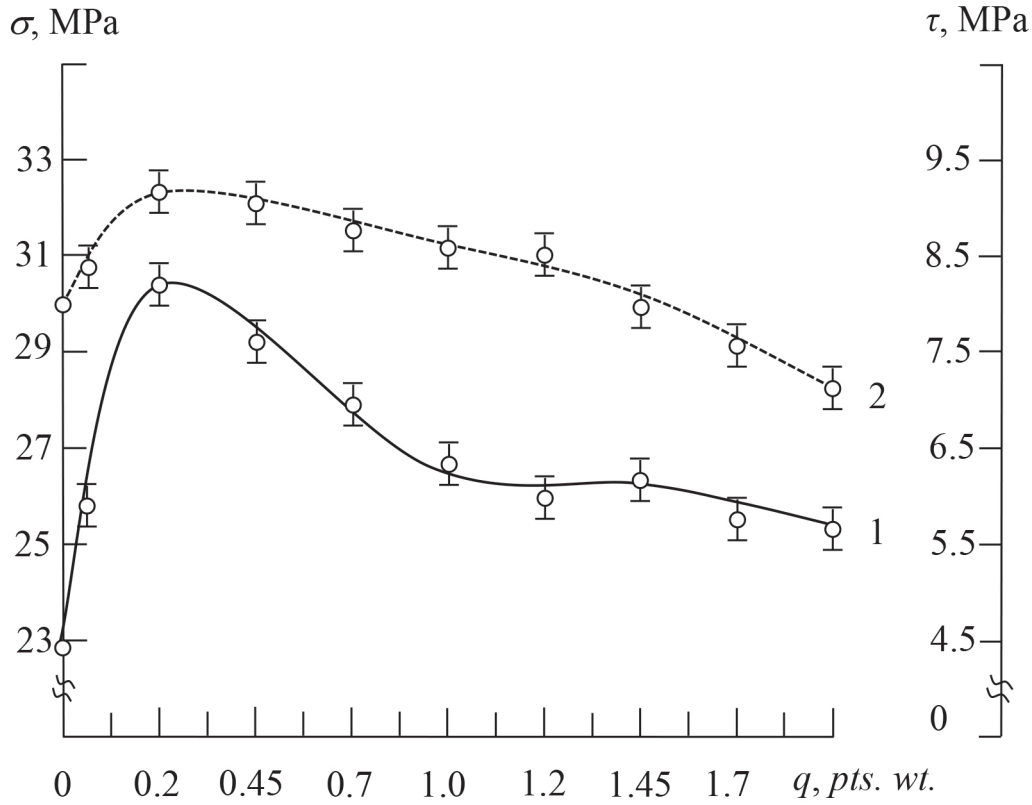


Figure 8 *The change of the strength of the CM adhesive joints depending on the additive concentration: 1 - peel strength of the adhesive joints (σ); 2 - shear strength of adhesive joints (τ)*

strength of adhesive joints was analyzed by authors.

It was established (Figure 8) that the presence of the additive concentration of 0.1 to 0.3 wt. provides increasing in the strength of adhesive joints from 8 MPa to 9 to 9.5 MPa. It shoud be noted that increasing of the additive concentration significantly worsens the strength of the adhesive joints at the materials shearing. Adhesion decreases from 9 MPa to 8 MPa (the amount of the additive is 2 pts. wt.). So, it must be admited that the highest strength of adhesive joints (9.2 to 9.5 MPa) was obtained for materials with an additive amount of 0.2 to 0.6 wt.

4 Conclusions

Based on the experimental analyses presented in this work, the following conclusions are drawn:

1. For formation of the materials with improved cohesion properties, it is necessary to use the composition with the following content: epoxy oligomer ED-20 (100 pts. wt.), PEPA hardener polyethylene polyamine (10 pts. wt.), and 4.4'-methylenebis (2-methoxyaniline) modifier (0.25 pts. wt.). Formation of such a material, in comparison to the original ultrasonically modified epoxy matrix, provides the increase of the following physical and mechanical properties:
   - ❑ modulus of elasticity in bending in the range of 2.8 GPa to 3.2 GPa;
   - ❑ breaking stresses in bending in the range of 48.0 MPa to 54.4 MPa;
   - ❑ impact strength in the range of 7.4 kJ/m^2 to 9.0 kJ/m^2.
2. The fracture surface of the original matrix is heterogeneous that is proved by optical microscopy technique. The crack propagation front is displaced during the shock loads that indicates the presence of a stress state in the polymerized material. After analysing the fracture image of the composite, filled with the modifier in the amount of 0.25 pts. wt., we point out that the crack propagation trajectory during the impact is of the zigzag form. We can confirm the formation of a material with high residual stresses, on the one hand, as well as increased cohesive properties on the other hand. That is, a sufficient number of physical and, especially, chemical bonds in the material resist the spread of cracks. As for the samples from the composites filled with the modifier in the amount of 0.5 pts. wt. and 1.0 pts. wt., it should be noted that the crack propagation trajectory is straight, but the area of materials destruction at the final stage is slightly shifted from the point of impact. That confirms the presence of net with a sufficiently high degree of crosslinking and the density of

physicochemical bonds in composites, although it is not in the same amount in comparison to the material of modifier content of 0.25 pts. wt.

3. In addition, the adhesive joints strength of the developed composites dependence on the amount of the additive has been investigated in the work. The required content of the modifier, the introduction of which provides the maximum strength iof the adhesive joints among all the studied materials, has been revealed. It has been substantiated that the additive concentration (0.2 to 0.6 pts. wt.) must be introduced into epoxy resin for formation of the materials with maximum adhesion. These materials have the following properties: peel strength of the adhesive joints 28 to 32 MPa, and shear strength of the adhesive joints - 9.1 to 9.7 MPa.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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IMPACT OF CONSUMER VALUE ON THE SELECTION OF A SAFE CHILD SEAT

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Resume

Unfortunately, nowadays, choosing the right child seat is a real problem, especially for new parents. When choosing a child seat, parents have to consider many factors. These include the method of mounting the seat, the mass of the seat, compatibility with a pram and information about crash tests and approvals. The main purpose of the article is to draw attention to the problem of choosing a safe child seat and the purchasing preferences of parents or legal guardians who decide to buy a child seat. For this purpose, a survey was conducted on a group of 950 people with children. The conducted research has shown that the main parameter influencing the choice of a child seat is the price for men and the social opinion and mass of the child seat for women. In addition, research has shown that most people decide to buy a child seat based on the installation system using a standard ISOFIX base.

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1 Introduction

Before the youngest vehicle users started traveling safely, vehicle seats had come a long way. The golden age of producers in this industry has only lasted for about 40 years. The first regulations for the safety of children in a vehicle were approved in 1971 in the USA. Previously, the constructors wanted to implement many ideas, but they did not always put the safety of the child in the first place. Today, it is the protection of the little passenger that is the most important. It took about a hundred years for baby seats to resemble today's vehicle seats. In 1907, Henry Ford launched a vehicle factory and it was the first drivers who tried to invent something that would effectively limit the movements of the youngest family members while traveling [1-3].

The prototypes of current vehicle seats certainly include a structure resembling a swing seat from the 1930s. The "child seat" of that time was mounted on handles to the rear seat and effectively limited the movements of a small passenger. Some models were even equipped with a steering wheel so that the child could feel like a real driver. Another interesting concept in the 1940s was the creation of a metal box in which a child would sit. Of course, there was no mention of seat belts yet, and the "seat" itself still did not increase safety while driving [2, 4-5].

The breakthrough came in the 1950s. Roger Grisswold designed the 3-point vehicle belt for the first time in the world. After a few years, they became standard equipment in every vehicle that left the factory [2, 6].

In 1964, Swedish professor Bertil Aldman discovered the protective effects of rear-facing vehicle seats after watching an American television program showing the location of astronauts in the Gemini space capsule. He designed the first rear-facing vehicle seat. Thanks to Aldman's research and the pressure of researcher Thomas Turbell, Sweden set a "T standard" that was so strict that it was almost impossible to get past a forward-facing vehicle seat. This started the tradition of transporting children in a rear-facing vehicle seat until the age of 4, which continues to this day. Thus, less than 10 years after the invention of the seat belt, the first prototypes of the current rear-facing vehicle seats - RWF - were created. Yes, the constructors already knew that such a setting would increase the safety of the passenger and, in accordance with the laws

of physics, reduce possible injuries in the event of an accident [7-9]

The first regulations regarding the safety of children transported in a vehicle were approved in the USA in the 1970s. The first designs of vehicle seats did not resemble those that are installed in modern vehicles. Their construction and appearance resembled a swing, which was attached to the backrest of the driver's or passenger's seat. After the three-point seat belts were patented, they began to be installed en masse, which also made them mandatory equipment in every vehicle. After about a decade, they were also fitted to vehicle seats [4-6].

The first safety tests were performed by the Swedes in the 1980s. Then the T-Standard was created. The tests involved the force of the body on the child's neck during a collision. The results of the tests allowed to refine vehicle seats and increase the safety of small passengers. The models designed at that time most resemble those currently used by children around the world [10-12].

However, this does not mean that manufacturers have stopped looking for new solutions, since already in the 90s, American and Canadian experts, after a decade of work, created Isofix - a system for quick and safe installation of vehicle seats for children. This modern system reached the old continent before 2000. It was implemented by the Britax Romer brand. With the passage of time, every company wanted to offer seats with the Isofix system, and the trend towards safety continues to this day [8-9, 12].

Over the years, the purpose of vehicle seats and their prototypes has changed. Their shape, materials used for production and range of functions have evolved. At first, their task was only to immobilize the child so that it would not disturb the driver and would not damage the vehicle. It was only later that the vehicle seat began to be used to protect the little passenger. The advantages of traveling in a rear-facing vehicle for children have been known almost since the first vehicles in the world were created. To this day, it is considered the safest position from birth to about 4 years of age. The Isofix system is still the most popular method of installing a vehicle seat in the vehicle [2, 6, 9].

Approval tests for child seats are focused on the assessment of protection against the harmful effects of collisions [13-15]. To this day, this type of research does not include the impact of vibrations on the body of a child transported in a child seat. It is worth paying attention to the fact that today's society is increasingly traveling with small children. A child seat is not used as an element of a passenger vehicle to transport a child in emergency situations, but is an element used every day. Vibrations transferred from the vehicle body to the seat of the child seat during long journeys have an impact on the child's body and have a negative impact on their health [7-8, 12].

Over the years, the amount of time spent in vehicles has increased drastically, which is why people are increasingly looking for more comfortable vehicles. Manufacturers of vehicle seats have become interested not only in the safety of the child seat, but also in its functionality and relative comfort (partly in vibration comfort and thermal comfort) [16-18]. Therefore, the quality of vehicle seats is very important for vehicle users. Vibrations while driving can cause many pathological symptoms of the digestive system, pain in the lumbosacral region and the cervical spine, kyphosis and lordosis of the spine, joint and muscle pain, vertigo symptoms (motion sickness), headaches [16, 19-20]. They can also contribute to the limitation of mobility, vision, free communication, weakening of memory processes and perception. The safest way for children to travel in vehicles is to transport them in vehicle seats that should be adjusted to both the mass and dimensions of the child. The dimensions of the vehicle seat are very important because the rapid anthropometric changes in body dimensions of young children require a good fit [17, 19-20].

Unfortunately, the vehicle seat classification system only refers to the age and mass of the child, not the dimensions. When designing child seats, the materials from which they are made play an important role. One of the innovations that improve the safety of products such as vehicle seats or baby carriers is the use of ultra-light, expanded polypropylene (EPP) [21-23].

Vehicle seats must meet stringent federal crash test regulations, which are also constantly evolving. Child seats also have an expiration date. Additionally, parents are taking safety product recalls seriously. These days, parents do extensive research on vehicle seat options. Many people take the extra step of having their vehicle seats checked for proper fit by a child safety technician. It should be noted that no one had heard of such a possibility to check the vehicle seat 25 years ago [24-26].

Road safety in the EU has improved over the last decade. The number of road accidents and fatalities in road accidents is decreasing [27-28]. Unfortunately, it should be noted that even the safest child seat, when it is poorly selected for a passenger car and poorly attached, will not fully protect the child.

2 Research methodology

The subject of the study was an analysis of the indications of purchase preferences of child seats made by parents or legal guardians. The results of the survey show the purchasing preferences of parents or legal guardians in the context of choosing a child seat. The aim of the research is to draw attention to the problem of choosing child seats and to draw attention to the purchasing preferences of child seats. The survey was carried out at the Department of Motor Vehicles and Transport at the Kielce University of Technology in

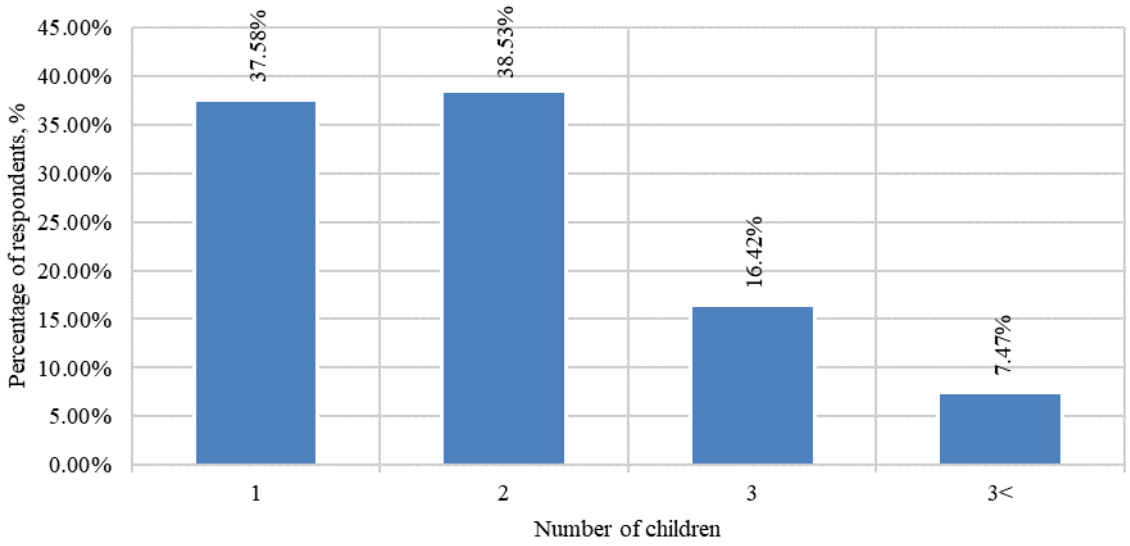

Figure 1 *Characteristics of the respondents in terms of how many children they have*

the period from October 1, 2020 to October 1, 2022. The survey was aimed at finding out the respondents' shopping preferences in terms of child seats.

The survey was created using the google survey form. The link assigned to the survey questionnaire was disseminated on social media and thematic forums on child seats. The survey was fully anonymous and consisted of closed-ended questions. Before entering the survey, respondents accepted voluntary participation in the survey and were then asked to indicate whether they had children. If the respondent did not have children, he or she could not take part in the further study procedure. At the beginning of the form, respondents were asked to indicate their gender, age, place of residence and the number of children they had. They could then move on to questions about their purchasing preferences for child seats. A total of 1752 interested people took part in the study. It should be noted that as many as 802 respondents did not have children, so they did not participate in the questions regarding their purchasing preferences for child seats. The study involved 950 respondents with children. Respondents were diverse in terms of gender and age. 521 women (55% of all respondents) and 429 men (45% of all respondents) participated in the study.

3 Survey research

According to the data of the Central Statistical Office, in 2022, 305,000 children were born in Poland. This result is lower by 26.5 thousand children as compared to 2021. A total of 1,367,300 were born in Poland in the last 4 years. Each of these children will need a child seat so that they can travel safely in a passenger vehicle. One will need a carrier-type child seat, which is designed for newborns, in addition, after about 12 months, the child will have to change from a carrier-type seat to a child seat for children from 12 kg to 36 kg. Each of the newborn children must be transported rear-facing. Manufacturers of child seats for infants and newborns, when designing the seat, do not allow it to be installed facing the direction of travel. This is mainly due to the provisions of Polish law, which clearly state that in vehicle seats designed for a mass of 0-13 kg, children can only be transported rear-facing. This applies to children up to about 15 months of age. In the case of older seats, if the seat is mounted on the ISOFIX base, they have the option of transporting the child rear-facing. Specialists agree that if a toddler can still drive rear-facing, a forward-facing FWF vehicle seat should appear in our vehicle as late as possible. The forces acting on a child's body during a collision or collision are extremely strong. Specialized tests confirm that RWF vehicle seats protect children better, and traveling rear-facing is much safer than when we have a forward-facing vehicle seat.

Only people with at least one child participated in the study. The respondents are diverse in terms of age, the survey involved 487 people aged 18 to 25, 275 people aged 26 to 35, 112 people aged 36 to 45, 55 people aged 46 to 60 years of age and 21 persons over 60 years of age. Figure 2 shows the characteristics of the respondents in terms of age. The largest group of respondents were people with 2 children (38.53 %). Moreover, 37.58 % of the respondents had one child, 16.42 % of the respondents had three children. Only 7.47 % of the respondents had more than three children. The characteristics of the respondents in terms of children they have is presented in Figure 1.

In the next question, respondents were asked about the frequency of travel of a child in a child seat. This question uses a 5-point Likert scale. The respondents' answers are presented in Figure 2. The frequency of

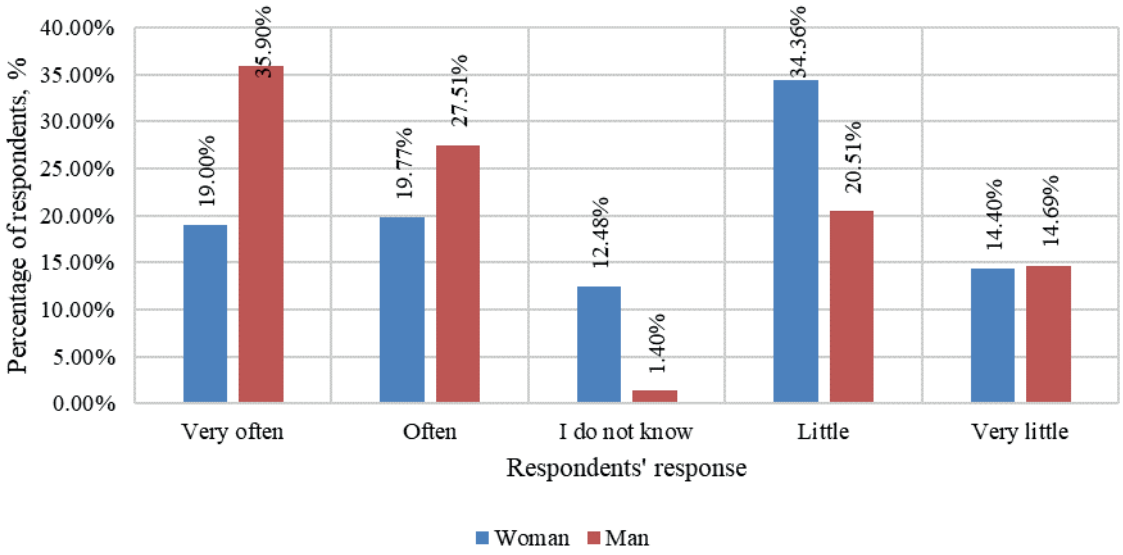

Figure 2 *Frequency of travel of a child in a child seat with one parent driving the vehicle*

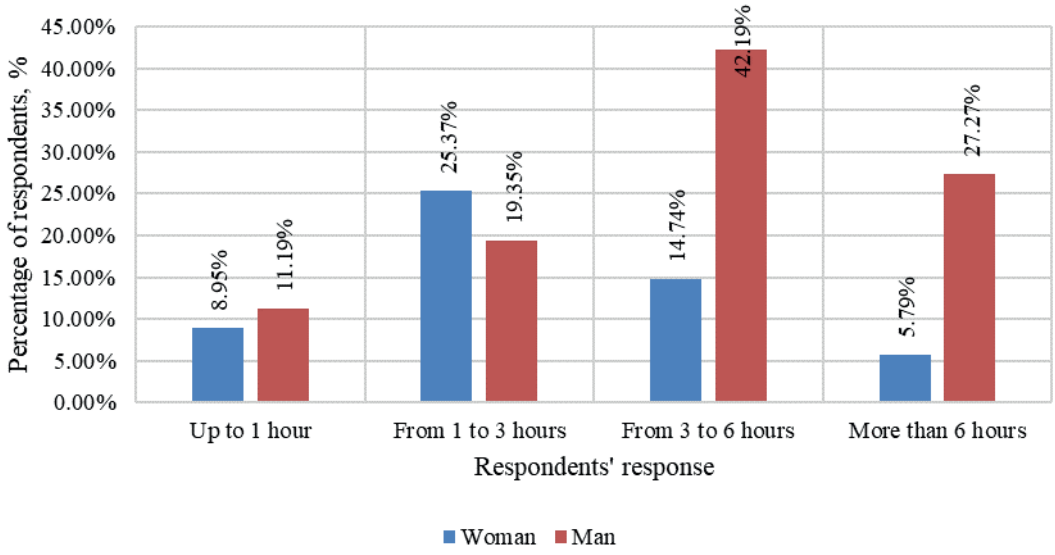

Figure 3 *Total time of transporting a child during the week*

children traveling in child seats is very diverse in terms of the respondents' gender. It should be noted that 19% of women and 35.90% of men travel with a child very often, and 19.77% of women and 27.51% of men travel often with a child. A different opinion is held by 14.40% of women and 14.69% of men who travel very little with a child, and 34.36% of women and 20.51% of men who travel a little with a child. At the same time, it should be noted that as many as 12.48% of women did not give a clear decision. The survey results suggest that men are more likely to travel with children than women. This may be due to the fact that men drive more often than women.

In the next question, respondents were asked about the average travel time of a child in a vehicle seat. The respondents' answers are presented in Figure 3. It should be noted that men travel with a child longer than women during the weeks. The data shows that during the week only 14.74% of women travel together with a child placed in a vehicle seat for 3 to 6 hours, compared to 42.19% of men. In addition, in the case of the total time of transporting a child in a child seat over 6 hours during the week, there are more men (27.27% of men and 5.79% of women). In the case of persons transporting a child between 1 and 3 hours per week, there are more women.

Respondents were asked in the next question about the type of fastening of the child seat currently in the respondent's vehicle. The answer to this question is presented in Figure 4. 27.26% of the surveyed women and 23.08% of the surveyed men have a vehicle seat fastened with standard seat belts. A child seat with an ISOFIX base is used by 41.65% of the surveyed women and 55.48% of the surveyed men. It is worth noting that

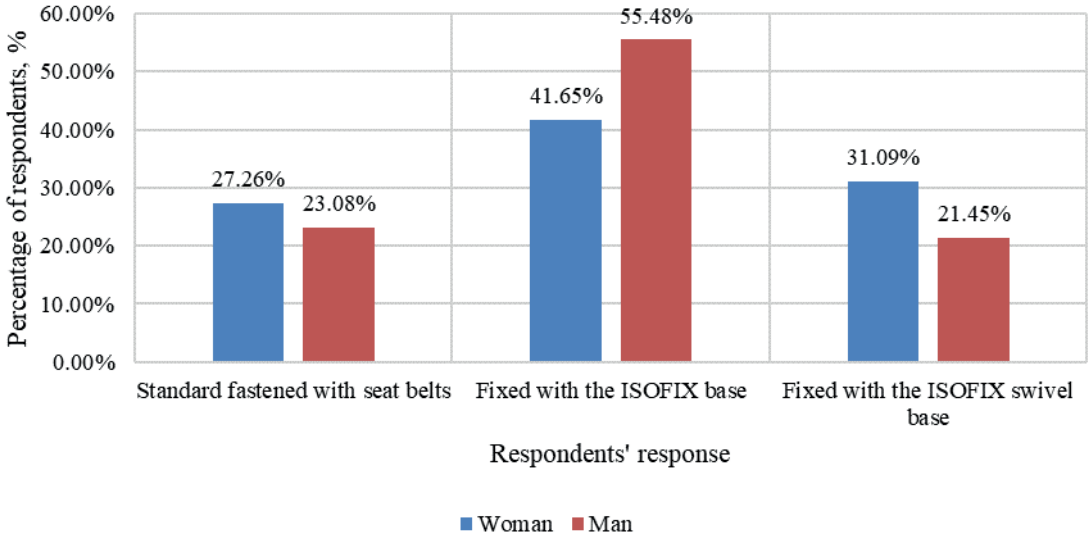

Figure 4 *Type of child seat attachment*

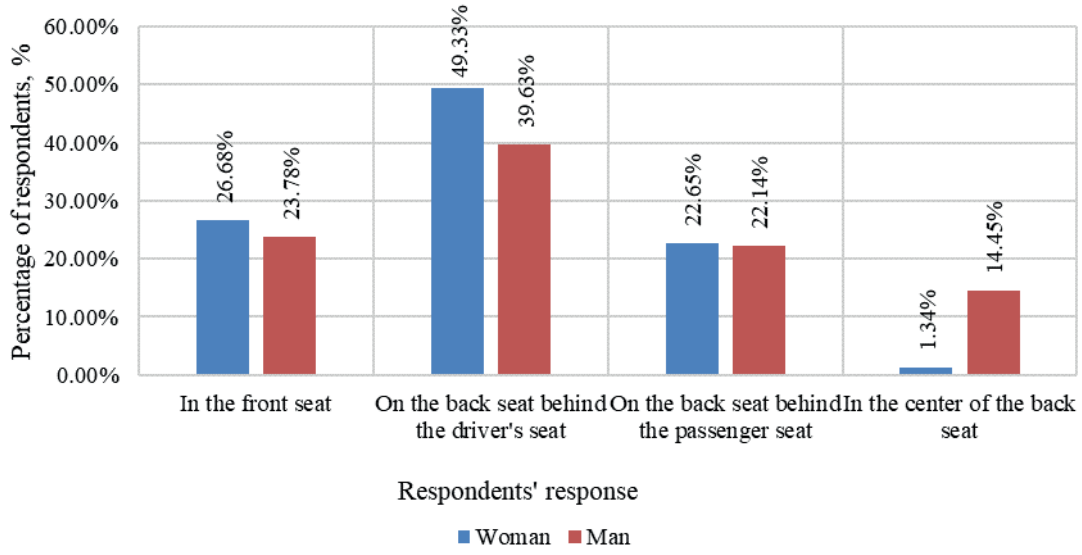

Figure 5 *Place of mounting a child seat*

a vehicle seat with an ISOFIX swivel base is used by 31.09 % of women and 21.45 % of men. At the same time, it can be seen that the most popular type of child seat mounting is the ISOFIX base and the ISOFIX swivel base.

In the next question, the respondents were asked to indicate the place of fixing the child seat in a passenger vehicle. The answer to this question is presented in Figure 5. It should be noted that as many as 26.68 % of the surveyed women and 23.78 % of the surveyed men have a child seat mounted on the front seat. 49.33 % of the surveyed women and 39.63 % of the surveyed men have a vehicle seat installed on the back seat of a passenger vehicle behind the driver's seat. As many as 22.65 % of the surveyed women and 22.14 % of the surveyed men have a child seat installed on the back seat of a passenger vehicle behind the passenger seat. Only 1.34 % of the surveyed women and 14.45 % of the surveyed men have a child seat installed on the rear seat of a passenger vehicle in a central position.

In the next question, the respondents indicated their own shopping preferences for a child seat. The characteristics of the respondents' shopping preferences are presented in Figure 6. Undoubtedly, it should be noted that choosing the right vehicle seat is a difficult decision for parents and legal guardians. A lot of information presented by sellers, manufacturers of child seats, scientists, can be contradictory. In addition, the lack of awareness of parents about crash tests, materials used, and how to install a child seat can lead to wrong decisions. The collected survey data show that 78.55 % of men and 41.07 % of women, when choosing a child seat, are guided by its price. The mass of the child seat is suggested by 52.39 % of women and 37.06 % of men;

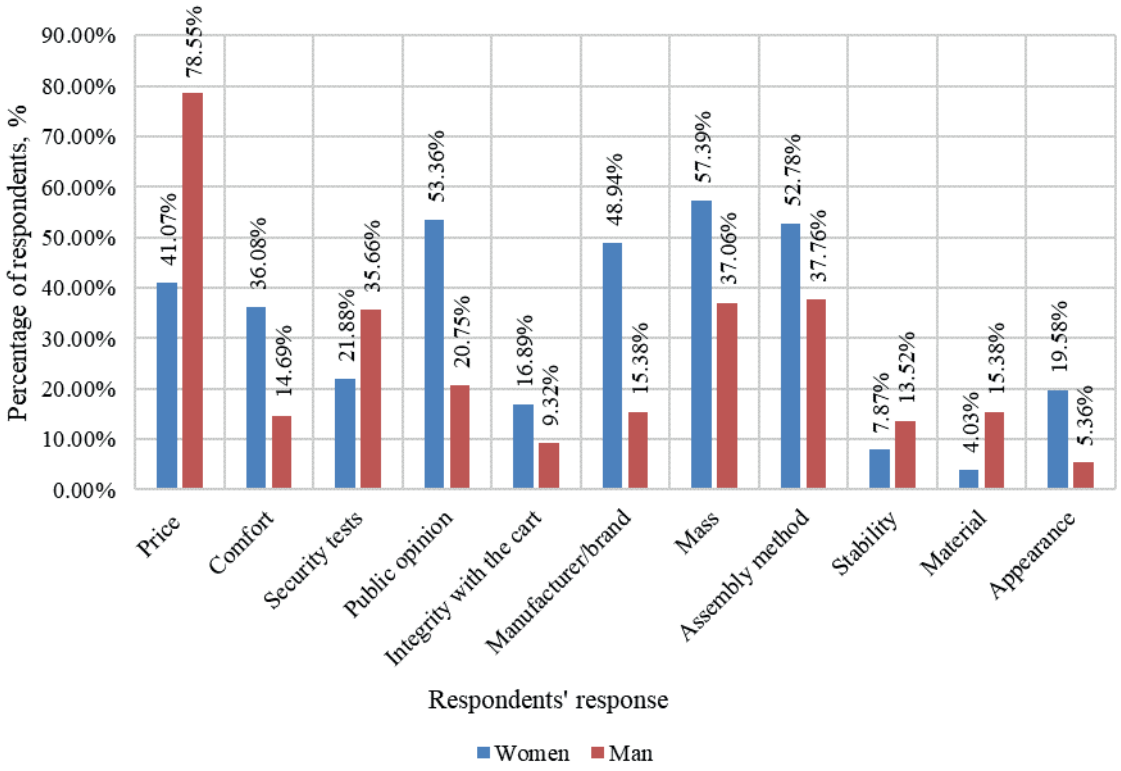

Figure 6 *Characteristics of respondents' shopping preferences*

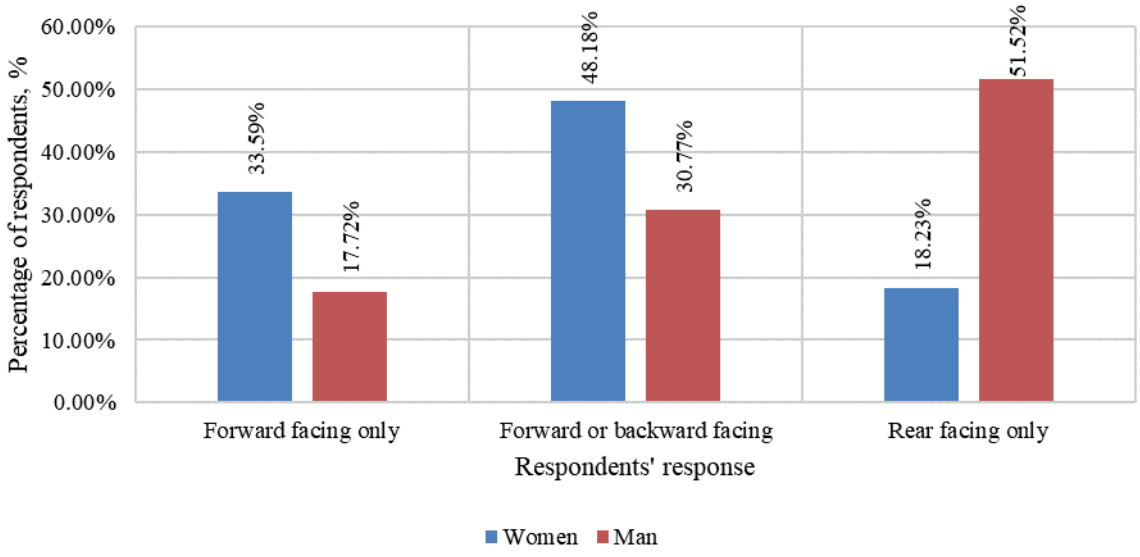

Figure 7 *Possibility of a child seat in the direction of transporting a child*

52.78% of women and 37.76% of men are interested in the method of installing a vehicle seat in a passenger vehicle. The public opinion on the child seat is suggested by 53.36% of women and 20.75% of men. Only 21.88% of women and 35.66% of men are interested in crash tests of a child seat. Undoubtedly, it should be noted that when choosing a child seat, men pay more attention to the price, crash tests, stability of the seat after assembly and the materials used. On the other hand, women are more likely to pay attention to the comfort of the child in the child seat, public opinion, integration of the child seat with the stroller, the brand of the child seat, the mass of the child seat, the method of assembly and the overall appearance.

In one of the questions, the respondents were asked to specify the possibility of transporting a child in their child seat according to the direction of travel. The answer to this question is presented in Figure 7. It should be noted that 33.59% of surveyed women and 17.72% of surveyed men have the option of transporting a child in a child seat only facing the direction of travel. Only rearward facing 48.18% of surveyed women and

30.77% of surveyed men. At the same time, it should be noted that 51.52% of the surveyed men and 18.23% of the surveyed women have a child seat that can transport a child both rearward and forward facing.

In the next question, the respondents were asked "Did the seller offer to try the vehicle seat on when buying the vehicle seat". The respondents' answers to this question are presented in Figure 8. It should be noted that as many as 39.35% of the surveyed women and 14.92% of the surveyed men, when purchasing a child seat, had the opportunity to try the seat directly on a passenger vehicle. Moreover, 10.56% of women and 16.32% of men declare that they probably had such a possibility. Lack of such possibility is declared by 17.66% of women and 8.16% of men. In addition, as many as 30.90% of women and 55.01% of men declare that they did not have such a possibility. The collected data shows that very few people try on a child seat in their vehicle before making a purchase.

In the next question, the respondents were asked to indicate the presence or absence of a system that monitors the correct installation of a child seat. The respondents' answers to this question are presented in Figure 9. It should be noted that 48.18% of the surveyed women and 21.21% of the surveyed men declare that such a system is present in their child seats. In addition, 19.39% of women and 27.97% of men declare that such a system is rather present in their purchased child seat; 20.15% of women and 31.70% of men probably do not have such a system in the purchased vehicle seat. Certainly, there is no such system in the purchased child seat by 10.56% of women and 16.32% of men.

In the last question, respondents were asked to indicate the frequency of crying of a child in a child seat. The respondents' answer to this question is presented in Figure 10. It should be noted that an incorrectly selected vehicle seat may be the cause of frequent crying of a child when traveling in a child seat. However, these reasons may be more and may be related to incorrect installation of the seat, the place of attachment or the method of attachment. The collected data show that the child usually always cries in the child seat

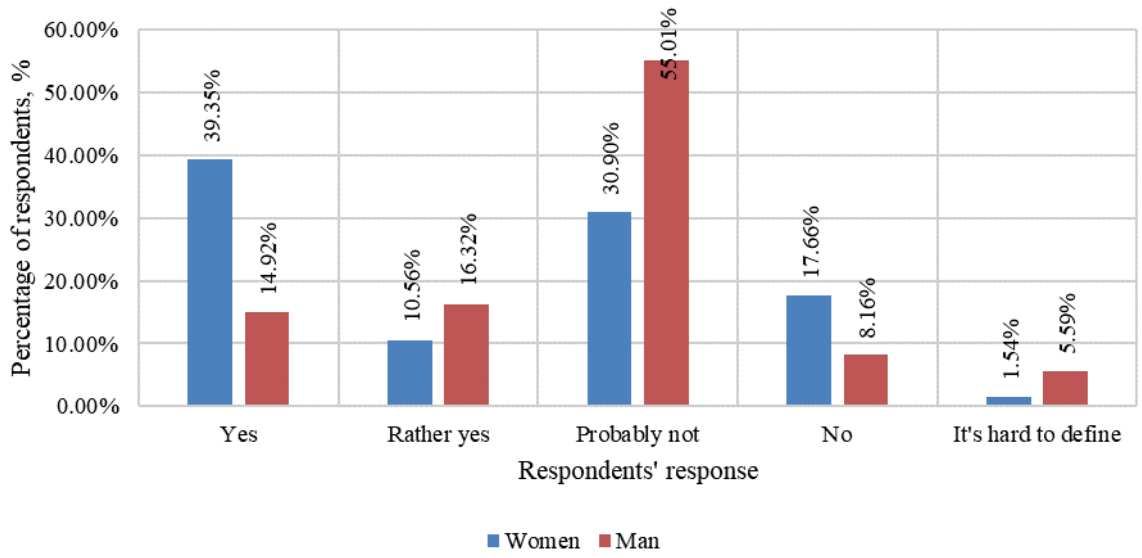

Figure 8 *Possibility of trying on a child seat before buying it for a passenger vehicle*

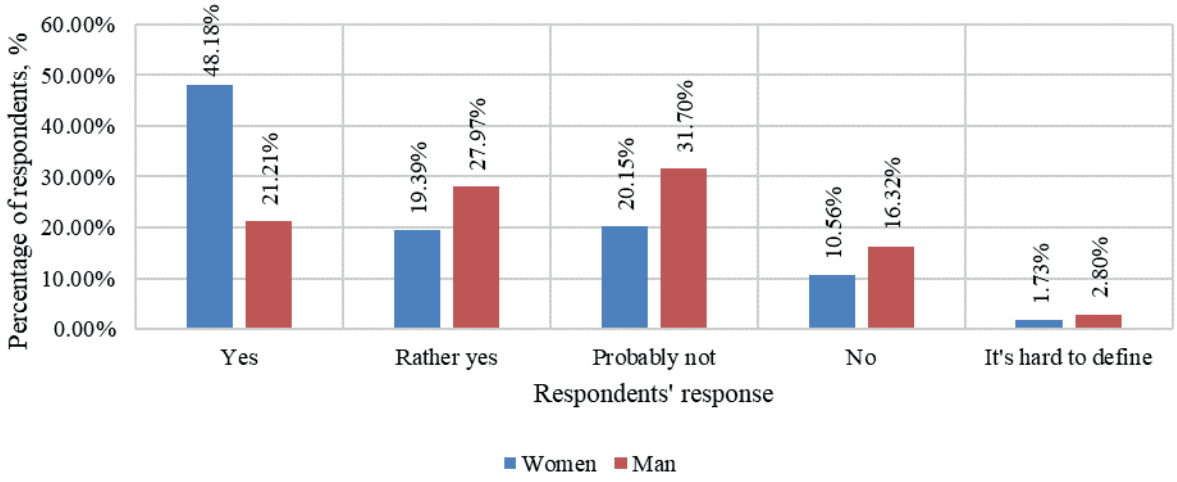

Figure 9 *Possibility of a system informing about the correct installation of a child seat*

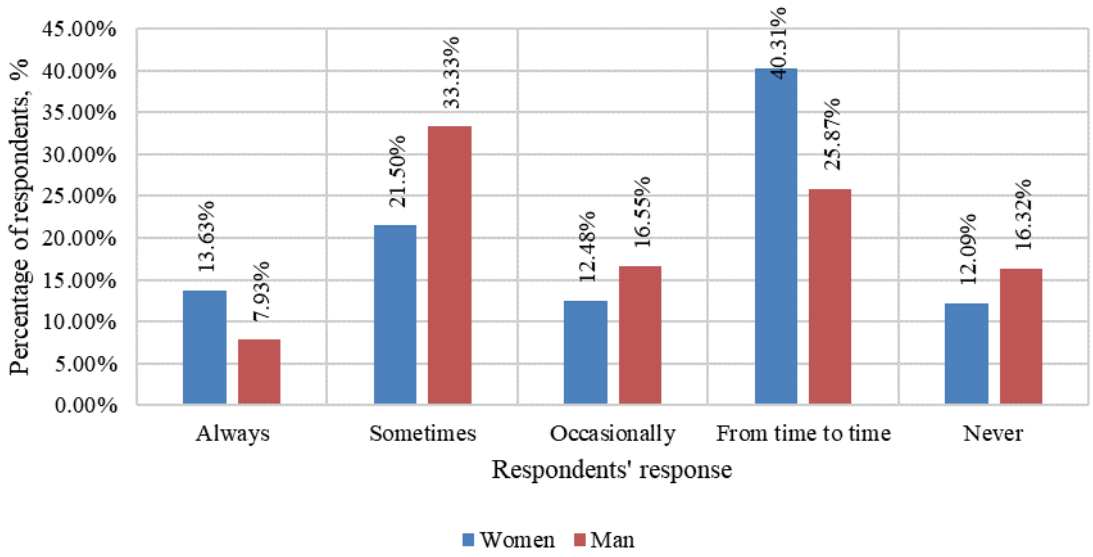

Figure 10 *Crying frequency of a child placed in a child seat during a vehicle journey*

during the journey in 13.63% of surveyed women and 7.93% of surveyed men. In addition, crying of a baby is sometimes declared by 21.50% of women and 33.33% of men. Occasional baby crying is declared by 12.48% of surveyed women and 16.55% of surveyed men. Crying of a baby occurring from time to time while traveling is declared by 40.31% of the surveyed women and 25.87% of the surveyed men. Total lack of crying is declared by 12.09% of surveyed women and 16.32% of surveyed men.

4 Discussion

Many parents wonder which vehicle seat to choose for their child. Choosing the right vehicle seat model is very important. After all, it is an accessory that keeps child safe during everyday vehicle journeys. Different models of vehicle seats are available in stores, which does not make it easier to make the right purchase decision. There is a lack of scientific publications in the scientific literature informing what aspects should be paid attention to when choosing a child seat, as well as how the process of selecting and installing a child seat in a passenger car should be carried out. In scientific articles, we can find a division of child seats according to categories and the method of installation. In the articles [4, 16, 19] the authors were focused on the vibrational comfort preferences of a child transported in a child seat. The results of the study confirmed that the child is more uncomfortable when travelling when transported in a child seat placed on an ISOFIX base. The survey showed that 27.26% of the surveyed women and 23.08% of the surveyed men transport their children in a child seat installed with standard seat belts.

Based on the results of a survey conducted on a group of 900 respondents, the author [29] presented that more than 80% of respondents pay special attention to the safety certificates of the child seat when making purchasing decisions about a child seat. Unfortunately, our own research has shown that over the last 3 years, parents' shopping preferences have changed significantly. Our own research has shown that the main feature determining the purchase of a child seat is the price, while 21.88% of women and 35.66% of men pay attention to the safety certificates of child seats. At the same time, it should be noted that our own research has shown that men pay attention to the technical aspects of child seats more often than women.

In the articles [17, 25], the authors discuss the topic of installing a child seat in a passenger car before buying. It should be noted that this option can only be available to people who buy a car seat in a stationary store. In addition, not every brick-and-mortar store will offer such a service. Surveys showed that only 39.35% of the women surveyed and 14.92% of the men surveyed had the opportunity to try the seat directly on a passenger car when buying a child seat. In addition, it should be noted that most manufacturers of child seats recommend that before buying a child seat, try it on a passenger car in order to check whether it will fit the back seat of a passenger car. Despite the fact that manufacturers treat such an activity before buying, most buyers do not have such a possibility, because most often sellers do not offer such a service. Most often, they only allow the installation of a child seat on a specially prepared viewing stand in a stationary store.

Manufacturers of child seats, on the other hand, often point out the advantages of their own child seats. To this end, they focus the buyer's attention on additional aspects such as seat belt applications or the use of magnets in the seat belts to make it easier to fasten the child [8, 13]. Unfortunately, additional things added to a child seat distract buyers from the basic function that a child seat is supposed to fulfil. The seat

is to ensure maximum safety for the child, so the most important issue for the buyer should be the results of the crash tests of the child seat and the materials used in the child seat, taking into account the aspect of the child's comfort in the child seat.

The problem of parents and legal guardians with choosing the right child seat for their car is visible on various forums and online groups. Unfortunately, public opinions most often concern the usability of a child seat, its compatibility with a stroller or its weight. Unfortunately, the safety aspect of a child seat is often overlooked. The priority is given to the price, accessories to the seat and its brand, while what is most important, i.e., the level of safety, is the secondary element among the surveyed respondents.

5 Conclusions

The article draws attention to the problem of choosing a child seat and the purchasing preferences of child seats. In addition, the surveys showed differences in the purchasing preferences of child seats between men and women. Men are more likely than women to pay attention to the technical aspects of child seats, such as the method of installation and crash test certificates, while women are more likely to be influenced by public opinion, brand and weight of the seat when buying a child seat.

The results of the research showed that the most common factor determining the choice of a child seat was the price. Other important factors influencing the shopping preferences of the respondents were the mass of the child seat and the method of its assembly. Based on the collected data, it should be noted that parameters such as safety certificates or the level of comfort (including vibration comfort) are important only for almost 30 % of buyers of child seats. The collected data from the survey showed existing differences in shopping preferences for child seats that depend on the gender of the parents or legal guardians of children. Studies show that men pay most attention to the price of child seats, and women more often than men suggest social opinion, the mass of the vehicle seat or compatibility with a pram. However, only 21.88 % of women and 35.66 % of men pay attention to crash tests of child seats. Unfortunately, in the case of children, this parameter should be considered more often because, above all, the child seat is designed to protect the child during a possible collision.

Survey studies show a problem in the society of adults with a child resulting from the lack of information about the safety of children in a child seat. Price should not be the main criterion when choosing a child seat. A dangerous situation is the small percentage of people looking at the safety certificates of child seats. In addition, it should be noted that the correct choice of a child seat should be based on the comfort of the child. A vehicle seat that is not adapted to the dimensions and size of the child will not fulfil its function. In addition, the child in such a seat will feel uncomfortable, which may cause the child's reluctance to transport. In further works, the authors will pay attention to the selection of a vehicle seat for a passenger vehicle and the types of crash tests that determine the safety level of a child seat.

Undoubtedly, the authors believe that the safety of transported children should be a priority when transporting them. Therefore, to ensure the safety of transported children, one must first select the child seat correctly and then install it correctly. In further works related to child seats, the authors will present the scope of activities necessary for the parent to purchase a properly selected and safe child seat.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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PREDICTIVE ASSESSMENT OF BUS BODY LIFE IN THE MATLAB SIMULINK SOFTWARE ENVIRONMENT

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Resume

The lifespan prediction of the bus body of the load-bearing structure has been made and compared to the results of real operation. The maximum approximation of the simulation modelling results in Matlab Simulink to real operation is explained by taking into account a sufficient number of factors influencing durability. This research has the particularity that it allows determining the durability of the bus body even at the design stage, which was not possible with accelerated tests or during the operation of the bus on real routes. The obtained results can be used by bus manufacturers at the design stage, allowing them to change the construction and technology of anticorrosion protection, thereby influencing the durability. In addition, operating organizations will be interested in the obtained results when using the developed methodology in various operating conditions.

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1 Introduction

Usually, to determine the durability of a bus body, accelerated durability tests are carried out on routes that can be as close as possible to real operating conditions. Given that the durability of the bus body can reach 1 million km, such durability tests require significant time and costs. Therefore, bus factories may neglect such resource tests, referring to the durability of previous similar models of buses. As a result, the bus begins operation, during which the durability of buses of this model can be tracked for 5-10 years. However, over such a long period, the results of durability tests may become irrelevant. Moreover, it is impossible to accurately track the roads on which these buses were operated, as well as with what loads (overloads) of passengers the buses were moving on those roads. During the development of new bus models for manufacturers, it is important to know how certain materials in combination with anti-corrosion protection technologies will affect its durability. By predicting the durability of a bus when using various structural materials, manufacturing technologies, and anti-corrosion protection of the body, it is possible to influence the durability of the body at the design stage.

Today, it has become possible to conduct durability testing of buses using simulation modelling methods, due to the development of modern applications. One such program is the Matlab Simulink software environment (USA). Matlab Simulink allows for the simultaneous solution of systems of differential equations. In this process, the spectral density of the road microprofile is transformed into real deviations of the microprofile, and stresses are formed in the investigated cross-section at the output in the form of spectral density, which allows calculating the body's durability using known

dependencies.

Scientific research on this topic is important because it becomes possible to conduct simulation modelling countless times, taking into account various operating conditions, body materials, and anti-corrosion protection technologies.

The results of such research are necessary for practice, as they open up new opportunities in designing bus bodies with the influence of new design solutions on its durability even at the design stage without significant costs.

Thus, prognostic evaluation in the Matlab Simulink software environment will allow for improving the design of bus bodies by influencing the body's lifespan already at the design stage. Additionally, operating organizations can forecast the lifespan depending on operating conditions and predict when it is advisable to perform restorative repairs on the body at a particular mileage in the future.

The work [1] presents a mathematical model for predicting the service life of bus bodies. It is shown that when tested for adequacy, the model has a right to exist. However, there are unresolved issues related to the absence of a description of suspension punctures in the model, which often occur when driving on low-quality roads. The reason for this may be the lack of classical calculation methods in the "road-vehicle" systems, which would allow for a more realistic description of the movement of buses on roads with potholes. One way to overcome these difficulties may be to take into account the suspension punctures by applying new dependencies. Such an approach is used in work [2], which maximally approximates the movement of a bus on low-quality roads (low-quality pavement), but does not directly take into account suspension punctures. The work [2] also investigates the durability of non-bearing bus structures, but similar research on frame-type buses is not performed. One way to overcome such difficulties may be to study the durability of the frame-type buses, as well. Such an approach is used in work [3]. However, here only compliance with UN Rule No. 66 on passive safety is checked during the operation of frame-type bus bodies. The authors [4] suggest using calculation methods with the use of simulation modelling instead of natural experiments when checking compliance with the Rule [5] for buses. However, in work [4], the research only concerns new buses without taking into account the degradation of the bus body material. In work [4], confirmation of the use of simulation modelling is important, which significantly simplifies the work and reduces the cost of conducting an experiment. Work [6] describes methods for studying the transmission of disturbances from the micro-profile of the road surface to the body of a new car. However, here again, the deterioration of the properties of the body material during the operation is not taken into account. Further development of work [6] may be the consideration of the degradation of car body elements. The article [7] describes methods for studying the road surfaces, which can be used to investigate the influence of road micro-profile on the bus body.

The paper [8] explains how corrosion processes in bus bodies increase losses during the passenger transportation. Therefore, when making a predictive assessment of bus bodies, it is also important to take into account the corrosion processes during the operation of public transport buses.

The methodology for determining the passenger load [9] can be useful in predicting the number of passengers during the bus operation. Such an approach [9] will allow for more realistic research on the durability of public transport buses.

As a result of the analysis of studies [10-14], it was found that accelerated durability tests were conducted using laboratory stands. However, such studies did not take into account the corrosive processes that have a significant impact on the durability of the bus.

All of this allows us to assert that it is expedient to conduct research dedicated to the predictive assessment of the bus body durability using simulation modelling.

The aim of the research was to make a prognostic assessment of the bus body durability using Matlab Simulink software. This will allow predicting the durability of the body through simulation modelling without conducting long-term, high-cost durability tests on buses in real operation.

The following tasks were set to achieve the goal:

- develop a methodology for prognostic assessment of the body structure durability of a bus with a non-bearing and frame structure;
- implement the developed methodology in Matlab Simulink software, taking into account suspension failures;
- conduct simulated modelling of the durability of non-bearing and frame structure bus bodies and compare them.

2 Materials and methods

The object of the research was the permissible limits of aging of bus bodies during operation and the possibility of forming recommendations for bodybuilding design under the conditions of regulated body durability.

The main hypothesis of the study is that simulation modelling using modern applications allows for forecasting the resource of bus bodies through the mathematical description of the impact of road micro-profile, passenger load, speed, and corrosion on the body.

The assumptions adopted in the study indicate that the bus body's durability is influenced by corrosion and road microprofile impacts combined with passenger loading and bus speed. The punctures in the suspension, which inevitably occur when driving on low-quality roads, overloading, and increased bus speed, also play an important role in simulation modelling.

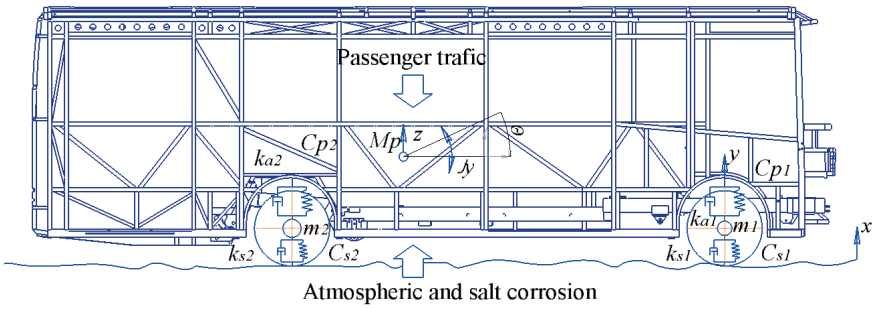

Figure 1 *Calculation scheme*

The simplifications adopted in the study involve the use of simulation modelling instead of conducting the long and high-cost durability tests on buses.

To conduct the prognostic assessment of the bus body durability, the Matlab Simulink 2017b software environment (USA) [15] was chosen. Matlab [15] is a high-level programming language designed for engineers and scientists that directly expresses matrix and array mathematics. Matlab can be used for everything, from performing simple interactive commands to developing large-scale applications. Thus, Matlab Simulink allows solving the tasks related to determining the durability of the bus body, taking into account the selected factors.

The predictive assessment methodology of the bus body durability of the non-load bearing and frame structure is implemented as follows. The durability of the bus body and frame is influenced by a number of factors. The main ones include micro-profile of the road, passenger loading, bus speed, and corrosion. Passenger loading is selected within the limits corresponding to operating conditions, taking into account possible overloads. That is, the minimum number will correspond to the number of passengers occupying all the seats. The maximum number of passengers will correspond to the number corresponding to one and a half times the overload. It should be noted that in the design practice of developing the bus bodies, an overload factor equal to 1.7 is assumed. Bumps from micro-profile irregularities on the road are transmitted through the bus wheels and suspension to the frame and/or bus body. The strength of shocks from the road will increase as the speed of the bus increases and deviations from the micro-profile of the road increase. For buses on a frame chassis, forces are transmitted to the body through the frame. In buses with non-load-bearing bodies, forces from the suspension are transmitted directly to the body. The damping and elastic properties of the tires and suspensions directly affect the transmission of forces from the micro-profile of the road to the bus body. To describe the process of converting the action of the micro-profile of the road into the bus body, the second-order Lagrange equation [16] should be used. In this case, in addition to disturbing and potential forces, there are also resistance forces acting on the dynamic system, so the Lagrange equations will take the form:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_k}\right) - \frac{\partial T}{\partial q_k} = -\frac{\partial P}{\partial q_k} - \frac{\partial F}{\partial \dot{q}_k}, \tag{1}$$

- where $k = 1, 2, \ldots, n$;
- n is the number of degrees of freedom of the dynamic system (the proposed mathematical model will have four degrees of freedom);
- T is the kinetic energy of the system;
- P is the potential energy of the system;
- F is a scattering function (Rayleigh function);
- q_k is the k-th generalized coordinate.

This dynamic system has only two degrees of freedom, and its position in space is determined by the two generalized coordinates $q_1 = x$ and $q_2 = z$. However, for the full implementation of the mathematical model describing the movement of the bus in real operating conditions, a dynamic system describing four degrees of freedom must be used.

Consider the vertical and longitudinal-angular fluctuations of the sprung masses of the bus M_p and unsprung masses m_1 and m_2 relative static equilibrium according to the calculation scheme (Figure 1).

$$\left.\begin{aligned} T &= \frac{1}{2}(M_p \cdot \dot{z}^2 + J_y \cdot \dot{\Theta}^2 + m_1 \cdot \dot{x}_1^2 + m_2 \cdot \dot{x}_2^2); \\ P &= \frac{1}{2}\begin{bmatrix} c_{s1}(y_1 - x_1)^2 + c_{s2}(y_2 - x_2)^2 + \\ + c_{p1}(x_1 - z - \Theta \cdot l_1)^2 + \\ + c_{p2}(x_2 - z + \Theta \cdot l_2)^2 \end{bmatrix}; \\ F &= \frac{1}{2}\begin{bmatrix} k_{s1}(\dot{y}_1 - \dot{x}_1)^2 + k_{s2}(\dot{y}_2 - \dot{x}_2)^2 + \\ + k_{a1}(\dot{x}_1 - \dot{z} - \dot{\Theta} \cdot l_1)^2 + \\ + k_{a2}(\dot{x}_2 - \dot{z} - \dot{\Theta} \cdot l_2)^2 \end{bmatrix}; \end{aligned}\right\} \tag{2}$$

- where l_1 and l_2 are the distances from the vertical axis of the center of mass of the bus to the vertical axis of the front and rear wheels, respectively; $L = l_1 + l_2$;
- J_y is the moment of inertia of the sprung mass of the bus performing longitudinal and angular oscillations;
- Θ is the angle by which the bus deviates from the horizontal axis during longitudinal-angular oscillations.

All the three functions in Equations (2) are sign-changing positive quadratic forms of the velocities,

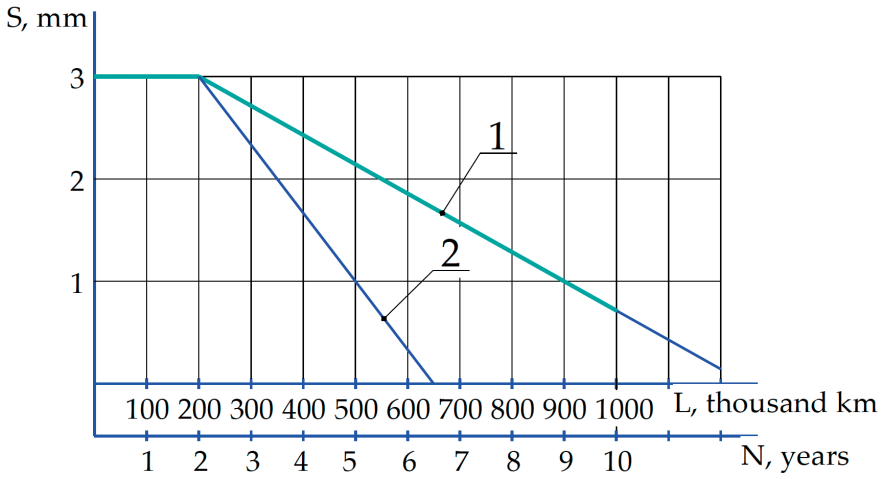

Figure 2 *Graphical dependence showing the decrease in the thickness of the walls S of the base frame, which decreases with an increase in the service life N and an increase in the bus mileage L [2]: 1 - in cities with up to one million inhabitants; 2 - in the metropolises*

coordinates of the vertical wheel displacements of the bus, vertical displacements and longitudinal-angular oscillations of the bus body.

After differentiating the system of Equations (2), the results of differentiation are substituted into the Lagrange Equation (1).

It should also be noted that the rear wheels will repeat the microprofile of the road with a time lag. This time lag is obtained by dividing the wheelbase of the bus L by its speed V_a.

Thus, the values from the road microprofile will be fed into the input of the obtained system of equations. It is assumed that the microprofile under the wheels of one axis is the same. This simplification indicates that there will be no lateral angular oscillations during the bus movement. The values of the road microprofile can be obtained based on spectral densities that were previously studied on special test tracks. In addition, the parameters of the road microprofile can be obtained on a real route on which the bus moves, the durability of the body of which is determined.

As a result of solving the obtained system of equations in Matlab Simulink, the vertical acceleration of the bus's center of mass $\ddot{z}$ can be obtained. Then this value can be brought to the cross-section that limits the durability of the bus body. Typically, such cross-sections are located near the mounts of suspension elements (points 1 and 2 in Figure 1). The force F_i, that arises in the cross-section is determined by the second Newton law. Then, having found the force F_i, and knowing the area of the investigated cross-section of the body frame or frame, the stress σ_i can be determined.

During the operation of the bus, the cross-sectional area of the body frame elements will constantly decrease due to corrosion. The characteristics of the reduction in wall thickness of the body frame elements are obtained based on statistical data from the operation of buses of a similar class. The intensity of corrosion will depend on the operating conditions and anti-corrosion protection. Experience shows that during the first two years of operation, the body frame elements hardly corrode due to the factory anti-corrosion protection. In accordance with the improvement of manufacturing technology and the use of advanced anti-corrosion materials, it is possible to achieve such a level of anti-corrosion protection that the body frame will be protected from corrosion during longer periods of operation (more than two years). However, after that, intensive corrosion of the body frame elements begins because the operating organizations do not renew the worn-out factory anti-corrosion protection. The use of the road deicing agents has a significant effect on the intensity of corrosion. The more roads are sprayed or sprinkled with such reagents, the more the thickness of the body frame elements decreases. Bus operating experience shows that in large cities with a population of over 1 million, the reduction in the thickness of the body frame elements is almost twice as intensive as in small cities. Figure 2 shows the regularities of the change in the thickness of the bus base frame pipes during operation.

The data shown in Figure 2 are obtained on the basis of statistical data obtained from the data of the repair practice of operating organizations as a result of the operation of buses in cities with a population of up to one million or more (this technology can be taken as basic). Additionally, with the improvement of manufacturing technology and the use of advanced anti-corrosion materials, the wall thickness of the body frame pipes will remain unchanged for more than two years. It will be possible to evaluate new technical solutions for improving the corrosion resistance as a result of durability laboratory studies comparing the impact of an aggressive environment on existing and improved samples. In this way, it is possible to obtain correcting coefficients depending on the degree of improvement of the basic technology.

The proposed methodology also involves determining

the stress σ_i in the investigated cross-section using the strain gauging. This means that sensors are attached to the investigated cross-section and the corresponding signal is transformed and transmitted to a laptop using a portable strain gauge. This allows for obtaining a series of stress data and converting it into the spectral density of stresses corresponding to a specific route under specific operating conditions. This method of stress determination, on the one hand, allows for a more accurate calculation of the bus body's durability for specific operating conditions on the chosen route, and on the other hand, prevents the correction of the body structure and research into the influence on the durability_ at the design stage. The driving technology can be evaluated by the average speed on the route, which allows the research to be brought closer to real operating conditions.

To determine the durability of the bus body over time, the Reichert formula [17] has been chosen, which involves substituting the spectral density of stress in the investigated cross-section and the characteristics of the endurance curve of the investigated material. At the selected average speed of the bus, the durability of its body is determined in units of mileage.

3 Results of the assessment of the durability of the bus body in the Matlab Simulink software environment

3.1 Implementation in the Matlab Simulink software environment of the methodology for prognostic the assessment of the durability of the bus body taking into account suspension breakdowns

The system of blocks in the Matlab Simulink software environment allows to build an algorithm for solving a system of equations. This algorithm makes it possible to bring the vertical and longitudinal-angular movements of the bus body to vertical movements in the studied section. As a result of substituting the differentiated System of Equations (2) into the Lagrange Equation (1), the resulting system of equations is reduced to a convenient form in Equation (3) for solving in Matlab Simulink.

In operating conditions, taking into account the quality of the road surface, punctures of the bus suspension inevitably occur. The puncture of the suspension is accompanied by the contact of the bumpers with the corresponding suspension elements. In particular, in the "Ataman" A092N6 buses, the puncture of the front suspension is accompanied by contact with the bumper, and the rear suspension punctures upon contact with the buffers inside the pneumatic spring. When the suspension is punctured, it begins to work as a whole with the sprung mass of the body and does not perform its function. Thus, alternating loads from the road microprofile will be transmitted, taking into account only the energy absorption by the tires, directly to the sprung mass of the bus body. When the suspension (unsprung mass) works as a whole with the body (sprung mass), the stiffness coefficient c_{pi} reaches its maximum value and tends to infinity.

$$
\begin{aligned}
\ddot{z} &= \frac{1}{M_b}\cdot\begin{bmatrix} -(k_{a1}+k_{a2})\cdot\dot{z}-(c_{b1}+c_{b2})\cdot z+ \\ +k_{a1}\cdot\dot{x}_1+c_{b1}\cdot x_1+k_{a2}\cdot\dot{x}_2+c_{b2}\cdot \\ \cdot x_2+(k_{a2}\cdot l_2-k_{a1}\cdot 1)\cdot\dot{\Theta}+ \\ +(c_{b2}\cdot l_2-c_{b1}\cdot l_1)\cdot\Theta \end{bmatrix}; \\
\ddot{\Theta} &= \frac{1}{J_y}\cdot\begin{bmatrix} (k_{a2}\cdot l_2-k_{a1}\cdot l_1)\cdot\dot{\Theta}+(c_{b2}\cdot l_2- \\ -c_{b1}\cdot l_1)\cdot(k_{a1}\cdot l_1^2+k_{a2}\cdot l_2^2)\cdot\dot{\Theta}- \\ -(c_{b1}\cdot l_1^2+c_{b2}\cdot l_2^2)\cdot\dot{\Theta}-(c_{b1}\cdot l_1^2+ \\ +c_{b2}\cdot l_2^2)\cdot\Theta+k_{a1}\cdot l_1\cdot\dot{x}_1+c_{b1}\cdot \\ \cdot l_1\cdot x_1-k_{a2}\cdot l_2\cdot\dot{x}_2-c_{b2}\cdot l_2\cdot x_2 \end{bmatrix}; \\
\ddot{x}_1 &= \frac{1}{m_1}\cdot\begin{bmatrix} k_{a1}\cdot\dot{z}+c_{b1}\cdot z+k_{s1}\cdot\dot{y}_1+c_{s1}\cdot \\ \cdot y_1-(k_{s1}+k_{a1})\cdot\dot{x}_1-(c_{s1}+c_{b1})\cdot \\ \cdot x_1(k_{a1}\cdot\dot{\Theta}+c_{b1}\cdot\Theta)\cdot l_1 \end{bmatrix}; \\
\ddot{x}_2 &= \frac{1}{m_2}\cdot\begin{bmatrix} k_{a2}\cdot\dot{z}+c_{b2}\cdot z+k_{s2}\cdot\dot{y}_2+c_{s2}\cdot \\ \cdot y_2-(k_{s2}+k_{a2})\cdot\dot{x}_2-(c_{s2}+c_{b2})\cdot \\ \cdot x_2(k_{a2}\cdot\dot{\Theta}+c_{b2}\cdot\Theta)\cdot l_2 \end{bmatrix};
\end{aligned}
\quad (3)
$$

To cause the suspension failure, it is necessary for the product of acceleration of the unsprung mass by the unsprung mass itself (force towards the body caused by road micro-profile irregularities) combined with the load of the distributed sprung mass on the given unsprung mass (load of the bus's sprung mass with passengers, which compresses the suspension's elastic elements), to be equal to or greater than the suspension's spring force (product of the stiffness coefficient c_{pi} and displacement up to suspension failure).

The condition for suspension failure can be expressed as follows:

$$\text{when } m_i\cdot\ddot{x}_i+M_{Pi}\geq F_{PPi},\quad c_{Pi}=c_{Ppri}\to\infty; \qquad (4)$$

$$\text{when } m_i\cdot\ddot{x}_i+M_{Pi}<F_{PPi},\quad c_{Pi}=\text{const},$$

- where $m_i\cdot\ddot{x}_i$ is force in the direction of the body, caused by the irregularities of the micro-profile of the road through the i-th suspension;
- M_{Pi} - the load of the sprung mass of the bus with passengers compressing the elastic elements i-th suspension; $(M_P=M_{P1}+M_{P2})$;
- F_{PPi} is the elastic force of the i-th suspension;
- $F_{PPi}=c_{Pi}\cdot x_{Pi}$;
- $F_{PP1}=c_{P1}\cdot x_{P1}$ is the elastic force of the front suspension;
- $F_{PP2}=c_{PRes}\cdot x_{P2}+F_{PBal}$ is the elastic force of the rear suspension (with springs and pneumatic cylinders);
- c_{PRes} is the stiffness coefficient of the rear springs;

- F_{PBal} is the maximum elastic force of the pneumatic cylinder;
- c_{PPri} is the stiffness coefficient of i- th suspension in the event of a failure;
- x_{Pi} is the displacement of the i-th suspension before the failure.

The condition in Equation (4) is implemented in the Matlab Simulink software environment as follows. A subsystem is created, and using the blocks in the Simulink library, the given algorithm is solved. All the necessary variables for calculation are specified in the Matlab workspace and are also taken from the calculation of the System of Equations (3). For example, Figure 3 shows the implementation of the algorithm for the front suspension failure.

The "IN" (Figure 3) receives calculated forces in the direction of the body, caused by the irregularities of the micro-profile of the road through the front suspension $m_1 \cdot \ddot{x}_1$. From the "OUT" the values of the suspension stiffness coefficients are sent to the calculation Equations (3), which realizes the normal operation of the suspension (when supplying $c_{Pi} = const$) or failure during overloads and bus traffic on low-quality roads (when supplying $c_{Pi} = c_{Ppri} \rightarrow \infty$).

The implemented model in the Matlab Simulink software environment was also checked for adequacy [1]. Data confirming the adequacy of the model were obtained based on the real road tests with the determination of stresses in the investigated element of the base frame [1].

3.2 Comparison of the results of the simulation modelling of the durability of the bus bodies of non-load bearing and frame construction

Simulation modelling of the durability of bus bodies with monocoque and frame construction was carried out at an average speed of 40 km/h and movement on a paved road at maximum permissible passenger load. For comparison, the "Ataman" A092N6 bus with a monocoque body and a maximum permissible number of 52 passengers, and the "Etalon" BAZ-A079 bus with a frame construction and a maximum permissible number of 40 passengers were chosen.

From Table 1, it can be seen that the bus body on a frame chassis has 1.4 times higher durability under the same conditions compared to a body of unibody construction. In addition, during the simulation modelling, a series of values for the durability of the unibody bus body were obtained, which allow us to construct a graphical dependence of the body durability on passenger loading and road type (Figure 4).

In Figure 4, the parameter Y is the durability in units of mileage (km); parameter X_1 is the type of road surface: asphalt concrete (-1), deviation of the microprofile in numerical values is 10 mm; even paving stones (0), deviation of the microprofile in numerical values is 30 mm; low-quality paving stones (1), deviation of the microprofile in numerical values is 50 mm; parameter X_2 is the passenger load: 21 passengers (-1), 52 passengers (0), 83 passengers (1).

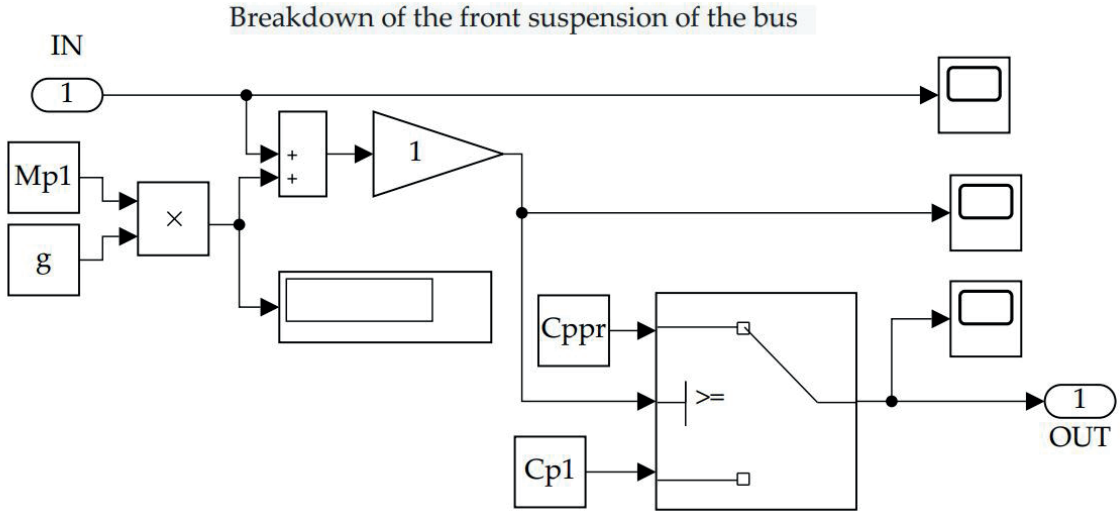

Figure 3 *Implementation scheme of the front suspension breakdown algorithm in the Matlab Simulink software environment*

Table 1 *Comparative assessment of durability of bus bodies of load bearing and frame construction*

Construction of the bus body	Durability of the body frame, km	Durability of the frame (if available), km
Body of load bearing construction	640635	-
Body on frame construction	907653	1452406

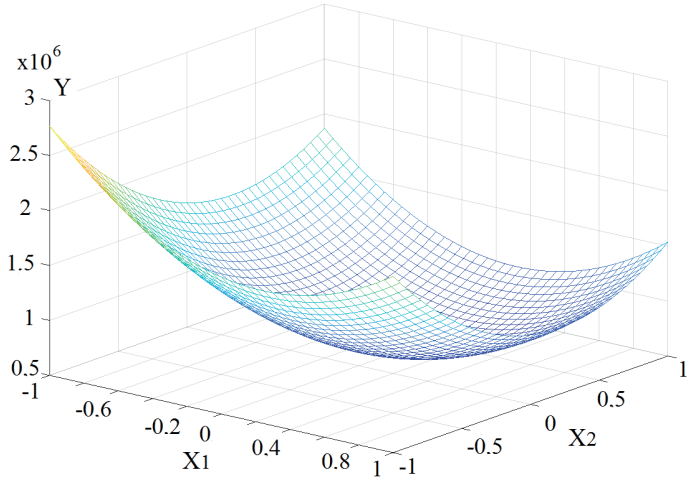

Figure 4 *Dependence of the durability of the bus body with a load of passengers and road type for a non-load-bearing construction*

That is, the X_1 factor corresponding to the limits from -1 to 1 will correspond to the deviation of the road microprofile from 10 mm to 50 mm, and the X_2 factor from -1 to 1 will correspond to the number of passengers from 21 to 83 people.

4 Discussion of the proposed methodology for prognostic assessment of the durability of the bus body in the Matlab Simulink software environment

The proposed methodology for forecasting the body durability of a bus in the Matlab Simulink software environment allows for determining the durability of buses with both non-supporting and frame constructions. The appropriateness of this methodology, and its adequate implementation in the Matlab Simulink software environment, are confirmed by the real experimental trials, as well as by the experience of operating buses with frame and non-supporting body constructions. As a result of simulation modelling, it was established that the durability of a bus body on a frame chassis is 1.4 times greater than that of a non-supporting body. The increased of the durability of the bus body is explained by the fact that the use of a frame provides a more rigid body structure. The frame has a durability that is 2.3 times greater than that of a non-supporting body. Thus, a frame with an increased durability will limit deformation of the body frame during the longer periods of bus operation. This durability of the frame (1452406 km) is explained by the fact that frames are usually made of alloyed steels and are heat-treated. In addition, the frame has an open design, which provides better ventilation and prevents the accumulation of moisture that could cause corrosion. The body frame of a non-supporting construction, which is made of closed-type pipes, contributes to the development of corrosion in closed cavities. Considering that corrosion of internal cavities of the body frame does not practically develop in the first two years (due to the factory protection), it is advisable to treat the internal cavities of pipes every two years. Based on the research results, it could be assumed that a bus body on a frame chassis would be a better option. However, bodies on frame chassis complicate registration/re-registration, repair, and increase the cost of the vehicle kit with a frame by 20 %, as well. The frame also has a number that is entered into registration documents. Over time, the frame number is damaged by corrosion during operation. A heat-treated frame made of alloyed steel under average operating conditions (1452406 km) will require replacement.

The use of simulation modelling compared to high-cost; the long-term durability testing allows for determining the body's durability of a bus under specific operating conditions with minimal expenses in the shortest possible time. The accuracy and maximum approximation to the real operation of simulation modelling is ensured by taking into account the suspension failures of the bus. Unlike [3], which proposes determining the compliance of the body with UN ECE Regulation No. 66 [5] during operation, the prognostic assessment of the bus body's durability in the Matlab Simulink software environment allows predicting the bus body's durability at the design stage. This becomes possible due to the simulation of the influence of the road's microprofile through the wheels and bus suspension on the durability of the body frame (chassis) depending on the material properties, profile section, and corrosion resistance. The proposed methodology allows predicting the durability of the body under different passenger loads, speeds on roads of varying quality, and the intensity of the road treatment with chemical anti-icing agents.

Unlike studies [10-14] that conducted accelerated durability testing using the laboratory stands, the

prognostic assessment of the bus body's durability in the Matlab Simulink software environment takes into account corrosion processes that have a significant impact on the bus's durability.

The limitations of this study consist of the fact that the simulation modelling utilized known spectral densities of such types of road surfaces as asphalt, interlocking paving stones, and low-quality paving stones. The properties of the micro-profile of other road surfaces are not applied here. Therefore, to enable research expansion, it is possible to gather micro-profile characteristics of the roads on which a particular bus will operate. Additionally, it is possible to conduct strain gauge measurements of the investigated cross-section on a specific route. However, this option cannot be applied during the design phase, and for operating organizations, this option will be more accurate. In addition, limitations may arise due to the absence of fatigue curve characteristics of new alternative materials for the body or frame structure in reference literature.

The shortcomings of the research include not taking into account the ambient temperature, which could also affect the body's lifespan. There may also be a need for the laboratory durability testing of new body materials, which will increase the cost of research.

The development of this research will involve laboratory durability testing of new body materials and the collection of microprofile of roads of different qualities. As an alternative to roads of different qualities, different known microprofile of roads can be combined in certain proportions to be as close as possible to the actual route.

5 Conclusions

A methodology has been developed for the prognostic assessment of the bus body's durability of the cantilever and frame design, which can be implemented through the transfer function from the road microprofile to the investigated cross-section or by strain gauging the investigated cross-section. The implementation through the transfer function is a universal option and can be used both at the design stage and after production and commissioning. The option using strain gauging of the investigated cross-section will be of interest to operating organizations in specific operating conditions on a real route.

The developed methodology has been implemented by converting the system of equations into a convenient form for solving in the Matlab Simulink software environment. Taking into account the suspension failures allowed for simulation modelling to be closer to the operating conditions when driving on low-quality pavement.

As a result of simulation modelling of the durability of bodies of bearing and frame constructions, it was established that the body of bearing construction has shorter durability by 1.4 times than the body on a frame chassis. The durability of the frame is maximum and 2.3 times greater than the bearing body due to the open and well-ventilated profile made of alloy steel with subsequent heat treatment. The greater durability of the body on the frame chassis is 1.4 times longer than the durability of the bearing body due to its increased rigidity due to the frame.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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METHOD FOR DETERMINING THE FACTOR OF DUAL WEDGE-SHAPED WEAR OF COMPOSITE BRAKE PADS FOR FREIGHT WAGONS

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Resume

The work highlights the results of a study into the dual wedge-shaped wear of composite brake pads for freight wagons. It has been found that the over-normative wear makes the area of a composite brake pad larger in the lower part up to a value directly proportional to the wagon mileage and smaller in the upper part. To assess the braking efficiency of a rail vehicle, a graphical analytical method has been developed; it allows determining the factor of dual wedge-shaped wear of pads depending on the wagon mileage. The results of calculation were verified by comparing two samplings obtained by mathematical and computer modelling. The results of calculation have proven that the hypothesis on the adequacy is not rejected.

The results of the study conducted will allow more accurate assessment of the braking efficiency of freight rolling stock to be made, as well as contribute to improving the safety of train traffic.

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1 Introduction

The statistical data of recent years on the traffic safety released by the Wagon Department of Ukrzaliznytsia have shown that the mechanical equipment of brake systems of wagons has become too vulnerable due to higher speeds and greater volumes of freight transportation.

One of the factors negatively affecting the braking efficiency of rail transport vehicles is the dual wedge-shaped wear (Figure 1).

Currently, considerable effort is being made to solve the problem of dual wedge-shaped wear of composite brake pads of the freight wagon bogies used for the 1520-mm mainline rail network [1]. This problem is the result of design features of the brake leverage. It is this deviation from the normative wear established for composite brake pads that is associated with lower braking efficiency of the rail vehicle due to a smaller contact area between the pad and the wheel. This may cause increased maintenance and repair expenditures, as well as extra energy costs for the train traction. Therefore, there is a need to develop measures for eliminating the dual wedge-shaped wear of composite brake pads used for the rolling stock [2].

2 Analysis of recent research and publications

In the mechanical braking system of the running gears of freight wagons, the triangles, when the force is transmitted to them through a system of rods and levers from the brake cylinder during braking, work in a way that the brake shoes are pressed against the wheels simultaneously and with an equal force. However, due to the dynamic processes during the movement of a wagon and the interaction of a wheel with a track irregularity, this balance is disturbed, the pads touch the upper edges

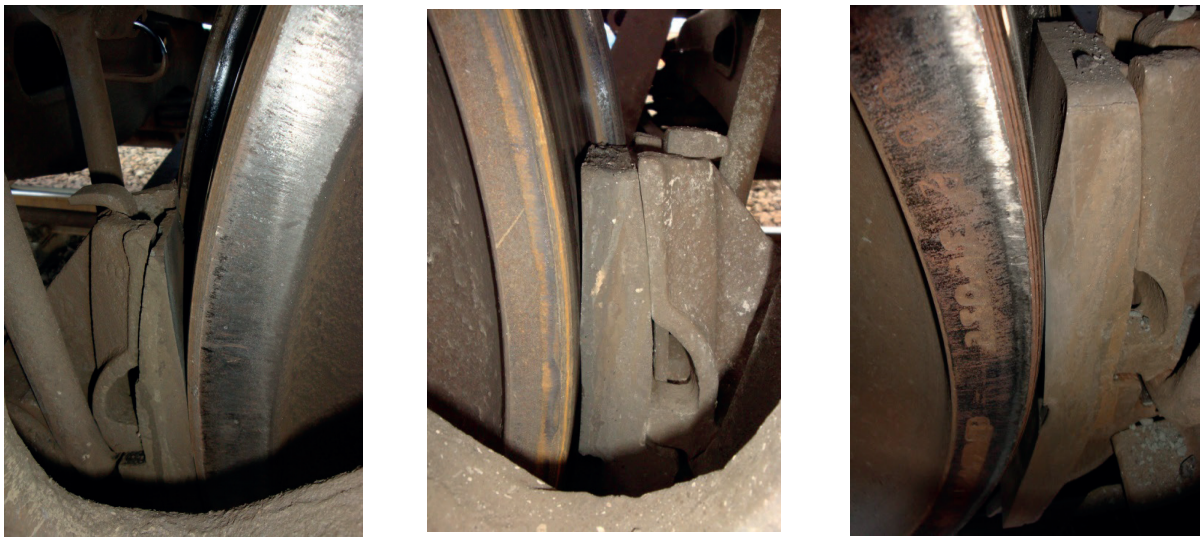

Figure 1 *Wagon pads with wedge-dual wear*

of the wheels, and this causes their dual wedge-shaped wear [3].

Study [4] describes some structural changes in the elements of the brake system of the freight wagon bogie, which were designed to eliminate the dual wedge-shaped wear of composite brake pads. However, the authors did not consider the wear of composite brake pads that could exceed the normative values according to [5] because this wear had not been sufficiently studied regarding the brake leverage of the bogie intended for the 1520-mm track.

Ukrainian and foreign specialists and scientists in the field have tried to change the difficult situation in the railway industry regarding frequent replacement of worn composite brake pads by designing special devices to eliminate their wear. Thus, some tests were carried out on full-scale samples of rail vehicles for the reliability of brake systems of bogies during which the wear and temperature values were measured [6-7].

Study [8] presents an analysis of performance indicators of cast iron and composite brake pads used for various types of the rolling stock. Some negative characteristics of composite brake pads that can damage the rolling surface of wheels of the rolling stock and lead to higher costs of freight transportation were analysed. Moreover, the authors described negative environmental effects of composite pads.

The study of the design features of innovative brake systems of modern rolling stock is given in [9]. The main factors impacting the efficiency of brake systems were identified. The temperature load on the components of tribotechnical pairs "brake pad-wheel" during braking of the rail vehicle was calculated. However, the study did not take into account the dual wedge-shaped wear of composite brake pads, which is frequent in the brake system of a bogie, and its negative impact on the braking efficiency in the freight train consisted of loaded and empty wagons.

Study [10] presents some modifications that can eliminate angular displacements of the brake cylinder rod at its maximum extension out of the body and restrict these displacements. The optimal parameters of the safety element of the brake cylinder rod of the wagon at the permissible moment of resistance were also chosen. The strength of the brake cylinder was calculated using the finite element method, which made it possible to prove that the strength requirement was satisfied. However, it should be noted that an equally important factor affecting the braking efficiency is the brake leverage, which is a determining factor of the train traffic safety. However, the authors did not consider how and whether the extension value of the brake cylinder rod actually changes, if the brake pad is worn, especially when this wear is dual wedge-shaped.

Article [11] presents the study into the performance indicators of various types of brake pads used for the rolling stock. The main advantages of cast iron brake pads, as well as disadvantages of composite ones are given. The price of composite pads depends on the compositions and production technology. The authors present the quality requirements for the manufacture of brake pads and measures to improve the specifications, standards and other documentation. Different types of composite brake pads should be evaluated not only by coefficient of friction and wear resistance, but also by the performance indicators that affect the rolling surface of the wheel and cause various defects due to high temperatures. Among such defects are hollows, slides, cracks, metal tearing all of which cause extra expenditures for repairs of wheels through turning their rims [12].

Study [13] presents a review of publications and an analysis of the quality performance of cast iron and composite pads. The disadvantages of composite brake pads are also given, among them, for example, low thermal conductivity on the rolling surfaces of

Table 1 *The statistical data obtained through in-service inspection of pads*

Average mileage of a wagon, km	Wear value of pads, mm				Total length of the pad with its dual wedge-shaped wear (AB), mm	Length of the slot, (*CD*), mm	Working area according to the mileage (*KP*), mm
	At the upper part	Along the plane delimitation line	At the lower part	Length of harmful abrasion			
7,200	3.5	2.5	1	44	296	40	30
14,400	8	4	3	50	290	40	22
26,400	13	9	4	56	284	40	19
36,000	20	16	8	64	276	38	12
42,300	26	21	9	67	269	37	11
48,000	30	24	11	70	265	37	10
54,600	37	29	12	75	265	37	9
62,400	42	35	13	81	259	37	8
68,300	49	44	14	83	257	36	7
74,400	56	50	15	90	250	36	6

wagon wheels, which can cause numerous thermal malfunctions. This can require additional expenditures for repairs of wagon wheelsets. Another significant drawback is insufficient information in the manuals for production of composite pads and other regulatory documents regarding the rubber mixture ingredients used as well as their chemical composition. This contradicts the current legislation of Ukraine and makes it impossible to control these substances. However, the authors did not present the operating costs of brake pads with dual wedge-shaped wear that mainly occurs when the train moves without braking.

At present it is almost impossible to solve the problem the dual wedge-shaped wear of composite brake pads for freight wagons in operation. Therefore, while designing innovative brake systems for freight wagons, it is necessary to develop measures aimed at eliminating the over-normative wear of the pads when the train moves without braking. This will ensure the train traffic safety and significantly increase the speed of modern freight trains.

3 The aim and main objectives of the article

The purpose of the study was to determine the factor of dual wedge-shaped wear of composite brake pads used for freight wagons.

To achieve this purpose, the following tasks were assigned:

- to determine the braking area of the composite pad taking into account the dual wedge-shaped wear;
- to design a graphic analytical method for determining the factor of dual wedge-shaped wear of composite brake pads relative to the freight wagon mileage; and
- to verify the results of the factor of dual wedge-shaped wear of composite brake pads by comparing samplings obtained by analytical and computer modelling.

4 Features of the detection of factor of dual wedge-shaped wear of composite brake pads

In operation the train speed is regulated by means of brakes when the brake pad is pressed to the rolling surface of a wheel. When the train mileage increases, the wear of the composite brake pad is gradually becoming worse. Moreover, due to the imperfect design, the upper part of the brake pad *AK* (Figure 1) suffers the dual wedge-shaped wear; it reduces the total length of the pad *AB*, the nominal dimensions of which is $AB = a_v = 340$ mm. Therefore, when the length *AK* decreases, the area Q_{ef} at the top of the pad also decreases (Table 1). The similar reduction can be seen for the angle α_{bp} formed between the centre of mass of the pad and its both ends.

So that to determine the area Q_{ef} of the working area of the pad depending on the wagon mileage, the design diagram shown in Figure 2 was drawn up. The calculation was made on the example of a composite brake shoe type 2TR-11.

AB is the total length of the pad; *AK* is the length of the top of the pad; *KB* is the length of the bottom of the pad; *CD* is the length of the air slot of the pad; α_{bp} is the angle formed between the centre and both ends of the pad; β_n is the angle formed between the centre and both ends of the air slot of the pad; R_{bp} is the radius of the working (braking) area of the pad.

To determine the total area Q_{ef} of the brake pad, determine the length of the arc $\smile l_{AB} = l_{ba} = l_{ba\,v}$ by the formula:

$$l_{ba\,v} = \frac{\alpha_v}{180^\circ} \cdot \pi R_{bp}\,. \tag{1}$$

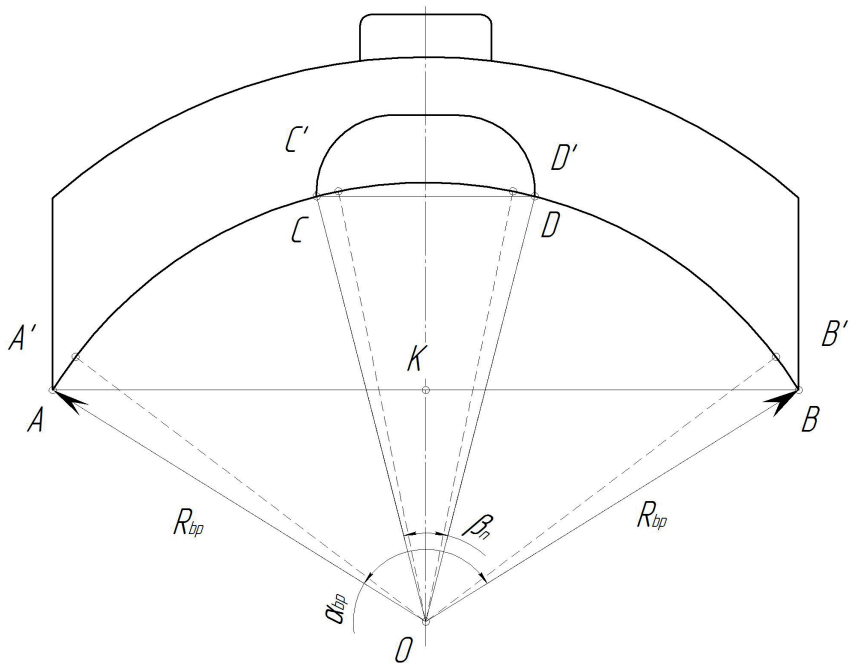

Figure 2 *The design diagram of a composite brake pad type 2TR-11*

From the triangle AOB determine the angle α_{bp} formed between the centre of mass of the pad and its both ends; this angle changes with an increase of the wagon mileage, therefore $\alpha_{bp} = \alpha_v$:

$$\cos\alpha_v = \frac{R_{bp}^2 + R_{bp}^2 - a_v^2}{2R_{bp}^2} = 1 - \frac{a_v^2}{2R_{bp}^2} = \\ = 1 - \frac{a_v^2}{5202}. \tag{2}$$

Hence,

$$\alpha_v = \arccos\left(1 - \frac{a_v^2}{2R_{bp}^2}\right). \tag{3}$$

By substituting α_v in Equation (1) with Equation (3) we get:

$$l_{ba\,v} = \frac{\arccos\left(1 - \frac{a_v^2}{2R_{bp}^2}\right)}{180^\circ} \cdot 3.14 \cdot 51 = \\ = 0.89 \cdot \arccos\left(1 - \frac{a_v^2}{2R_{bp}^2}\right). \tag{4}$$

Determine the length of the small arc of the slot in the pad $\smile l_{CD} = l_{sa} = l_{sa\,v} = l_n$, which changes during braking along with the angle β_n formed between the centre of mass of the pad and the ends of the air slot, therefore the angle $\beta_n = \beta_v$.

The length of the slot $CD = b_v = 40\,mm$.

$$l_{sa\,v} = \frac{\beta}{180^\circ} \cdot \pi R_{bp}. \tag{5}$$

From the triangle COD find the angle β_v formed between the centre and the ends of the air slot of the pad:

$$\cos\beta_v = \frac{R_{bp}^2 + R_{bp}^2 - b_v^2}{2R_{bp}^2} = 1 - \frac{b_v^2}{2R_{bp}^2} = \\ = 1 - \frac{b_v^2}{5202}. \tag{6}$$

Hence,

$$\beta_v = \arccos\left(1 - \frac{b_v^2}{5202}\right). \tag{7}$$

By substituting β_v in Equation (5) with Equation (7) we get:

$$l_{sa\,v} = \frac{\arccos\left(1 - \frac{b_v^2}{2R_{bp}^2}\right)}{180^\circ} \cdot \pi R_{bp}^2. \tag{8}$$

It follows from here that:

$$l_{sa\,v} = \frac{\arccos\left(1 - \frac{b_v^2}{5202}\right)}{180^\circ} \cdot 3.14 \cdot 51 = \\ = 0.89 \cdot \arccos\left(1 - \frac{b_v^2}{2R_{bp}^2}\right). \tag{9}$$

Find the total length of the composite brake pad

$$l = l_{AB} - l_{CD}. \tag{10}$$

All braking levers of freight wagons from wagon manufacturers and after car repair works must be operable [14-15]. Therefore, the width *MK* of a new composite pad with the appropriate profile (Figure 2) will gradually be increased to *MF* depending on the wagon mileage; this can be explained by a decrease

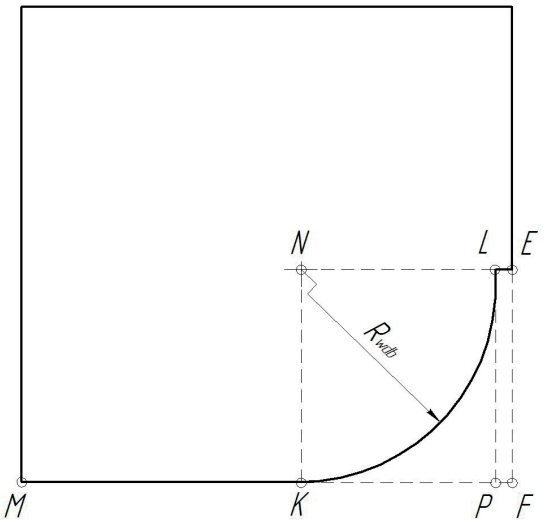

Figure 3 *The cross-section of a composite brake pad*

in the radius R_{wdb}, which also increases the area Q_{ef}. However, due to low mileage of freight wagons, the device for the parallel retraction of brake shoes can become inoperable, thus it does not retain the shoes at a distance from the rolling surfaces of wheels. Therefore, composite brake pads will have the dual wedge-shaped wear in the upper parts [16]. In addition, due to the dual wedge-shaped wear of the pads, their area Q_{ef} will increase in the lower part to a certain extent directly proportional to the wagon mileage, and in the upper part this area will be decreased. For example (Figure 3), determine the working area of the pad by implementing the above method that takes into account the average wear for:

a) pads with nominal dimensions when the device for the parallel retraction of brake shoes is operable and the wagon mileage is zero;

b) pads when the device for the parallel retraction of brake shoes is operable and the wagon mileage is 74,100 km;

c) pads when the device for parallel retraction of brake shoes is inoperable and the pads have dual wedge-shaped wear after the wagon mileage 7.200 km. According to the measurements, such a pad has the following averaged values of the dual wedge-shaped wear: thickness at the top $b_U = 3.5$ mm; thickness along the plane delimitation line $b_{BL} = 2.5$ mm; thickness at the bottom $b_B = 1$ mm; and length of harmful abrasion at the top of the pad $l_H = 44$ mm;

d) pads when the device for the parallel retraction of brake shoes is inoperable and the pads have the dual wedge-shaped wear after the wagon mileage 74,400 km. According to the measurements, such a pad has the following averaged values of dual wedge-shaped wear: thickness at the top $b_U = 56$ mm; thickness along the plane delimitation line $b_{BL} = 50$ mm; thickness at the bottom $b_B = 15$ mm; and length of harmful abrasion at the top of the pad $l_H = 90$ mm.

MF is the width of the working (braking) area of the pad.

Determine the width of the pad m_v:

$$\begin{aligned} &m_v = MK = MF - KF, \\ &KF = KP + PF, \\ &MF = 80\,mm;\ NK = NL = KP = R_{wdb} = 35\,mm; \\ &LE = PF = 3\,mm. \end{aligned} \tag{11}$$

According to the calculation, the following working (braking) areas Q_{ef} of the pad were obtained:

a) for a pad with the nominal parameters at zero wagon mileage Q_{ef} = 12891.27 mm²;
b) for a wagon mileage of 74,100 km Q_{ef} = 20683.86 mm²;
c) for a wagon mileage of 7,200 km and a pad with the dual wedge-shaped wear Q_{ef} = 12335.23 mm²;
d) for a wagon mileage of 74,400 km and a pad with the dual wedge-shaped wear Q_{ef} = 15096.76 mm².

The averaged statistical experimental data for determining the factor of dual wedge-shaped wear that depends on the harmful wear of brake pads were obtained during control measurements of the geometric parameters of pads after different wagon mileage.

The optimal number of statistical data was determined by formula [17]

$$n = \frac{t^2 \cdot \sigma^2}{\delta^2}, \tag{12}$$

where t is the Student's test value for a given sampling;
σ is the root mean square deviation of a random variable under study;
δ^2 is the absolute error of the measurement.

It was found that at the mathematical expectation 14784.65, the root mean square deviation 3865.728 and the Student's coefficient 2.3, the number of experiments was sufficient.

On the basis of the calculations, the graphical dependence between the working (braking) area of

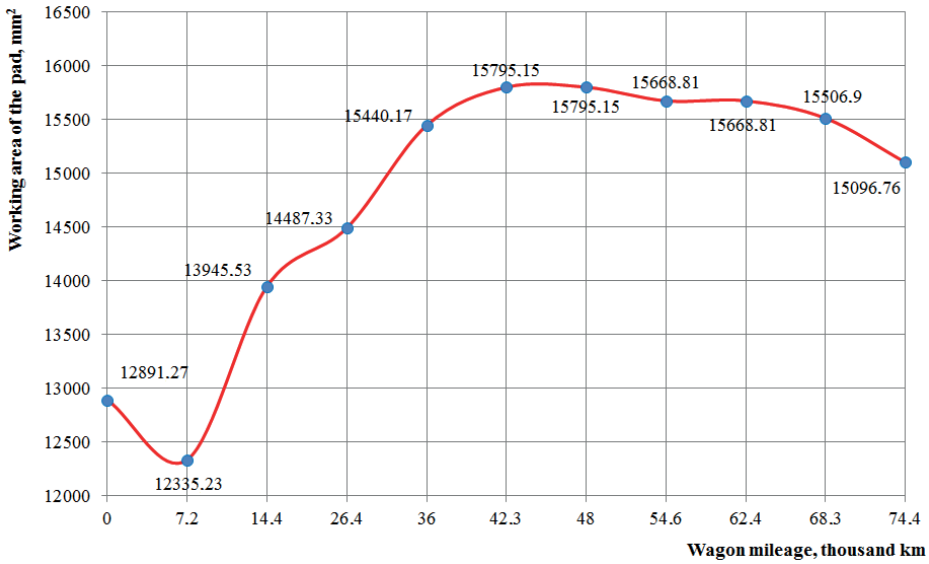

Figure 4 *Dependence of the working (braking) area of the pad with dual wedge-shaped wear on the wagon mileage*

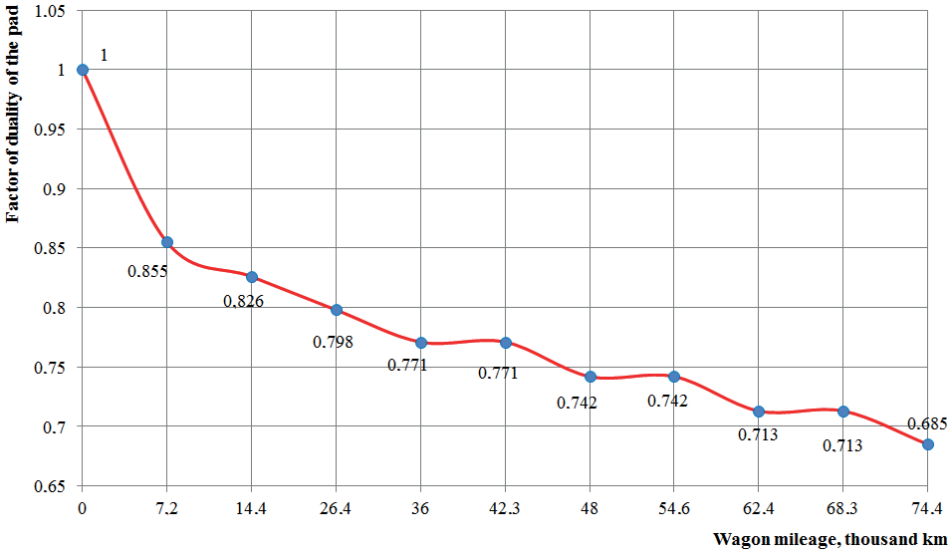

Figure 5 *Dependence of the factor of duality of the pad on the wagon mileage*

the pad with dual wedge-shaped wear (Figure 4) and the factor of duality (Figure 5) was built, these characteristics depend on the wagon mileage.

Thus, on the basis of the braking efficiency of freight trains with composite brake pads, the empirical values and the graphical dependence of the factor of dual wedge-shaped wear, which is directly proportional to the wagon mileage, a graphic analytical method has been developed. It will help to determine the factor of dual wedge-shaped wear for the given mileage of a freight wagon. The factor of dual wedge-shaped wear shows which part of the working surface of the pad is used for braking. In operation, its numerical value can range from 1.0 (no harmful abrasion and the whole useful working area of the pad is used for braking) to less than 0.685 (abrasion in the top of the pad, it approaches the centre). Such cases were observed during production tests; they may lead to the breakage of composite brake pads when used for freight wagons.

It is important to notice, that the temperature factors were not taken into account when carrying out the calculations, because these pads are all-season.

The results obtained were verified with appropriate calculations using an F-test. The verification was carried out by comparing two samplings (Table 2) obtained analytically and with computer modelling. The area of the pad was determined using the spatial model of the pad created in SolidWorks [18-22]. In this case, the nominal parameters of the 2TR-11 brake pad were taken into account, i.e. a 3-D model of the pad was created

Table 2 *Dependence of the working area of the composite brake pad on the freight wagon mileage*

Average mileage of a freight wagon, km	Surface area of the pad, mm²	
	Analytical calculation	Computer calculation
7,200	12,335.23	112,498.2
14,400	13,945.53	13,029.09
26,400	14,487.33	13,576.79
36,000	15,440.17	14,055.32
42,300	15,795.15	14,190.95
48,000	15,795.15	14,430.69
54,600	15,668.81	14,160.63
62,400	15,668.81	14,485.31
68,300	15,506.9	14,935.79
74,400	15,096.76	14,731.45

Table 3 *Basic properties of the 2TR-11 brake pad material*

Indicator name	Value
Brinell hardness, HB	1.2 - 3.0
Modulus of elasticity, Pa	5,000
Poisson's ratio	0.37
Mass density, kg/m³	2.2
Compressive strength, MPa	15
Thermal expansion coefficient, K⁻¹	$4.1 \cdot 10^{-6}$
Friction coefficient	0.1

based on its drawing dimensions. The main parameters of the material of this pad are listed in Table 3. Then this model was imported to Solid Edge, where, with the built-in options the area was determined (Figure 6).

The design value of the factor according to the F-test was determined by [20]

$$F_p = \frac{S_{ad}^2}{S_y^2}, \tag{13}$$

where S_{ad}^2 is the adequacy variance;
S_y^2 is the error mean square.

The adequacy variance was found according to the formula:

$$S_{ad}^2 = \frac{\sum_{i=1}^{n} (y_i - y_i^p)}{f_i}, \tag{14}$$

where y_i^p is the design value obtained by modelling;
f_i is the number of degrees of freedom.

The error mean square was determined by the formula:

$$S_y^2 = \frac{1}{N} \sum_{i=1}^{n} S_i^2, \tag{15}$$

where S_i^2 is the variance in each line where parallel experiments were conducted.

It was assumed that the model under study was linear (Figure 7) and characterized the change in the friction area of the pad according to the wagon mileage.

The calculation demonstrated that at the error mean square S_y^2 = 585928.3 and the variance dispersion S_{ad}^2 = 1232018.8, the actual value of the factor is F_p =2.1, which is less than the tabular value F_t=3.07. Thus, the hypothesis on the adequacy of the developed model is not rejected.

It should be noted that in order to reduce wear on the friction surface of the brake pads, it is possible to introduce devices for their uniform removal from the wheel rolling surface. Such a device was developed by the authors of the article and presented in previous publications [23]. Moreover, one of the options for reducing brake pad wear is the introduction of new materials for their manufacture. The attention will be payed to these issues in subsequent research in this field.

5 Conclusions

The braking area of a composite pad with dual wedge-shaped wear was determined. It was found that the dual wedge-shaped wear makes the area of a composite brake pad Q_{ef} larger in the lower part to the value of the wear directly proportional to the wagon

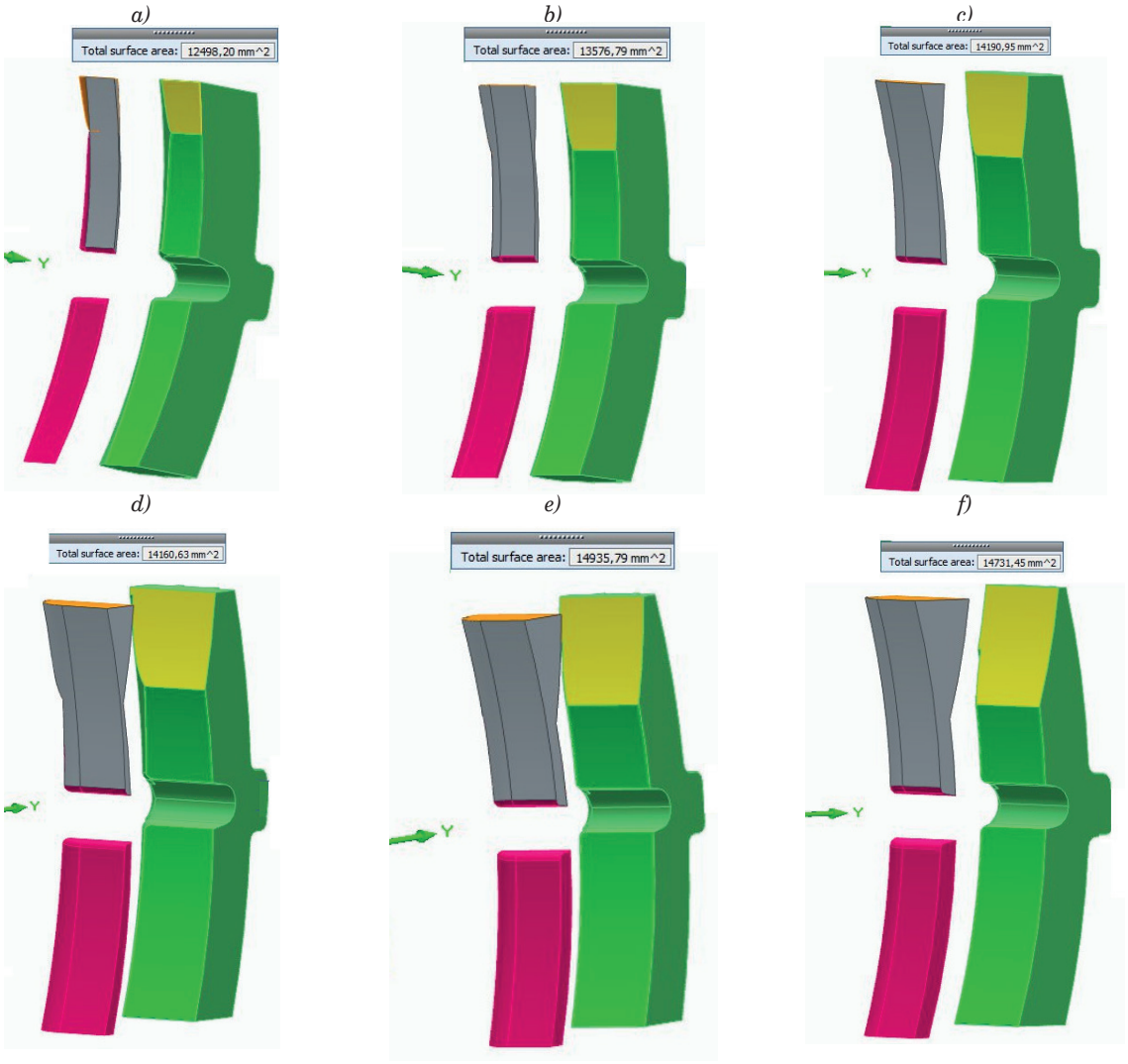

Figure 6 *Results of computer modelling for determining the area of the pad with dual wedge-shaped wear according to the freight wagon mileage a - 7,200 km; b - 26,400 km; c - 42,300 km; d - 54,600 km; e - 68,300 km; f - 74,4000 km*

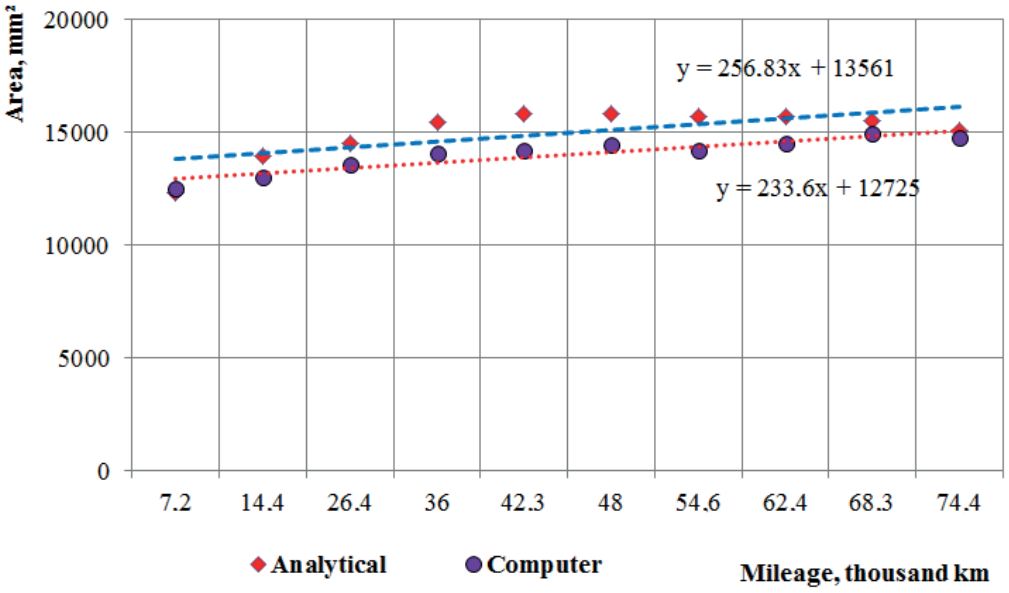

Figure 7 *The graphical dependence of the working area of the composite brake pad on the freight wagon mileage*

mileage, and smaller in the upper part. The area of the working part of the pad was determined using the developed method that took into account the average wear. For a pad with the nominal parameters and with zero wagon mileage Q_{ef} = 12,891.27 mm^2; with the wagon mileage 74,100 km Q_{ef} = 20,683.86 mm^2; with the wagon mileage 7,200 km and the dual wedge-shaped wear Q_{ef} = 12,335.23 mm^2; and with the wagon mileage 74,400 km and the dual wedge-shaped wear Q_{ef} = 15,096.76 mm^2. On the basis of the calculation, the graphical dependence between the working area of the pad with dual wedge-shaped wear and the wagon mileage was built.

A graphic analytical method for determining the factor of dual wedge-shaped wear of composite brake pads that depends on the freight wagon mileage was developed. This method can be used for determining the factor of dual wedge-shaped were for the given mileage of a freight wagon; using this method the braking efficiency of the freight trains with composite brake pads can be assessed.

The results of the analytical and computer modelling used for the determination of the factor of dual wedge-shaped wear were verified by means of the samplings. It was found that at the error mean square S_y^2 = 585,928,3 and the adequacy variance S_{ad}^2 = 1,232,018,8, the actual value of the factor was F_p = 2.1; this value is less than the tabular value F_t=3.07. The results of the calculation have proven that the hypothesis on the adequacy of the developed model is not rejected.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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DEVELOPMENT OF CALCULATION METHODOLOGY FOR OPTIMIZING THE OPERATING MODE OF AN ELECTRIC PULSE UNIT FOR CLEANING EXHAUST GASES

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Resume

The results of research, devoted to operation of an electric pulse muffler designed for cleaning exhaust gases of an internal combustion engine, are presented in this article. The problem considered in this research is establishing the optimal operating mode of the electric pulse muffler by changing the parameters of the distance between the electrodes and the frequency of the electric pulse. To solve this problem, experimental research on laboratory and experimental stands was carried out, which confirmed effective reduction of the gas smoke indices at adjustment of the specified parameters. As a result, a methodology was developed to calculate the optimal values of the distance and frequency parameters, at which the operation of the electric pulse muffler will be considered productive and the degree of gas purification will be effective. The optimum value of the distance between electrodes is 0.78-6 ·10-3 m with an electric pulse frequency in the range of 127-128·10^{3}Hz.

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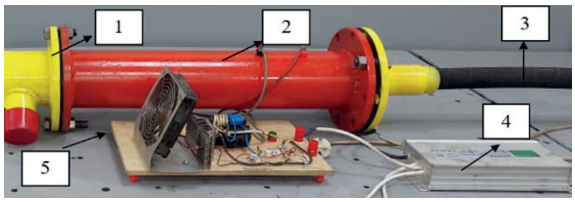
1 Introduction

To date, the steady increase in the number of motor vehicles worldwide leads to intense air pollution by exhaust gases. A high rate of air pollution was recorded in megacities, since most of the cars are concentrated on urban roads [1]. Air pollution is caused by the operation of automobile engines, which significantly worsens the urban ecological situation, which leads to deterioration of the overall quality of life of citizens through an increase in the number of various diseases, such as cardiovascular diseases, lung cancer and worsening metabolic syndrome [2-3].

The problem of emissions of harmful components of vehicle exhaust gases into the atmosphere in modern cars is solved by equipping the exhaust system with neutralizing catalysts, which are designed to neutralize harmful components of exhaust gas. In addition, the number of eco-friendly cars on the global automotive market is increasing, using the example of electric cars. However, in the coming years, it is impossible to replace all the cars with electric vehicles, since the electric vehicles on a single charge cannot ensure their long-term operation over long distances, and their charging at stations takes from 7 to 10 hours [4], at the same time catalysts are very expensive and have a short service life, every 100-120 thousand kilometres they need to be replaced [5].

In connection with the above, the search for new solutions for cleaning the exhaust gases of the internal combustion engine is relevant. One of such solutions is the application of electroimpulse method of purification in the exhaust system, as this method is characterized by a fairly fast rate of gas purification, and its purification efficiency is 98 % [6].

A number of patents have been registered for cleaning the exhaust gases with an electric field and an electric pulse [7-8]. In the first case, purification is carried out due to the formation of a smoldering corona discharge, and in the second due to shock ionization of the gas. The disadvantage of these inventions is the need to introduce new structural units in the exhaust system,



1 - muffler housing; 2 - two electrodes mounted inside the housing; 3 - hose to the intake opening of the muffler; 4 - electric current source; 5 - high voltage generator

***Figure 1** Experimental electric pulse muffler*

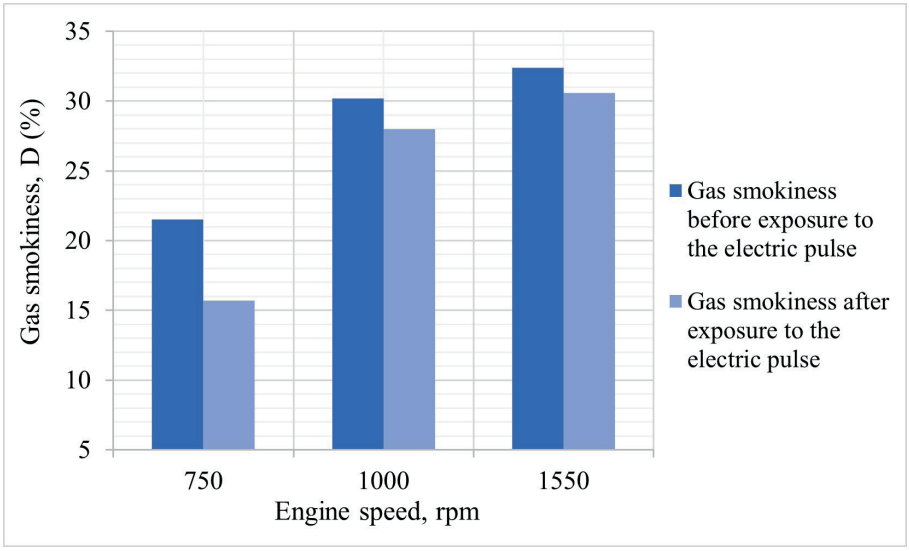


***Figure 2** Graph of the change in smokiness with and without the influence of an electric pulse*

which will weigh down the overall design and operation of the entire system.

We propose a new muffler design with placed electrodes inside the muffler, in which the shock ionization is carried out. The proposed design of the muffler does not weigh down the design of the exhaust system, as it is an alternative to the existing muffler, it does not have a significant load on the engine operation, as well, as the unit itself does not consume much power, and its development does not require large monetary costs. In addition, this muffler design can be a piece of equipment, not only in modern cars, but in the cars of earlier years of production, which correspond to the former "Euro" standards, as well.

However, when conducting theoretical and experimental researches of such a muffler, questions arise about obtaining the correct dependencies between parameters describing the muffler operation mode and the degree of gas purification. Consequently, it is necessary to develop a calculation methodology, determining the optimal values of parameters that allow to establish the operating mode of the electric pulse unit for exhaust gas purification.

The hypothesis of the study is the possibility of changing the gas purification mode and reducing its smokiness due to varying the distance between the electrodes and the frequency of the electric pulse.

The aim of the study was to establish the dependencies between the degree of gas purification, pulse frequency and the distance between the electrodes.

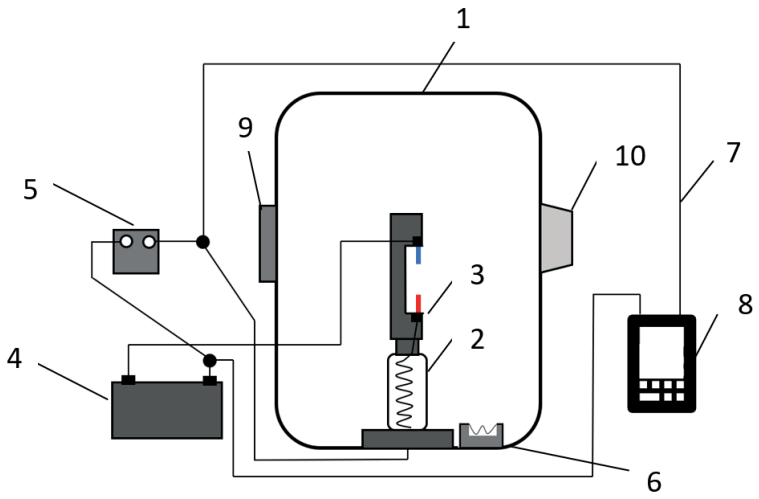
The scientific significance of the study is the establishment of dependences between the smoke content of the gas and the ratio of parameters pulse frequency and distance between the electrodes. The ratio of the indicators of the gas smokiness with and without the pulse treatment is taken as the criterion of purification.

The practical usefulness consists in obtaining correct dependencies for development of calculation methods for determining the optimum operating mode of the electric pulse muffler.

2 Materials and methods

The authors conducted an experiment that proved the effectiveness of the design with electrodes built into the muffler [9]. Figure 1 shows the experimental stand of an electric pulse muffler.

According to the experimental studies carried out on an experimental metal muffler stand the dependences of the gas smokiness indicators (after the impact and before the impact of the electric pulse) on the engine crankshaft speed were obtained (Figure 2).



1 - smoke storage tank; 2 - high-voltage ignition coil; 3 - spark plug; 4 - battery; 5 - frequency and duty cycle regulator; 6 - smoke source; 7 - connecting wires; 8 - luxmeter; 9 - light source

***Figure 3** Diagram of the experimental stand*

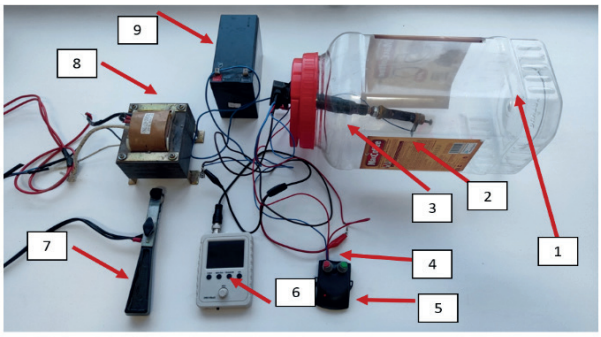


***Figure 4** Laboratory stand for determining the degree of gas purification*

The obtained results have generally shown the success of the experiment. From the graph it follows that the smokiness of the gas after exposure to an electric pulse has the lower values compared to the indicators of the smokiness of the gas that was not exposed to the electric pulse. However, in this experimental studies, in addition to the engine crankshaft speed, such important parameters as the distance between the electrodes and the frequency of the electric pulse were not taken into account, which has a direct impact on the quality of occurrence and duration of the corona discharge in the gas, which ensure the efficiency of the gas purification. In addition, by adjusting these parameters, it is quite possible to set the optimal mode of operation of the electric pulse muffler. For example, by varying the distance between the electrodes, it is possible to determine the optimal interval of the interelectrode space at which a corona discharge occurs and a high degree of gas purification is carried out. In addition, by selecting the value of the electric pulse frequency, it is possible to prevent cases of the transition of a corona discharge into a spark discharge [10], which leads to a violation of the stable mode of operation of the electric pulse muffler. Therefore, it is advisable to conduct experimental studies to determine the parameters of the gas smokiness with a change in the distances between the electrodes and the frequency of the electric pulse.

To determine the regularity of changes in the gas smokiness parameters' dependence on the parameters of the distance between the electrodes and the frequency of the electric pulse, the authors developed a laboratory stand with transparent dielectric walls, in which the distance between the electrodes changed and the frequency of the electric pulse was set. The scheme of the stand is shown in Figure 3.

The stand (Figure 4) consists of a smoke storage tank 1, a spark plug 2, a high-voltage ignition coil 3, connecting wires 4, a frequency and duty cycle regulator 5, an oscilloscope 6, a smoke source 7, an electric pulse generator 8, and a battery 9. .

A coil with a spark plug (NGK Iridium BKR5EIX-11 automotive spark plug) was placed inside the container. Spark plug has electrodes on it that can change their distance. The tank was filled with smoke from 10w 40 engine oil heated to a high temperature. To power the high-voltage coil, an electric pulse generator was used,

Table 1 *Results of calculations to determine the gas smoke indices*

Experiment number	Distance between electrodes Δ, (m)	Frequency of the electric pulse f, (Hz)	Gas illumination -E		Transparency coefficient -α	Total light absorption capacity of the gas β (Gas smokiness D_2/D_1)
			Before filling with the gas E_{of}	After filling with the gas E_i		
1	Δ_1=0.012	f_1=15.906	23 600	976	0.04136	0.95864
2	Δ_1=0.012	f_2=20.790	23 260	983	0.04226	0.95774
3	Δ_1=0.012	f_3=21.795	23 730	1058	0.04458	0.95542
4	Δ_2=0.015	f_1=15.906	23 570	1410	0.05982	0.94018
5	Δ_2=0.015	f_2=20.811	24 160	985	0.04077	0.95923
6	Δ_2=0.015	f_3=21.997	23 446	931	0.03971	0.96029
7	Δ_3=0.018	f_1=15.889	24 510	1981	0.08082	0.91918
8	Δ_3=0.018	f_2=20.725	23 285	1114	0.04784	0.95216
9	Δ_3=0.018	f_3=21.997	23 670	1121	0.04736	0.95264
10	Δ_4=0.021	f_1=15.889	23 832	1831	0.07683	0.92317
11	Δ_4=0.021	f_2=20.790	22 370	1286	0.05749	0.94251
12	Δ_4=0.021	f_3=21.975	22 235	1630	0.07331	0.92669
13	Δ_5=0.024	f_1=15.839	22 730	7387	0.32499	0.67501
14	Δ_5=0.024	f_2=20.790	20 977	6705	0.31964	0.68036
15	Δ_5=0.024	f_3=21.975	20 840	8078	0.38762	0.61238

assembled based on the KR1006VI1 (NE555) chip, operating in pulse-width modulation mode with the ability to adjust the frequency (from 15 to 35 Hz) on an oscilloscope. The stand was powered by a 12-volt battery.

The change of gas illumination in the container was recorded using an LED flashlight (HOROZ BECKHAM-1 HL341L,1W, 7000-9000K) and a special illumination sensor (UNI-T UT383).

Experimental studies at the laboratory stand were carried out in two stages: stage 1 - without exposure of the gas to the electric pulse, stage 2 - with exposure of the gas to the electric pulse. In addition, at the preparatory stage, the initial illumination of the container was measured without injecting smoke into the container, which averaged from 20.000 to 24.000 lk. The device was filled with smoke until the measured illumination decreased from an average of 800 to 400 lx. The readings were taken within 60 minutes. Moreover, to improve the accuracy of the results, readings were taken at every 15-second interval.

Experimental studies at the stand were carried out as follows. In the capacity of the laboratory stand, smoke came from a smoke source, the spiral of which was initially heated to a certain temperature appropriate for the applied engine oil. Measurements were taken on the illumination of the tank after filling with smoke. Then, a high-voltage electric discharge from the battery was applied to the electrodes located opposite each other at (Δ1= 0.012 m) in the spark plug and the frequency values (at f = 15 Hz) were adjusted using a regulator with a visual display of these values on an oscilloscope. The process of the smoke purification was observed in the tank and during which measurements of illumination were recorded. The order of the experiment was repeated in the same way several times, with changing the distance between the electrodes (at Δ_2 = 0.015, Δ_3 = 0.018 m, Δ_4 = 0.021 and Δ5 = 0.024 m) and adjusting the frequency of the electric pulse (at f_2 = 20 Hz and f_3 = 21 Hz).

According to the developed methodology of experimental data processing, the gas transparency coefficient α was calculated from the obtained values of the illuminance index E:

$$\alpha = E_i/E_{of}\,. \tag{1}$$

Transparency coefficient in turn allows to estimate the efficiency of gas purification by the parameter of gas light absorption capacity β. The dependence between the transparency coefficient and the gas light absorption parameter is as follows:

$$\beta = 1 - \alpha\,. \tag{2}$$

It should be noted that the light absorption capacity of gas β is a normative parameter describing the smoke index of the gas and is characterized by the ratio of the intensity of the light flux entering the receiver of the smoke path to the initial intensity of the light flux. Such ratio of light flux intensity is equivalent to the ratio of smoke indices after the impact and before the impact of the electric pulse on the gas in themuffler . Consequently, the parameter of light-absorbing ability of gas β is equal to the very index of ratios of gas smoke

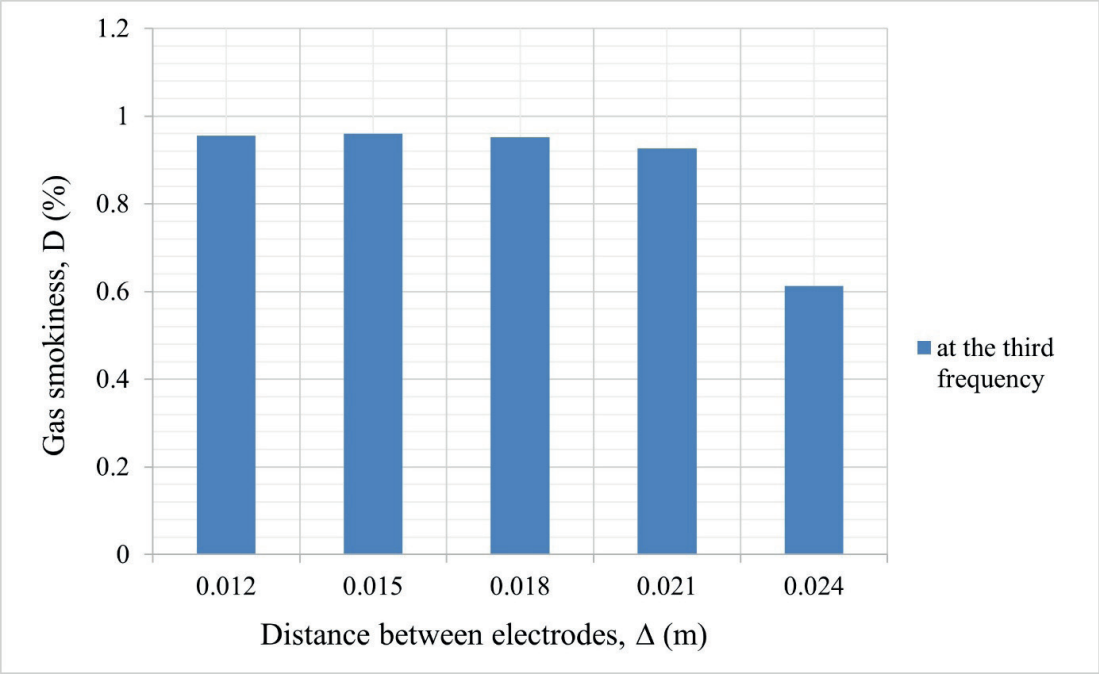


Figure 5 *Graph of the change in the gas smoke content depending on the distance between the electrodes*

after and before the impact of the electric pulse. Hence it follows:

$$\beta \approx D_2/D_1 . \quad (3)$$

It follows that, as a criterion for the optimality of the operation of an electric pulse muffler, it is advisable to choose the ratio of smoke indicators after (D_2) and before (D_1) the exhaust gas exposure to an electric pulse.

$$K_o = D_2/D_1 \rightarrow \min . \quad (4)$$

The results of calculations are presented in Table 1.

3 Results

According to the method of the experimental data processing, calculated values of the gas smokiness indicators were obtained, according to which, as a result, a graph of the dependence of the change in the gas smokiness on the distance between the electrodes and the pulse frequency was constructed (Figures 5 and 6, respectively).

From the graph in Figure 5 it follows that at a distance between the electrodes from 0.001 to 0.002 m, there was no qualitative change in the values of the smoke content of the gas. However, with an increase in the distance between the electrodes from 0.002 to 0.0024 m, the physical picture of the process of exposure to the electric pulse changed, in which there was a sharp jump towards a decrease in the values of the gas smokiness. This phenomenon can be explained by the fact that with the value of the distances between the electrodes from 0.012 to 0.0021 m, there was a spark discharge in the interelectrode gap and only with an increase in the distance between the electrodes to 0.0024 m, a spark discharge transition into a corona discharge occurred and gas purification became much more efficient. The degree of purification has increased by 40 %.

From the graph in Figure 6 it follows that the frequency range of the electric pulse from 15 to 21 Hz was not significant in the process of gasses exposure to an electric pulse, since the smoke values remained almost unchanged. However, with an increase in the frequency of the electric pulse (more than 21 Hz), a gradual decrease in the gas smoke content was observed.

The obtained graphs prove that the distance between the electrodes and the frequency of the electric pulse have the greatest influence on the degree of gas purification. As a result, a graph was constructed for the joint analysis of the ratio of the gas smoke content dependence on parameters of the distance between the electrodes (Δ) and the frequency of the electric pulse (f) (Figure 7).

According to the obtained graph, it follows that with the combined effect of the frequency of the electric pulse and the distance between the electrodes on the gas, the smoke index begins to change approximately in the range of distances between the electrodes from 0.0018 to 0.0024 m. However, according to the results of the experimental data processing, it is not possible to determine the exact values of the electric pulse frequency dependence on the distance between the

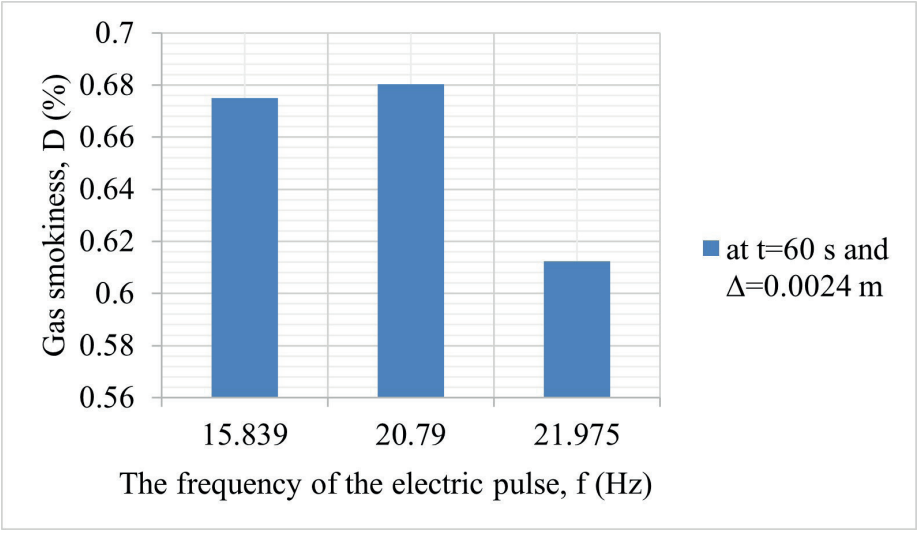


Figure 6 *Graph of the change in the smoke content of the gas depending on the frequency of the electric pulse*

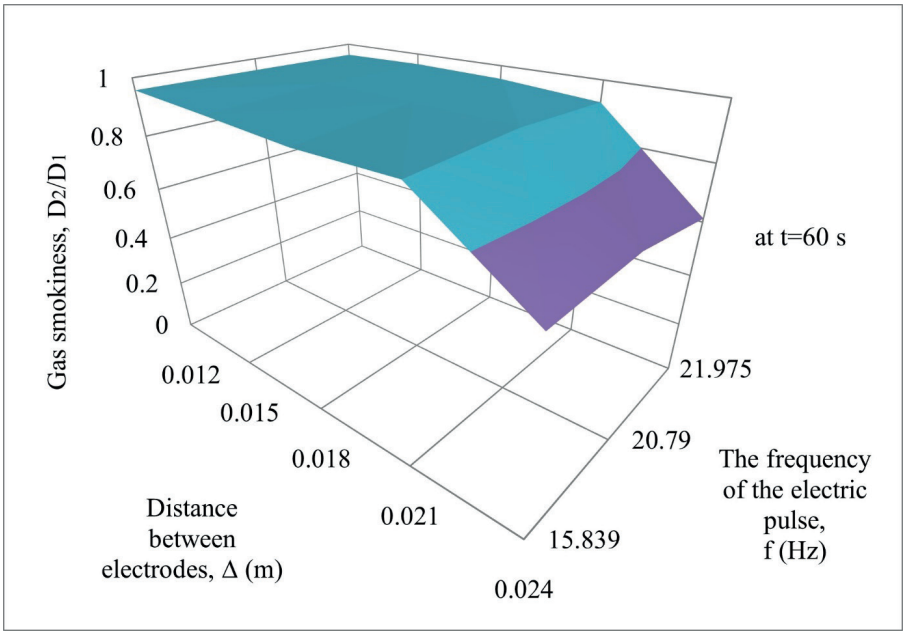


Figure 7 *The ratio of the gas smoke content dependence on the parameters of the distance between the electrodes (Δ) and the frequency of the electric pulse (f)*

electrodes, with the combined effect of which there is a decrease in the smokiness indicators. In this regard, it is necessary to establish dependencies that allow determining the relationship between the parameters of the frequency of the electric pulse and the distance between the electrodes.

To determine the joint effect of the parameters Δ and f on the smokiness of the gas, the authors considered two indicators:

$$k_1 = \Delta \cdot f \text{ and } k_2 = \Delta / f . \quad (5)$$

The physical meaning of the value k_1 is the speed ϑ_e of the passage of the distance S by the electric pulse. The value of S is equal to the product of Δ by the number of cycles n, that is:

$$S = \Delta \cdot n , \quad (6)$$

$$\vartheta = \Delta \cdot n/t , \quad (7)$$

where $f = n/t$.

The physical meaning of the value k_2, equal to

$$k_2 = \Delta \cdot t/n , \quad (8)$$

lies in time t/n for which the impulse overcomes the distance Δ.

According to the obtained dependencies, the values of the parameters $k_1 = \Delta \cdot f$ and $k_2 = \Delta/f$ were determined by multiplying and dividing the values of the distance between the electrodes and the electric pulse frequency, respectively. The results of the calculations are presented in Tables 2 and 3.

Then, according to the obtained values of the parameters k_1 and k_2, a regression-correlation analysis

Table 2 *Data for determining the parameter k_1*

Distance between electrodes Δ (m)	0.012	0.015	0.018	0.021	0.024
Frequency of electric pulse (Hz)			Parameter k_1, $\Delta \cdot f$ (m/s)		
15.839	0.190	0.237	0.285	0.332	0.380
20.79	0.249	0.311	0.374	0.436	0.498
21.795	0.261	0.326	0.392	0.457	0.523

Table 3 *Data for parameter definition k_2*

Distance between electrodes Δ (m)	0.012	0.015	0.018	0.021	0.024
Frequency of electric pulse (Hz)			Parameter k_2, Δ/f (m · s)		
15.839	0.00075	0.0009	0.00113	0.00132	0.001
20.79	0.00057	0.0007	0.0008	0.00101	0.00115
21.795	0.0005	0.0006	0.00082	0.00096	0.00110

Table 4 *Smoke indicators from k_1*

Parameter k_1, $\Delta \cdot f$ (m/s)	0.190	0.374	0.523
Gas smokiness, D_2/D_1 (experimental values)	0.95864	0.95216	0.61238
Gas smokiness, D_2/D_1 (according to the regression equation) $y = -6.75x^2 + 3.77x + 0.49$	+0.96270	0.95553	0.61512

Table 5 *Smoke indicators from k_2*

Parameter k_2, Δ/f (m · s)	0.0005	0.0008	0.001
Gas smokiness, D_2/D_1 (experimental values)	0.955	0.9521	0.675
Gas smokiness, D_2/D_1 (according to the regression equation) $y = -439120.28x^2 + 611.88x + 0.75$	0.036	0.03943	0.316

of the experimental values of smokiness was carried out. According to the results of analysis, it is proposed to use a quadratic regression equation to describe the dependence of the change in the parameters of the smokiness of the gas on the parameters k_1 and k_2,

For parameter k_1

$$y = -6.75 \cdot x^2 + 3.77 \cdot x + 0.49\,. \tag{9}$$

For parameter k_2

$$y = -439120.28 \cdot x^2 + 611.88 \cdot x + 0.75\,. \tag{10}$$

Experimental and empirical values of the gas smokiness indicators from the parameters k_1 and k_2 are given in Tables 4 and 5, respectively.

Based on the data obtained, graphs of the dependences of the parameters k_1 and k_2 on the smoke indicators are constructed (Figures 8 and 9, respectively).

As follows from the graphs (Figures 8 and 9), according to the minimum gas smoke values, the following system of two linear equations was made:

$$\begin{cases} \Delta \cdot f = 0.5 \\ \Delta/f = 0.0015 \end{cases} \tag{11}$$

and by solving this system of equations the optimum value of parameters of distance between electrodes and frequency of electric pulse for laboratory electric pulse installation was obtained: $\Delta \approx 0.027$ and $f \approx 19$.

Thus, the presented methodology allowed to establish the optimal mode of operation of the laboratory stand for the gas purification by determining the optimal values of the parameters of the distance between the electrodes and the frequency of the electric pulse at

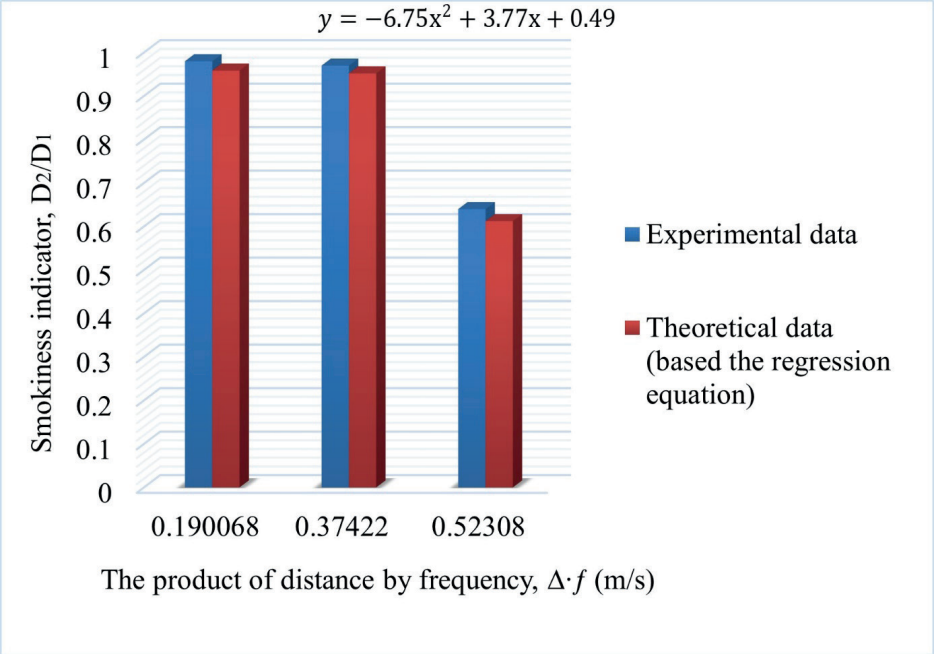


Figure 8 *Graph of the dependence of the comparison of experimental and theoretical curves for parameter* k_1

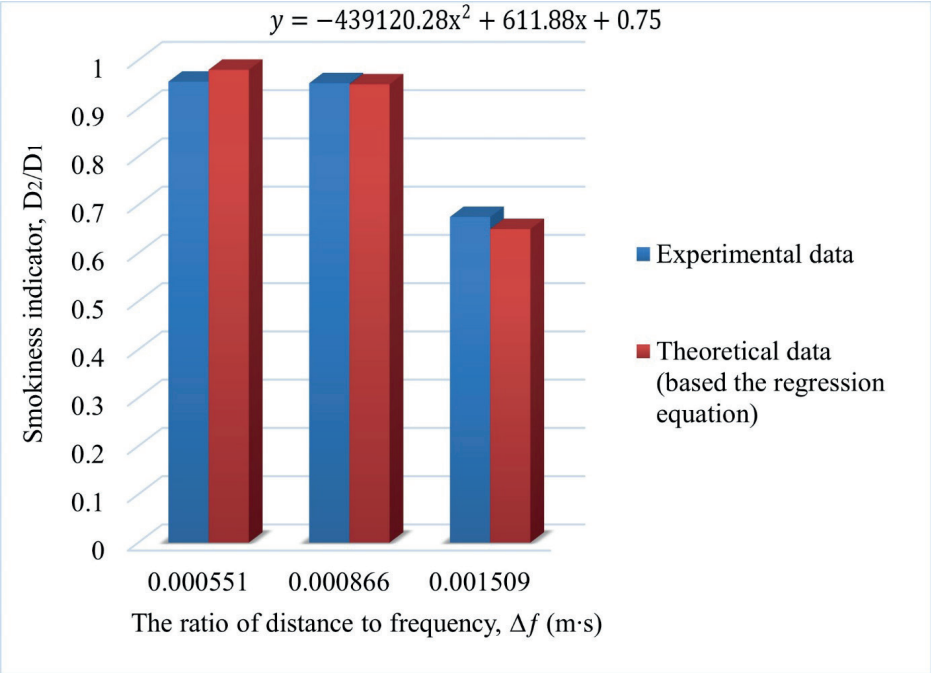
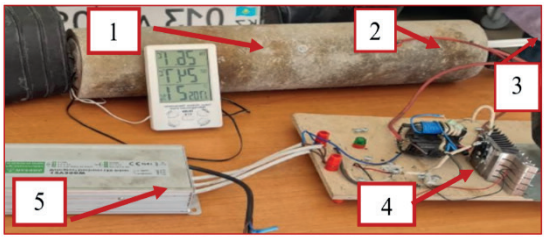


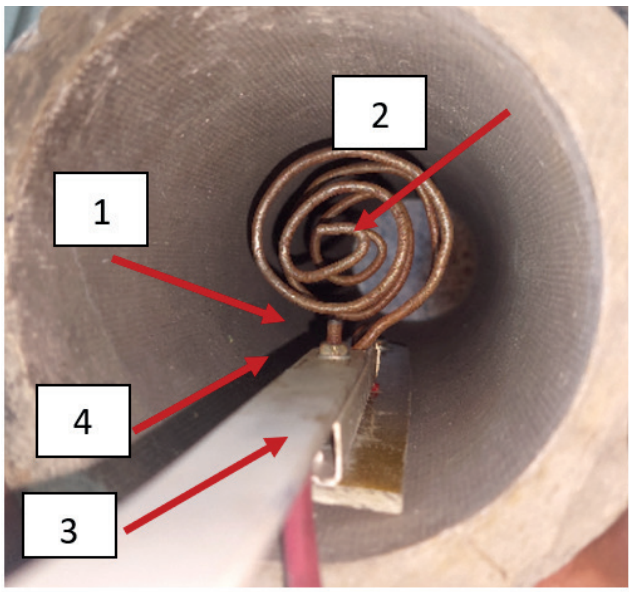
Figure 9 *Graph of the dependence of the comparison of experimental and theoretical curves for the parameter* k_2

which the lowest values of the gas smokiness indicators are achieved. However, the results obtained needed to be confirmed by experimental studies on an experimental stand of electric pulse muffler, since the influence of the engine crankshaft speed was not taken into account on the laboratory stand. After all, the engine crankshaft speed depends on how much gas is supplied to the electric pulse muffler. In addition, the establishment of optimal values of the parameters of the distance between the electrodes and frequency can prevent the transition of the corona discharge into the spark discharge, which is ineffective in the process of gas purification and has a destructive effect on the electrodes. In this regard, it is necessary to conduct additional experimental studies on the experimental stand to determine the indicators of gas smokiness dependence on the change in engine speed, taking into account the fixing of the electric pulse frequency indices and setting the distance between the electrodes, preventing the transition of corona discharge to spark discharge.



1 - asbestos muffler body; 2 - electrodes placed inside the muffler
3 - bar-rail for changing the distance between the electrodes;
4 - high voltage generator; 5 - power supply.

Figure 10 *Experimental stand of electric pulse muffler*



1 - anode; 2 - cathode; 3 - slat-rail for changing the distance between the electrodes;
4 - inner surface of the muffler housing

Figure 11 *Arrangement of spiral-shaped electrodes inside an electric pulse muffler*

Table 6 *Technical characteristics of the high voltage generator*

Indicators	Value
Input voltage	12 V
Output voltage	35000 V
Converter power	120 W

To determine the optimal mode of operation of an electric pulse muffler, depending on the change in the engine crankshaft speed, with the establishment of the optimal distance between the electrodes, the authors developed the experimental stand of an electric pulse muffler (Figure 10).

The cylindrical body of the muffler is made of asbestos, since this material has more positive characteristics compared to metal due to its low electrical conductivity, low thermal conductivity and high noise-absorbing ability. Inside the muffler housing, two electrodes are mounted on a special rail, to which a highvoltage electric current is supplied from the generator via the high-voltage wires (Figure 11).

The electrical circuit of a high-voltage generator consists of the following elements: a diode-cascade lowercase transformer (DCLT), a 1N5339BRLG zener diode, a TOSHIBA PNP 2SA1943 p-n-p transistor. The technical characteristics of the high voltage generator are presented in Table 6.

The experimental method consists of determining the parameters of the smokiness of the gas without exposure and with the influence of an electric pulse, depending on the change in the speed of the engine crankshaft with the establishment of optimal distances between the electrodes. The experiments were carried out in two stages: stage 1 - without affecting the gas with an electric pulse, stage 2 - with affecting the gas

Table 7 *Results of calculations of the ratio of the gas smokiness*

Engine crankshaft speed, (rpm)	750		950		1280	
Distance between the electrodes, (m)	0.01		0.078		0.06	
Frequency of the electric pulse, (Hz)	121 000		122 000		128 000	
Gas smokiness, (%)	Without the impact of an electric pulse (D_1)	With exposure electric pulse (D_2)	Without exposure to an electric pulse (D_1)	With exposure electric pulse (D_2)	Without the impact of an electric pulse (D_1)	With exposure electric pulse (D_2)
	50	45	40	34	39	29
	0.9		0.85		0.74	

with an electric pulse and setting the distances between the electrodes from 0.01 m to 0.006 m in increments of 0.02 m. The optimal distances between the electrodes for the experimental electric pulse muffler stand were selected based on the counter-proportional relationship between the parameters of the distance between the electrodes and the engine speed, which is described by the following equation:

$$\Delta = UqR^2/6Q\omega r\mu, \quad (12)$$

where:
U - voltage, V;
q - is the amount of charge, C;
R - is the radius of the muffler section, m;
ω - is the angular speed of rotation of the crankshaft, rad/s;
Q - capacity of the combustion chamber, m^3;
r - is the average radius of a gas particle, m;
μ - is the dynamic viscosity of the gas, Pa·s.

According to Equation (12), the greater the number of revolutions of the engine crankshaft, the smaller the distance between the electrodes should be. This is explained by the fact that at high frequencies of the crankshaft revolutions, the volume and velocity of the gas increase and this contributes to the fact that already at large distances between the electrodes, the process of electric pulse stitching of gases does not occur, namely, a corona discharge does not occur in the interelectrode space. Therefore, for a corona discharge to occur, it is necessary to reduce the distance between the electrodes. Consequently, for experimental studies, with an increase in the engine crankshaft speed, the distance between the electrodes was reduced.

Experimental studies on the experimental stand were carried out as follows. The car engine was started and warmed up to operating temperature. The experimental stand of an electric pulse muffler was connected to the car. A high voltage generator was connected to a muffler. The connection of the stand to the car was carried out through the inlet using a rubber hose feeding exhaust gases from the car. The engine crankshaft speed was set. The range of changes in the gas speed was 750, 950 and 1280 rpm. At each value of the engine crankshaft speed, the smoke content of the gas was measured using an optical smoke meter (BOSH BEA 070),. Then the same values of the engine crankshaft speed were set again and, depending on the change in their values, the gas smoke values were obtained, but with the influence of an electric pulse and with the distance between the electrodes (of 0.01, 0.0078, 0.006 m, respectively). Prior to exposure of the gas to an electric pulse, the distances between the electrodes were previously placed using a slat-rail. Then, an electric current was supplied from a high-voltage generator to the interelectrode space, during which a corona discharge was formed, followed by the beginning of the ionization process. The ionization of the gas led to the deposition of heavy particles on the inner surface of the muffler and the purified gas was released into the air through the outlet. The total exposure time of the electric pulse was 60 seconds, after which the smoke values of the gas were obtained.

Based on the conducted experimental studies on the obtained values of smokiness, their ratio was determined, namely, the ratio of the smokiness of a gas that was under the influence of an electric pulse to the smokiness of a gas that was not affected by an electric pulse. This ratio corresponds to the criterion of optimal operation of an electric pulse muffler, which characterizes the degree of gas purification, estimated by the degree of light absorption of the gas stream by suspended particles. The results of calculations of the ratio of smokiness of the gas are presented in Table 7.

According to the obtained calculated indicators of the gas smoke ratio, a graph of the dependence of their values on the engine crankshaft speed was compiled (Figure 12).

From the graph in Figure 12 it follows that the values of the gas smoke ratio tend to decrease as the engine crankshaft speed increases. For example, at 1250 rpm, the gas smoke values are 0.74 and the degree of purification has increased by 26 %. Such indicators are explained by a decrease in the degree of light absorption of the gas by harmful particles and a subsequent increase in the degree of purification of the gas from harmful particles. A decrease in the smoke

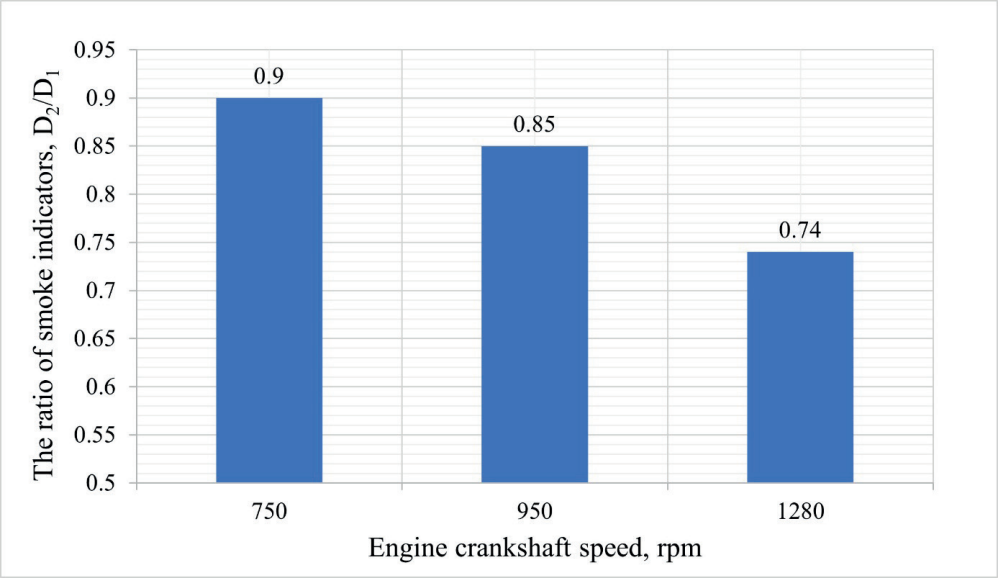


Figure 12 *Indicators of the gas smoke ratio depending on the change in the engine crankshaft speed*

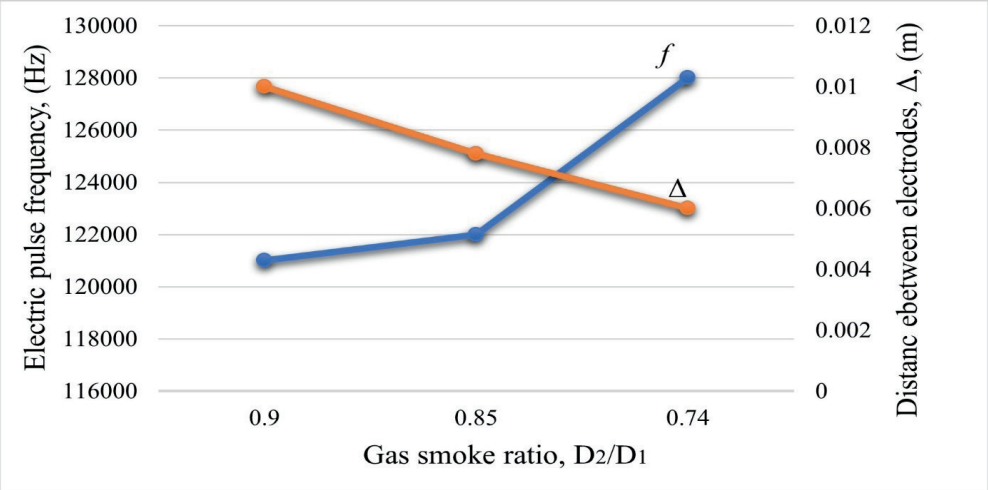


Figure 13 *Indicators of the gas smoke ratio depending on the change in the engine crankshaft speed and distance between the electrodes*

content of the gas, in turn, satisfies the condition of the optimality criterion, the value of which should tend to a minimum, which indicates an increase in the quality of gas purification and an increase in the efficiency of the electric pulse muffler.

Figure 13 shows the graph of change of the gas smoke ratio index dependence on the change of the electric pulse frequency and the distance between the electrodes.

According to the obtained graph it follows, the greater the influence of the frequency of the electric pulse, the lower the value of the gas smoke ratio. The lowest value of the gas smoke ratio was recorded in the area of the greatest influence of the electric pulse frequency of $128 \cdot 10^3$Hz, while the lowest value of the gas smoke ratio index was recorded at the smallest electrode spacing of 0.006 m.

The results obtained are explained as follows. As it was noticed earlier, for formation of the corona discharge it is necessary to vary the parameters of the distance between the electrodes and the frequency of the electric pulse. According to the conducted experimental studies on the laboratory and experimental stands, it follows that there is an inversely proportional relation between the distance and frequency, if the distance between the electrodes is large, then the frequency of the electric pulse will be small and vice versa, if the distance between the electrodes is small, then the frequency of the electric pulse will increase.

This inversely proportional relation is proved by the calculated results of the optimal parameters of distance and frequency, which were obtained according to methodology for the laboratory stand. For the experimental stands, the optimum values of the distance between the electrodes (Δ) and the frequency of the electric pulse (f) were also determined by using the previously presented methodology and they also confirm the existing relations between these parameters:

$$\Delta \approx 0.006\,\text{m} \text{ and } f \approx 127 \cdot 10^3 \text{ Hz}. \quad (13)$$

Therefore, the distance between the electrodes of 0.006 m and the frequency of the electric pulse of $127 \cdot 10^3$ Hz are considered optimal for the formation of a corona discharge and subsequent effective gas purification in the experimental stand of a muffler.

4 Conclusions

According to the results of the conducted studies, the hypothesis about the possibility of changing the gas purification mode in the electric pulse muffler dependence on the change of the parameters of the distance between the electrodes and the frequency of the electric pulse was confirmed.

With the purpose of confirmation of the put forward hypothesis the laboratory and experimental stands were developed, allowing to carry out experimental research on definition of indicators of the gas smokiness dependence on parameters of distance and frequency.

Experimental studies on the laboratory stand allowed to determine that in the installation when the distance between the electrodes increases from 0.012 to 0.0021 m, there is a spark discharge in the inter-electrode gap, which is not effective for the gas purification, as the indicators of gas smokiness changed insignificantly. However, when the distance was 0.0024 m in the electrode gap there was a transition of spark discharge into corona discharge and gas purification became much more effective. It was established, that the increase in gas cleaning amounted to 40 %. Gas smoke indices were obtained according to the developed methodology of experimental processing. This calculation methodology allows to determine the coefficient of gas light-absorbing ability from the experimental values of gas illumination, which is equivalent to the gas smoke indices. The calculation methodology, which determines the optimal values of the parameters of the distance between the electrodes and the frequency of the electric pulse, and allows to establish the optimal mode of operation of the laboratory electric pulse installation, was also developed. Thus, at the frequency of the electric pulse of 19 Hz and the distance between the electrodes of 0.0027 m the operation of the laboratory electric pulse unit will be considered optimal.

The obtained research results needed to be confirmed on the experimental stand of the electric pulse muffler, taking into account the influence of the parameter of the engine crankshaft revolutions frequency and with establishment of the optimal distance between the electrodes. According to the results of the experiment the reduction of gas smoke indices was established, satisfying the condition of the optimality criterion of the electric pulse muffler operation, and the increase in the gas cleaning amounted to 26 %. In addition, the experimental results confirmed the opposite dependence between the parameters "distance and frequency". According to the previously proposed methodology, the values of the parameters of distance (0.006 m) and frequency ($127 \cdot 10^3$ Hz) were established for the electric pulse installation of the experimental stand, at which its operation and the process of gas purification would be considered optimal.

Thus, the obtained results allow to have scientific and practical significance for the development of calculation methodology for the design of electric pulse mufflers. In addition, the conducted research makes an important contribution to solving the problem of environmental pollution by cars and opens new perspectives for development of the electric pulse installations in the field of exhaust gas purification.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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ANALYSIS OF GRAIN DAMAGE BY THE BUCKET ELEVATOR DURING LOADING/UNLOADING

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Resume

The purpose of the study was to identify problematic issues in the operation of bucket elevators during the loading and unloading of grain, which can lead to damage to seeds. To achieve this goal, methods of analysis and evaluation of factors that affect the damage rate of grain were used. The main results were an increase in the safety of the grain loading and unloading process using bucket elevators and a reduction in the risks of crop losses. The analysis of grain damage by a bucket elevator is of practical importance for the agricultural sector and can bring the following practical benefits: reducing the risk of product losses, as it helps to identify problem areas in the operation of the elevator and develop measures to eliminate them, improving the efficiency of work and the quality of seed grain.

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1 Introduction

With the favourable development of the seed grain industry, problems have recently arisen related to their damage. Damage to the grain leads to serious consequences, as they not only damage the seed germs, but also lead to a decrease in nutrient reserves in the main part of the grain, the endosperm. The study of the grain damage is an important aspect of ensuring efficiency and safety in the agricultural sector, since damaged grains are not only losses for producers, but lead to a decrease in the yield and product quality, as well. Destruction of valuable seed grains and thinning out of crops prevent the maximum possible yield from healthy grains. Technological processes of seed treatment should be organized in such a way as to minimize the impact of ups and downs on them, including the number of bends and turns. Sheet rubber should be used to cover the places of bends and turns. Excessive movements and sharp protrusions on the route of the movement of seeds should be eliminated. The equipment must be loaded at least half of the rated capacity. To avoid damage to seeds in bucket elevators, it is necessary to limit the number of lifts to five or six throughout the seed treatment process, and the speed of movement of the burrowing belts should be reduced. It is important to detect and eliminate areas where the seed damage is possible in time. The purpose of the study was to identify damage to grain seeds caused by the use of bucket elevators and substantiate the best design for the elevator, which will avoid damage to seeds.

To bridge the gap between the grain production and availability, it is crucial to adopt sustainable grain storage practices. The study conducted by Tushar et al. [1] explores the key factors affecting grain stability in emerging economies. Using a combination of analytical methods, it identifies “Proper training on advanced storage operations” as the most important factor in ensuring the sustainable grain storage. These findings can guide practitioners and policymakers in enhancing agricultural sustainability and food security.

2 Literature review and research gap

In their research, Kumar and Kalita [2] provide a comprehensive literature review of the grain postharvest losses in developing countries, the status and causes of storage losses, and discuss the technological interventions to reduce these losses.

Reducing postharvest losses, especially in developing countries, could be a sustainable solution to increase food availability, reduce pressure on natural resources, eliminate hunger, and improve farmers' livelihoods. Cereal grains are the basis of staple food, and account for the maximum postharvest losses on a calorific basis among all agricultural commodities. As much as 50% to 60% of cereal grains can be lost during the storage stage due only to the lack of technical efficiency. Use of scientific storage methods can reduce these losses to as low as 1% to 2%. The authors discussed in detail the basics of hermetic storage, various technology options, and their effectiveness on several crops in different localities.

According to Syzdykova et al. [3], grain damage is influential because damaged grain can cause significant crop losses and reduce the quality and value of the product. Damaged grain can lead to the loss of valuable nutrients and vegetable oils, which can reduce its total weight and reduce its price. Moreover, damaged grain can cause increased oxidation and rotting processes, which leads to loss of quality and unsuitability of the product for consumption. It may be less attractive to consumers. Damaged grain may have a degraded taste or a damaged shell, which may reduce its aesthetic appeal. In addition, damaged grain may contain various impurities, such as dust, dirt, and other pollutants, which may increase the risk of diseases associated with the use of products.

Following Irmulatov et al. [4], analysis of grain damage reduction is extremely important to guarantee high product quality. It is important to take measures to prevent plant diseases and pests, as this can affect the quality and value of the crop. It is necessary to carry out mechanical processing of grain, such as cleaning and separation from impurities using specialized equipment. This helps in avoiding the damage to the grain and improves its quality.

Mesterhazy et al. [5] outlined in their research that the main task is to reduce grain losses during production and storage and consumption. Better harvest and storage conditions could prevent losses of 420 mt. The education of farmers by adopting the vocational school system is a key issue in the prevention of grain loss. In addition, extension services should be created to demonstrate farmers' crop management in practice.

Shaimerdenova [6] states that in the conditions of growing demand for agricultural products, reducing crop losses and improving product quality are becoming especially urgent tasks for the agricultural sector. Therefore, it is necessary to pay attention to the problem of grain damage and take measures to reduce it, such as the use of modern equipment, prevention of plant diseases, and proper storage and transportation of grain. Such measures can help increase the efficiency of agricultural production and ensure the stable development of agriculture. In addition, reducing the damage rate of grain can reduce the cost of its processing and transportation, since damaged grain is often not suitable for the production of high-quality products and requires additional processing. It is also worth noting that reducing the damage contributes to decreasing the environmental impact, since damaged grain can become a source of soil and water pollution.

According to Koyshybaev et al. [7], bucket elevators have several disadvantages that can lead to grain damage and a decrease in its quality. Firstly, when the lifting grain, buckets can create strong friction, which leads to mechanical damage to the grain. Secondly, bucket elevators do not always provide uniform lifting and movement of grain, which can lead to its damage and mixing with other grains. In addition, elevators can have a negative impact on grain due to dust and pollution that can come from the environment or from the elevator itself.

Kaharmanova [8] notes that in order to reduce the negative consequences of using bucket elevators, it is necessary to take measures such as proper maintenance and lubrication of equipment, the use of special materials in buckets that reduce friction, and the installation of a grain quality control system at all the stages of its movement and storage. It is also worth considering that bucket elevators are not the only way to move grain, and there are more modern and efficient technologies that can be used in the agricultural sector.

Rsaliev [9] reports that there are a number of more modern methods of seed transportation that can reduce grain damage and increase processing efficiency, such as pneumatic transportation, which is based on the use of air to move grain, or gravity transportation. In this method, the seeds are moved along special inclined trays, which avoids sudden height changes and reduces the likelihood of damage. In some cases, special conveyors are used, which are equipped with soft belts or rubber coatings, which reduce impacts and decrease the amount of damage to grain during transportation.

In this comprehensive study, examining the impact of bucket elevators on grain damage, a significant research gap was identified. While existing literature thoroughly investigates general postharvest grain losses and various storage and transportation techniques, there is a notable lack of in-depth analysis specifically focused on the operational drawbacks of bucket elevators in agricultural processes. This gap is critical as it overlooks the detailed mechanisms through which the bucket elevators contribute to grain damage during the loading and unloading, a factor that can significantly influence overall grain quality and yield. Addressing this gap is essential for developing more efficient and less damaging grain handling methods, thereby enhancing agricultural productivity and reducing postharvest losses in the sector. The study is aimed at identifying the negative aspects of the operation of bucket elevators, which can damage seeds during their loading and unloading.

3 Methodology

3.1 Data

As a part of the study, the statistics of incidents at bucket elevators, associated with damage to seeds, during the loading and unloading of grain, were analysed. The work of elevators was monitored and problematic points were identified that could lead to seed damage. In addition, an analysis of the design of elevators was carried out and technical factors that may affect safety when working with them were identified. In this regard, a direct method of staining seeds was chosen, followed by viewing through a magnifying glass. This method is the most suitable for agricultural enterprises with a small number of mechanised processes and has sufficient accuracy to determine the degree of damage to seeds. It allows visualising and studying structural changes, such as damage to the shell, the presence of cracks, destruction of the embryo and changes in the colour or texture of seed tissues, and also has a number of advantages over other methods. For example, this method does not require complex tools or special conditions. This is a relatively fast and affordable procedure that can be performed using a conventional microscope or magnifying glass. If desired, it is possible to carry out a quantitative assessment of grain damage by counting damaged and undamaged seeds, which can be useful for the comparative analysis of various seeds. This method is non-invasive, that is, it does not require the destruction or separation of seeds into parts, which preserves the integrity of the seeds for further use or additional research. Staining seeds and viewing through a magnifying glass is a relatively inexpensive method, it does not require the use of expensive equipment or chemicals, which makes it available both in the laboratory and in production.

3.2 Research description

Before the analysis, two samples of grain weighing 1,000 g each were selected: one from the intake pit with a manual sampler before entering the bucket elevator, and the other before entering the grain cleaning machine. Two portions weighing 50 g each were taken from each sample and 200 seeds were randomly selected from each weighted portion for analysis, which eventually amounted to 400 seeds. Each of the 200 seed portions was immersed in a glass flask with an aniline dye for 2 minutes, used for dyeing cotton fabrics. Then the excess dye was removed, and the seeds were thoroughly washed with water, placed on filter paper, and dried in air. After that, the damaged seeds were randomly selected from each subsample using a manual magnifying glass and weighed on a scale. According to the literature data, the percentage of damaged seeds was determined in:

$$\Delta = \frac{W_{dam}}{W_{sub}} * 100\%, \quad (1)$$

where:
W_{dam} - weight of damaged seeds;
W_{sub} - weight of the initial subsample (200 seeds).

According to Equation (1), the number of damaged seeds in the intake pit (Δ_1) and before entering the grain cleaning machine (Δ_2) was determined. Since there were two subsamples in each sample, the average value in Equation (2), (3) was determined:

$$\Delta_1^{avg} = \frac{\Delta_1^1 + \Delta_1^2}{2}, \quad (2)$$

$$\Delta_2^{avg} = \frac{\Delta_2^3 + \Delta_2^4}{2}, \quad (3)$$

where:

$\frac{\Delta_1^1 + \Delta_1^2}{2}$ - respectively, the percentage of damaged seeds in the intake pit for the first and second subsamples;

$\frac{\Delta_2^3 + \Delta_2^4}{2}$ - respectively, the percentage of damaged seeds before entering the grain cleaning machine for the third and fourth subsamples.

The full amount of damage to seeds by the bucket elevator was determined based on:

$$\sum \Delta = \Delta_2^{avg} - \Delta_1^{avg} \quad (4)$$

Data on experimental studies and calculations of Equations (1)-(4) were entered in the Table 1.

4 Results

In this experiment, the two grain samples were selected, each weighing 1000 g. One sample was taken from the intake pit before entering the bucket elevator, and the other was collected before entering the grain cleaning machine. From these samples, we took smaller subsamples for detailed analysis. Using an aniline dye, we stained 200 seeds from each subsample for two minutes. After removing excess dye, washing, and drying the seeds, we inspected them using a magnifying glass to identify and weigh the damaged seeds. Our objective was to calculate the percentage of damaged seeds based on their weight relative to the total weight of the subsample.

In this study, the damage of grain by one burrow for a particular farm was 4.25 %. This means that for every 100 tonnes of grain loaded into the elevator, approximately 4.25 tons of grain were damaged. This level of damage can affect the quality of the product and lead to losses of harvest and income. But in general, the percentage of grain damage in the range from 3 % to 5 % is a fairly common indicator. For example, according to studies conducted in the USA in the period from 2005

Table 1 *Data on experimental studies and calculations*

Sample number	First (before the elevator)		Second (after the elevator)	
Subsample number	Subsample No. 1 (200 seeds)	Subsample No. 2 (200 seeds)	Subsample No. 3 (200 seeds)	Subsample No. 4 (200 seeds)
Weight of the subsample, g	8.66	8.53	7.95	7.86
Weight of damaged seeds, g	1.67	1.77	1.94	1.89
Δ_1 - % of damage to seeds before the bucket elevator, %	19.2	20.7	-	-
Δ_2 - % of damage to seeds before the bucket elevator, %	-	-	24.4	24
Average amount of damage to seeds	19.95		24.2	
% of damage to seeds by the bucket elevator	4.25			

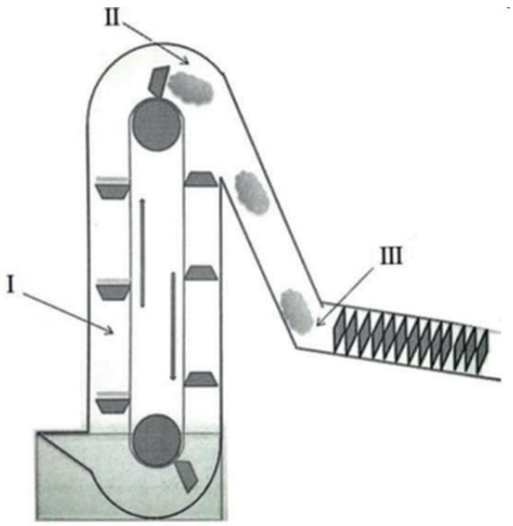

Figure 1 *Zones of the greatest damage to seeds*

to 2010, the percentage of damage to seeds ranged from 2 % to 5 %, depending on the type of grain and its storage method. In other studies, conducted in different regions of the world, the percentage of damage also ranged from 3 % to 6 %. Thus, a damage rate of 4.25 % is quite typical for this situation, and to reduce it, it is necessary to apply special methods and technologies to protect the seed grain from mechanical damage (Table 1).

It can be concluded with great certainty that in the process of operation of the bucket elevator under study, three factors have the greatest influence on the damage of seed grain [10] (Figure 1):

1. The presence of a "backlagging" when lifting seeds up. "Backlagging" when lifting seeds can have a negative impact on the quality and quantity of the crop, as well as on the safety of working with bucket elevators. The problem of the presence of "backlagging" in the elevator arises from the fact that some seeds may remain on the walls of the elevator and begin to fall down in the opposite direction due to gravity during the next ascent, thereby reducing the efficiency of pumping seeds. The problem may arise when using bucket elevators, especially in the case of an incorrect choice of operating mode. All this can lead to product losses, reduced productivity and increased costs for maintenance and repair of equipment.
2. The problem of the method of unloading buckets in the elevator and the impact on the damage of grain. There are several factors that can affect the damage of grain when using the bucket elevators. One of the main factors is the speed of unloading. If the unloading speed is too high, the grain may be damaged when falling into the elevator. Another factor that can affect the damage of grain when unloading buckets is the air pressure in the burrow. If the air pressure in the burrow is too high, it can also lead to damage to the grain when falling. Moreover, the design of the bucket elevator can also affect the damage to grain. For example, if the buckets are too narrow or too deep, this can damage the grain when filling them. The design of the buckets can also affect how the grain will be unloaded from the buckets, which can affect the damage of the grain.
3. The problem of collision of the discharged material with the working body of the subsequent machine. This factor is also a serious problem that can lead

to significant losses in grain quality. This problem arises due to the fact that the buckets when unloading the burrows can strongly toss grain, which can lead to collision with other surfaces inside the elevator. At this level, the speed of unloading the grain is the highest, and the buckets are at the maximum height. The grain must move quickly from the elevator to the next machine so as not to slow down the production process. But at such a high unloading speed, the buckets are at the maximum height, which leads to additional loads on the grain and, as a result, damage to its structure. For example, grain can be crushed or deformed, which can lead to loss of product quality.

There are several suggested ways to reduce the grain damage. The first one, is the installation of rubberised plates at the bottom of the bucket elevator, is one of the ways to eliminate the problem of "backlagging" when lifting seeds up. The process of installing the plates does not require special skills and can be performed by operators on the spot. Such plates are usually produced from high-quality rubber, which provides good adhesion to the grain and does not cause damage upon contact with it. They can be installed on the bottom of each bucket or only on those that work with the most difficult materials to pump. The use of rubberised plates in the lower part of the buckets allows reducing or completely eliminating the "backlagging" and preventing the grain loss. In addition, it can reduce the load on the elevator and extend its service life. However, the use of rubberised plates can affect the performance of the elevator and lead to an increase in energy consumption. In addition, such plates must be replaced periodically to maintain the efficiency of the installation. Thus, the use of rubberised plates at the bottom of the bucket elevator can be an effective way to eliminate the problem of "backlagging" when lifting seeds up, which can lead to a reduction in grain losses and improve product quality. However, before installing them, a thorough analysis and assessment of possible negative consequences should be carried out. In addition, the use of rubberised plates in the lower part of the bucket elevator may be ineffective when pumping bulk materials with a high moisture content since the rubber may not adhere well to wet grain and does not provide the necessary adhesion. In such cases, alternative methods of eliminating the problem can be considered, such as installing special foamed materials at the bottom of the bucket or using additional means to increase friction between the grain and the bucket. It is also necessary to remember that rubberised plates can be subject to wear and damage, especially when working with heavy materials, which may lead to the need for frequent replacement. In addition, the installation of rubberised plates may require additional maintenance and replacement costs, which should also be considered when choosing this method [11].

The second one, to ensure the optimal way of unloading buckets, is an important aspect of ensuring high-quality grain and efficient operation of bucket elevators. When choosing the optimal method of unloading buckets, it is important to consider the following parameters: the size and shape of the buckets, the speed of the conveyor, the type of material that is pumped, and the characteristics of the elevator, such as the angle of inclination and dimensions. One of the ways to achieve the optimal method of unloading buckets is to build the outline of the bucket head only for a specific brand with knowledge of its parameters and the drive mechanism. The use of an irregular shape of the bucket head can lead to problems with unloading grain. For example, if the head of the bucket elevator has a too sharp shape, that can lead to an uneven load on the buckets, which can lead to damage to the grain and reduce its quality. If the head of the elevator is too flat, then this can lead to congestion and reduce the capacity of the elevator. The optimal way of unloading buckets can be achieved only by constructing a bucket head, which considers all the parameters of the bucket elevator, including the size, shape of the buckets, the speed of the conveyor, and the type of material. This will help to reduce the grain damage, improve the quality of the product, and ensure the efficient operation of the bucket elevator [12].

The third way is to install a dispenser in the upper part of the elevator in the unloading area, which can help reduce damage to seeds when they collide with the working body of the subsequent machine. The dispenser is a device that controls the speed of unloading grain from the elevator, and also allows grain to be distributed over the unloading surface, which can reduce the likelihood of its collision with the working body. When installing the dispenser in the unloading area of the elevator, it can be configured to a certain speed of unloading grain, which allows controlling the process and preventing possible overloads that can lead to grain damage. In addition, the dispenser can be configured to evenly distribute the grain over the unloading surface, which can prevent its accumulation and reduce the likelihood of collision with the working body [13].

Dispensers can be of various types, including mechanical, electronic, and hydraulic. Mechanical dispensers are used for unloading grain with low productivity, while electronic and hydraulic dispensers are used for high-performance unloading systems. Electronic and hydraulic dispensers can be equipped with sensors to control the unloading speed and grain level, which allows automatically adjusting the unloading speed and preventing possible overloads [14]. Dispensers can also have different shapes and designs, depending on the operating conditions and user requirements. They can be installed both inside and outside the elevator, depending on the specific needs. In addition, dispensers can be made of various materials, such as steel, aluminium, plastic. When installing the dispenser, it is necessary to consider various parameters, such as the type and design of the elevator, the type of grain,

the required volume of unloading. It is also important to properly configure the dispenser for specific operating conditions. An additional advantage of installing a dispenser is the ability to control the process of unloading grain, which allows increasing the efficiency of the elevator and reduces the likelihood of emergencies [15-17]. Thus, the installation of a dispenser in the upper part of the elevator in the unloading zone is an effective way to reduce the damage of grain in collision with the working body of the subsequent machine. This allows improving the quality of unloaded seeds and reduces losses of crop and income.

5 Discussion

This study, aligning with the conclusions on the effectiveness of direct staining methods and magnifying glass inspection for assessing seed damage during transportation in bucket elevators, underscores the significance of these approaches. As indicated by Shahbazi [18], the staining technique, which uses brightly colored solutions, enhances the visibility of surface damage, providing crucial immediate feedback on transportation quality. This method is essential for pinpointing the causes of seed quality deterioration and taking corrective measures, although it falls short in revealing internal seed damage.

The observed 4.25 % seed damage rate within the bucket elevator, as noted in our findings, aligns with the insights from Fraczek and Slipek [19] regarding elevator efficiency and its impact on crop yield and quality. Regular measurements, as suggested by Warechowska et al. [20], are vital for maintaining and enhancing elevator performance. Innovative designs and modernizations, such as those explored by Gieroba and Dreszer [21] and Grundas and Mis [22], including diverse bucket shapes and sizes, improved drive mechanisms, and optimized unloading processes, have shown efficacy in minimizing seed damage.

Particular attention to modifications like rubberized plates in the elevator's lower section, customizing the bucket head outlines as per brand specifics as discussed by Wozniak [23], and installing dispensers in the upper unloading area has been emphasized. Those modifications, echoing the suggestions of Kaharmanova [8] and Rsaliev [9], have not only enhanced productivity but significantly reduced the rate of grain damage, as well. Those changes also facilitated continuous and slower grain movement, positively impacting transportation, as highlighted by Mesterhazy et al. [5] and Shaimerdenova [6]. Optimising the size and shape of buckets in bucket elevators, as discussed by Grundas and Mis [22], and controlling conveyor speed [24] are crucial for improving the efficiency of separators and avoiding grain damage. The integration of modern automation and quality control technologies, using sensors and control algorithms, can further enhance separator efficiency [25-28]. However, considerations such as the need for proper grain storage and processing before pumping [29], the potential for reduced capacity and increased equipment wear in new designs [30-33], and the importance of testing new designs [33], are essential for effective elevator operation.

Incorporating these references, the study underscores the practical importance of grain damage analysis in bucket elevators for the agricultural sector. It aids in identifying operational issues and developing solutions to reduce product losses and improve seed quality, as also supported by the findings of Kumar and Kalita [2] and Koyshybaev et al. [7]. This analysis is vital for comparing the grain handling methods, informing equipment manufacturing and maintenance, supporting operator training programs, and providing a standardized testing approach, as suggested by Syzdykova et al. [3] and Irmulatov et al. [4]. The economic, productivity, and quality benefits of reducing the grain damage through analysis and improved handling techniques are significant, contributing to the broader goal of food security.

For a more accurate and comprehensive assessment of the seed damage caused by bucket elevators, various research methods, including visualization techniques, should be employed, as discussed in the wider literature. Implementing these advanced technologies and developments can significantly reduce the seed damage rates, thereby enhancing product quality and elevator efficiency. Moreover, these advancements can lead to reduced wear and tear on equipment, decreasing maintenance and repair costs, as outlined by the broader research community. Future research could focus on analyzing and improving various factors that influence the grain damage during the loading and unloading processes in bucket elevators.

6 Conclusion

The use of the method of direct staining of seeds and their subsequent inspection through a magnifying glass is an effective way to assess the degree of damage to seeds during transportation using bucket elevators. This method quickly determines the presence of damage on the surface of the seeds and its degree. Staining of seeds is carried out with special solutions that allow identifying the damage, and also differ in bright colour, which facilitates their detection during examination. This method enables quick feedback on the quality of transportation, which can be useful in determining the reasons for the decline in seed quality and taking measures to eliminate problems. However, this method does not provide information about the internal state of the seeds and does not determine the presence of hidden damage. Therefore, to fully assess the quality of seeds, it is necessary to use additional methods and tools, such as strength tests and other methods of analysis.

According to the measurement results, the percentage of seeds damaged as a result of the bucket elevator operation is 4.25 %. This indicator is important for assessing the quality of the elevator, as damaged seeds can lead to a decrease in the yield and quality of the final product. The measurement results can be used to optimise the operation of the elevator and reduce the percentage of seed damage. Such measurements should also be carried out regularly to monitor and improve the quality of the bucket elevator. The reduction of seed damage caused by the bucket elevator can be achieved through the application of patent inventions and modernisation of the elevator design. These developments may include new bucket shapes and sizes, improved drive mechanisms, and methods to optimise the unloading process.

Special attention was paid to the installation of rubberised plates in the lower part of the bucket elevator, the construction of the outline of the bucket head only for a specific brand with knowledge of its parameters and drive mechanism, and the installation of a dispenser in the upper part of the elevator in the unloading area, which eliminated the presence of "backlagging", to ensure the optimal way of unloading buckets and to reduce the probability of collision of grain with the working body of the subsequent machine, resulting in a significant increase in productivity and a decrease in the percentage of damage to grain. This design also ensured the continuous supply of grain from the bucket elevator to the subsequent machine and reduced the speed of grain movement, which also had a positive impact on the transportation process.

The analysis of grain damage by a bucket elevator is of a great practical importance for the agricultural sector, as it helps to identify the problems in elevator operation and develop solutions to reduce product losses, improve work efficiency and seed quality, optimize equipment and processes to minimize mechanical damage, allow comparison of grain handling methods, inform equipment manufacturing and maintenance procedures, support operator training programs, and provide a standardized testing approach. Reducing the grain damage through analysis and improved handling provides economic, productivity, and quality benefits across the sector while supporting the food security.

For a more accurate assessment of the seed damage caused by a bucket elevator, various research methods can be used, for example, visualisation methods. The use of such patent developments can help significantly reduce the percentage of damage to seeds, which will positively affect the quality of products and increase the efficiency of the bucket elevator. In addition, the use of new technologies can reduce the wear and tear of equipment and decrease the cost of its maintenance and repair. Further study of grain damage by the bucket elevator during loading/unloading can be aimed at analysing and improving various parameters that affect the damage of grain.

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Conflicts of interest

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OPTIMIZATION BIODIESEL PRODUCTION FROM HONGE OIL (PONGAMIA PINNATA)

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Resume
Rapid industrialization and increased diesel engine usage have driven up diesel consumption, burdening economies with heavy petroleum product imports. Diesel fuel emissions, including carbon dioxide, carbon monoxide, and smoke, pose environmental concerns. Biodiesel produced from non-edible vegetable oils offers a sustainable solution.
Therefore, a study was conducted on optimizing Honge oil biodiesel production using Taguchi optimization. The research aimed to maximize biodiesel yield from Honge oil, employing Taguchi's technique for enhanced output. Through systematic optimization, the study sought to achieve an efficient and improved process for generating biodiesel from Honge oil. During experimental work, reaction time, reaction temperature and molar ratio of methanol/oil were varied. Among all the experiments conducted during the optimization process, the highest yield of biodiesel was about 88.7 %, as compared to weight of oil. These findings contribute to improving biodiesel production efficiency and promoting its use as an eco-friendly alternative to fossil fuels.

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1 Introduction

The increasing use of vehicles and industrialization has led to a significant increase in energy consumption. Many countries rely on fossil fuels, especially petroleum products, which are concentrated in a few parts of the world. These reserves are limited, and with increasing consumption, it is possible that they will be depleted in the near future [1-4]. This would put a strain on oil-deficient countries, like India, which import most of their petroleum products. Diesel fuel is a prevalent energy source for compression ignition engines in various sectors, such as automotive, power generation, and agriculture. From the literature review it is found that fossil fuels are depleting at faster rate, which may cause the fuel crises in the near future. One of the alternatives for fossil fuels (diesel fuel) can be the biodiesel derived from native vegetable oils [5-11].

Using straight vegetable oil in compression ignition engines leads to reduced thermal efficiency and increased smoke emissions, primarily because of its high viscosity and low volatility. In addition, the clogging of fuel filters and injectors, carbon deposits, and engine damage can be observed. The vegetable oil can be made suitable for diesel engine applications by reducing the glycerol content in it to promote its volatility [12-17]. Biodiesel production involves the conversion of vegetable oil/animal fats into their esters transesterification [18-20]. The yield of biodiesel can be optimized by adjusting process parameters.

In this study, the Taguchi method was employed to optimize the conversion of Honge oil (Pongamia pinnata) into its methyl ester, commonly referred to as Honge biodiesel. The highest yield of biodiesel was obtained with an 8:1 molar ratio of methanol to oil, a reaction temperature of 60 °C, and a catalyst concentration of 0.6 %. This study suggests that the Honge oil can be used for biodiesel production. By optimizing the production process using the Taguchi method, it is possible to improve the biodiesel yield. This could lead to increased utilization of biodiesel as a renewable fuel, thereby reducing reliance on imported petroleum products.

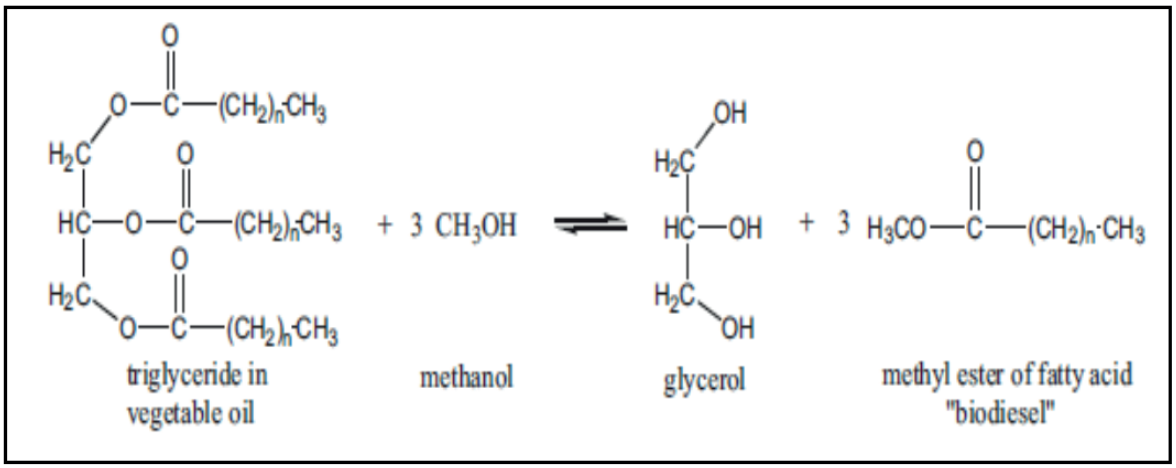

Figure 1 *Transesterification reaction*

2 Literature survey

Graboski et al. [21] studied the straight vegetable oils used in the engine, which leads to various problems like fuel filter clogging, poor atomization, and incomplete combustion because of its highly viscosity, high density, and poor non-volatility. To reduce the viscosity of the straight vegetable oil, the following four techniques were adopted: heating/pyrolysis, dilution/blending, micro-emulsion, and transesterification. Among all these techniques the transesterification is an extensive, convenient and the most promising method for the reduction of viscosity and density of the straight vegetable oils. However, this process introduces additional costs due to the transesterification reaction, which requires both chemical inputs and energy inputs in the form of the process heat.

Jana, et al. [22] focused on optimization of the transesterification of waste cooking oil under the CaO-based catalyst, derived from an ostrich eggshell by different types of machine learning approaches. They used various machine learning techniques like the fuzzy logic system (T1FLS), response surface methodology (RSM), adaptive neuro-fuzzy inference system (ANFIS), and type 2 fuzzy inference logic system (T2FLS). They studied the effect of various parameters on the biodiesel yield. They found the maximum yield of biodiesel at 93.3 % with fuzzy logic models.

Chintagunta et al. [23] studied production of biodiesel from waste cooking oil. They found that biodiesel is an eco-friendly, renewable, and potential liquid biofuel mitigating greenhouse gas emissions. They indicated that waste cooking oil can be a suitable feedstock for the biodiesel production.

Tamoradi et al. [24] goal was to optimize the production of Biodiesel from rapeseed oil and waste corn oil. They obtained the optimum yield of biodiesel at a molar ratio of 13:1 and a catalyst concentration of 8 %w/vol at 65 °C in 7 h reaction time. These results were validated over ANOVA and 3D response surface contour plots.

Degfie et al. [25] used a CaO nano-catalyst as a catalyst for biodiesel production from waste cooking oil. They achieved biodiesel yield of biodiesel at 96 % at waste cooking oil to methanol molar ratio of 1:8, 1 wt. % of CaO nano-catalyst, 50 °C reaction temperature and 90 minutes reaction time. The various properties of biodiesel, like the viscosity, specific gravity, water and sediment, total acidity, ash content and sulfur content, were tested according to the ASTM D 6571 and found in good agreement with the standard.

From the above literature survey, it can be found that combination of various factors effecting the biodiesel production varies with the type of feed stock.

3 The transesterification process

Transesterification process involves conversion of triglyceride from vegetable oil or animal fat into its esters and glycerol through a reaction with alcohol and a catalyst. This reaction is depicted in Figure 1. It shows that reaction between the triglyceride and alcohol (molar ratio of 1:3), results in three moles of fatty acid esters and one mole of glycerol. It is important to note that transesterification is a reversible reaction and tends to proceed at a relatively slow rate [19-20, 26-27].

4 Factors effecting the biodiesel production

4.1 Molar ratio of alcohol and oil

A molar ratio of alcohol to oil is a crucial factor in transesterification process, impacting both the reaction rate and cost. A higher molar ratio accelerates the transesterification reaction but reduces catalyst availability, potentially lowering the biodiesel yield. The recommended molar ratio typically ranges from 4:1 to 10:1, with methanol commonly used due to its affordability. Achieving the optimal molar ratio depends on the specific oil type and desired biodiesel

characteristics. By precisely managing the alcohol-to-oil ratio, it is feasible to produce the high-quality biodiesel with a favorable yield [28].

4.2 Reaction temperature.

Rate of any chemical reaction depends on reaction temperature. With increase in temperature, chemical reaction accelerates, which reduces the time for completing the reaction. In the case of the transesterification process, an increase in temperature results in a shorter reaction time due to the reduction in the viscosity of the oil. However, increasing the reaction temperature beyond a certain limit, speeds up the saponification of triglycerides resulting in lower biodiesel yield. Heating reactants beyond the vaporization temperature of alcohol, results in lower biodiesel yield due to decreased availability of reactants for reaction [29]. Hence, during the transesterification reaction, reactants are to a temperature, which accelerates the reactions and does not cause evaporation of alcohol.

4.3 Free fatty acid and water content in oil

The quantity of free fatty acid (FFA) and water within the oil plays a significant role in determining the biodiesel yield. Oils with elevated FFA levels necessitate a greater amount of alkali catalyst to counterbalance these acids, resulting in increased production expenses. Moreover, heightened FFA levels can impede the reaction process, slowing it down notably. Water present in the oil also contributes to this deceleration, creating hurdles in the separation of glycerol. Additionally, it has the potential to generate foam during the reaction, further complicating the process [30]. By carefully controlling the FFA and water content, it is possible to achieve optimal conditions for transesterification and produce the high-quality biodiesel with a satisfactory yield.

4.4 Catalyst

Choice of catalyst and its quantity in the transesterification process significantly impacts the yield and quality of biodiesel. Alkali catalysts like KOH and NaOH are commonly employed due to their effectiveness at lower temperatures and cost-effectiveness. However, their usage can result in soap formation when the oil's free fatty acid (FFA) content is high. Acid catalysts, such as H_2SO_4 and HCl, are less sensitive to FFA content but exhibit slower reaction rates and higher corrosiveness.

The quantity of catalyst employed also influences the biodiesel outcome. A higher catalyst amount accelerates the reaction, but it may lead to soap formation. Conversely, a lower catalyst amount prolongs the reaction time and can result in incomplete conversion [29]. The optimal catalyst type and quantity depend on the specific oil type and desired biodiesel properties. By carefully selecting and balancing these factors, it is possible to achieve high-quality biodiesel with a satisfactory yield.

4.5 Stirring rate

The transesterification process is a chemical conversion that transforms triglycerides into esters and glycerol, facilitated by an alkali, acid, or enzyme catalyst. Since the reactants, alcohol, and oil, have different densities and are immiscible, the reaction occurs solely at their interface. To ensure uniformity, continuous mixing of the reactants is employed using either a mechanical or magnetic stirrer. The mixing intensity must strike a balance between the thorough mixing and prevention of soap formation, which can occur if the reaction is reversed due to excessive agitation [31]. Achieving the optimal mixing intensity is crucial for producing the high-quality biodiesel with a favorable yield, contingent on the specific oil type and desired biodiesel properties.

4.6 Reaction period

Conversion of triglycerides to esters increases with reaction time, but it is crucial to find the optimal duration as the reaction is reversible and prolonged reaction times can result in the reversion of esters to triglycerides. The optimal reaction time depends on factors such as the type of oil, catalyst quantity, and desired biodiesel properties [17]. Typically, a reaction time of 1-2 hours is sufficient, but other considerations include reaction temperature, catalyst type, and FFA content. Experimentation is recommended to determine the ideal reaction time for achieving the high-quality biodiesel production with a desirable yield.

5 Methodology

5.1 Production of biodiesel

Honge seeds are collected from trees planted on roadsides, forests, and dry private land around Bidar city. The seeds are manually decorticated and dried for four days until they become completely dry. Using an oil extraction machine, the dried seeds are crushed to obtain the oil, which has a recovery rate of about 45% compared to the kernel weight. Chemicals, such as phenolphthalein indicator, anhydrous methanol, potassium hydroxide, sulphuric acid, and potassium hydroxide pellets, are purchased from the local market. A biodiesel preparation kit consisting of a 2-liter capacity three-neck round bottom flask, a magnetic stirrer with

(a) (b)

Figure 3 *a) Transesterification reactor b) settling of biodiesel and glycerol*

Figure 2 *Determination of FFA in oil*

speed control, and other glassware is used for the conversion process.

Initially the FFA content of Honge oil is determined using the titration method. During this method, Honge oil is titrated with phenolphthalein indicator until oil turns into pink color as shown in Figure 2 and accordingly FFA content is determined. The Honge oil is initially subjected to esterification to reduce the FFA below 4%. To achieve this, methanol and sulphuric acid are used in a molar ratio of 6:1, with the acid concentration of 0.5% of the oil. The esterification is carried out at 60 °C for 75 minutes, while stirring at 400 rpm. After the reaction, the mixture is left to settle for 5-8 hours, and the FFA content is determined, resulting in approximately 3.2% FFA. Subsequently, the transesterification is performed using methanol and potassium hydroxide. The oil-methoxide mixture is maintained at 60 °C for 1.5 hours during which it is stirred at 400 rpm in Figure 3(a). Once the trans-esterification is finished, the products of reaction are allowed to settle for 24 hours, leading to separation of biodiesel and glycerol into distinct layers, with the biodiesel as the upper layer, which can be seen in Figure 3(b). The biodiesel and the glycerol are separated in distinct layers (upper layer is the biodiesel and the lower layer is glycerol). It should be noted that the biodiesel might contain impurities like residual methanol and soap. Therefore, the raw biodiesel is washed using the distilled water to eliminate the soap content. The biodiesel is heated to 100 °C to remove traces of water if any present in it. Finally, the biodiesel is filtered to eliminate i mpurities.

5.1.1 Optimization of factors affecting the transesterification process

As previously mentioned, yield of biodiesel is influenced by various factors. To determine the optimal combination of these factors for achieving the highest biodiesel yield, it would be impractical and costly to systematically vary each factor individually. Instead of that, in this study was employed the Taguchi method, an approach to design of experiment, to efficiently identify the best combination of molar ratio, catalyst concentration, and reaction temperature that would

Table 1 *Factors affecting the biodiesel production*

Process parameters	Levels		
	1	2	3
Molar ratio of methanol to oil	4:01 (A1)	8:01 (A2)	10:01 (A3)
Catalyst concentration % (w/w of oil)	5 (B1)	0. 6 (B2)	0. 8 (B3)
Reaction temperature	50 (C1)	60 (C2)	65 (C3)

Table 2 *Orthogonal array*

Trial No.	Methanol-oil molar ratio (A)	Catalyst concentration (B)	Reaction temperature (C)
1	4:1	0.5	50
2	4:1	0.6	60
3	4:1	0.8	65
4	8:1	0.5	60
5	8:1	0.6	65
6	8:1	0.8	50
7	10:1	0.5	65
8	10:1	0.6	50
9	10:1	0.8	60

maximize the biodiesel yield, while minimizing the number of trials required.

The Taguchi method is a statistical technique used to optimize the process by identifying and minimizing the variability associated with influential factors. By utilizing this method, effort is made to determine the optimum combination of process parameters, which results in the highest yield of biodiesel. This study highlights the value of utilizing the Taguchi method as a robust tool for process optimization, as it allows for identification and mitigation of influential factors' variability.

In the study, the process parameters are carefully selected to determine their optimal levels. A literature review and equipment availability were considered in choosing the following parameters. In the present study, a molar ratio of methanol to oil levels of 4:1, 6:1, and 8:1; concentration of catalyst at levels at 0.5%, 1%, and 1.5% (w/w) as compared to oil and reaction temperature at levels from 50 °C to 70 °C, were considered. Those parameter levels were based on extensive research and practical considerations, forming the basis for subsequent experiments and analysis. Table 1 shows the parameters that are affecting the biodiesel production.

To analyze the effect of different levels of process parameters on the biodiesel yield, an orthogonal array (OA) was chosen. The choice of the OA is done based on the total number of degrees of freedom (DOF) of all the process parameters. The number of DOFs for each process parameter is calculated using the formula (L - 1) [27], where L is the number of levels of each process parameter. For example, the number of DOFs for the molar ratio is 2, as there are 3 levels (3-1 = 2). Similarly, the number of DOFs for catalyst concentration and reaction temperature is also 2. The total number of DOFs for all the process parameters is calculated by multiplying the numbers of DOFs of each parameter by the number of parameters, resulting in a total number of DOFs of 6. According to the OA selection criteria, the OA chosen for analysis should have the number of trials equal to N+1, where N represents the total number of DOFs of all the process parameters.

A standard L9 orthogonal array (3x3) was selected for the present investigation, which suggests that conducting 9 experiments would be sufficient to optimize the parameters. The details of the L9 orthogonal array used in the present work are shown in Table 2.

After conducting the experiments according to the selected orthogonal array, the signal-to-noise ratio was calculated for each trial. The signal-to-noise ratio is a logarithmic function, which measures the deviation of the quality characteristics from the optimum value. The objective in this study was to maximize the yield of biodiesel. Hence, the "higher the better" S/N ratio is used. The mean S/N ratio and the S/N ratio for each level of each process parameter were determined to predict the optimal results. Table 3 presents the biodiesel yield and S/N ratio for each trial.

After computing the signal-to-noise ratio for each trial, the average S/N ratio for each level process parameter was determined. These values are then plotted in Figures 4, 5, and 6, respectively. From these

Table 3 *Biodiesel yield and S/N ratio for each trial*

Trail No	Biodiesel yield (% of wt of oil)	S/N Ratio
1	83.3	38.413
2	86.5	38.74
3	85.7	38.66
4	87.5	38.84
5	87.3	38.82
6	87	38.79
7	83.7	38.455
8	85.2	38.609
9	85.7	38.66
Average	85.7	38.665

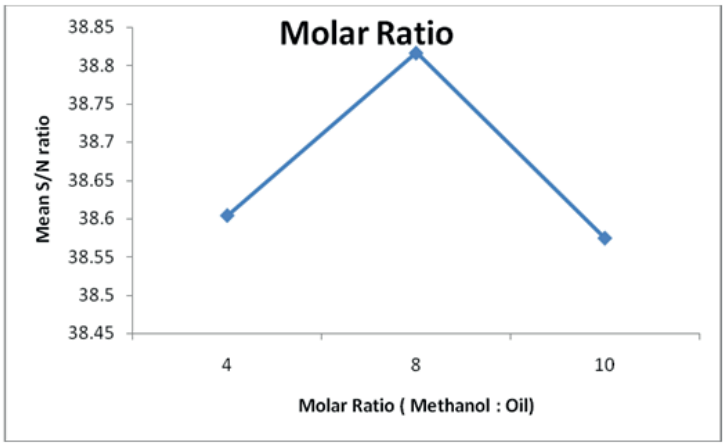

Figure 4 *Molar ratio*

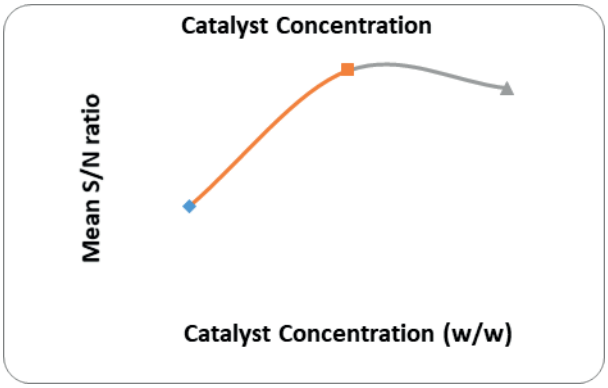

Figure 5 *Catalyst concentration*

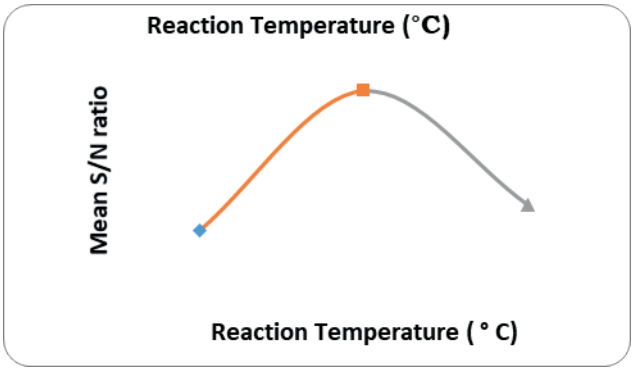

Figure 6 *Reaction temperature*

figures is found that the S/N ratio for all the three parameters is the highest at level 2, which shows that at those levels of process parameters the biodiesel yield can be the highest. The optimal combination of process parameters for achieving the highest biodiesel yield is identified as A2-B2-C2 (highest S/N ratio). In other words, according to the S/N ratio analysis, the optimal parameters are: A at level 2 (8:1), B at level 2 (0.6 wt. %), and C at level 2 (60° C).

The biodiesel yield, at optimal combination of process parameters (Yopt), is determined by

$$Yopt = M + \sum_{i=1}^{0} (X_i - M), \quad (1)$$

where M represents the overall mean of the biodiesel yield of all test runs, and X_i represents the mean biodiesel yield for the trials with i-th level of the given control parameter X. The biodiesel yield, at the optimal combination A2-B2-C2, was observed to be 88.7 %. To confirm the validity of these results, a confirmation test was conducted at the same combination of A2-B2-C2, and the biodiesel yield is found to be 87.43 % of the weight of Honge oil. This value is very close to the calculated value, which supports the accuracy of the optimization process.

6 Conclusions

This study employed the Taguchi approach for optimizing the biodiesel yield by determining the optimal combination of methanol to oil molar ratio, concentration of catalyst and reaction temperature. The Taguchi method is a statistical approach that identifies influential factors in a process. An orthogonal array (L-9) experimental design was used to evaluate all the possible combinations of the process parameters economically. The study revealed that at combination of a methanol to oil (molar ratio of 8:1), a catalyst concentration (0.6 wt. %), and a reaction temperature (60 °C) a biodiesel yield is approximately 88.7 %. The results of the Taguchi analysis are compared to those of the experimental confirmation test. The results of Taguchi prediction are close to results of the conducted confirmation test. At optimized combination of process parameters, the biodiesel yield is the highest of all the experiments conducted. In conclusion, this study demonstrates the efficacy of the Taguchi method in determining the optimum combination of process parameters for the maximum yield of biodiesel from the Honge oil.

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Without the support and collaboration of these individuals and organizations, this work would not have been possible. We are immensely grateful for their contributions. Moving forward, we are excited to continue our research endeavors in the field of biodiesel production, aiming to make further advancements and meaningful contributions to the field.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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In its over 70 years of successful existence, the University of Žilina (UNIZA) has become one of the top universities in Slovakia.

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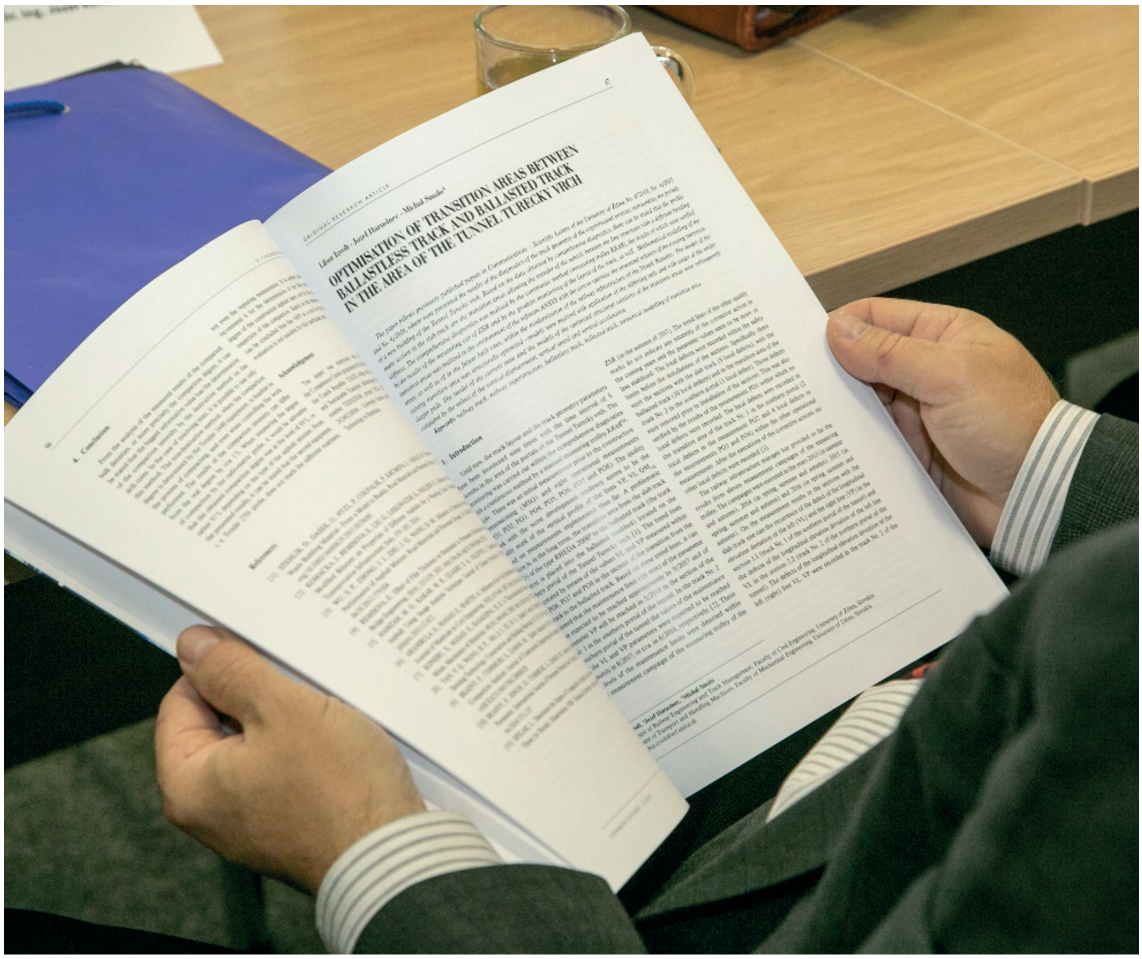
The journal Communications - Scientific Letters of the University of Žilina is now an established open access scientific journal focusing primarily on topics related to the field of transport. The main areas, related to transport, include Civil Engineering, Electrical Engineering, Management and Informatics, Mechanical Engineering, Operations and Economics, Safety and Security, Travel and Tourism Studies.



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RELIABILITY ANALYSIS OF BENCHMARK WATER DISTRIBUTION SYSTEM

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Resume

Water is a necessary component of urban structures and a source of life. Nowadays water distribution system's performance might decline for various reasons, resulting in water waste, hence, to maintain a reliable water distribution network, assessing each water distribution study's validity is crucial. Therefore, this research has focused on using durability assessment to evaluate a water supply system. A water distribution network includes an overhead tank and nodes, pipelines, and nodes. The hydraulic properties of every node as well as pipe, including pressure and flow, are calculated utilizing EPANET. This research evaluates the reliability analysis based on the benchmark data's various diameter of pipes, such as 0.6 m, 0.4 m, 0.3 m, 0.2 m, and 0.15 m, usage. Finally, this research analyses the reliability of each set of diameter pipes in the water supply system.

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1 Introduction

Water supply systems move freshwater from centralized rehab centres or groundwater supplies to service connections or consumer taps [1-2]. These devices work to maintain enough pressure in the water supply system, while also maintaining the quality and amount of the water. This network comprises a network of pipes, pumps, valves, reservoirs, storage tanks, and other parts. The supply chain is based on the local topography [3-5]. For distribution, one may use one of the following processes or methods: gravity method, mixed gravity plus pumping system, or pumping system. Water is accessible with appropriate pressure at numerous locations throughout the area due to the gravity system establishing the water supply origin inside the transmission area. The gravity method often requires no pumping [6-9]. The pumping system is the one that is used the most frequently. Water is forced directly into the supply system to generate the necessary force in this manner. Typically, two pumps must be run at different speeds due to the difference in the transmission. The first pump must move fresh water from the reservoir to the treatment facility.

The following described pipelines are primarily used in the water distribution system [10]. Further, Massive pipelines often include steel pipes specially made with space for any required coatings, including cement, mortar, epoxy, etc. Cast iron, ductile iron, PVC, and other pipelines transmit drinking water in minor transportation networks. Freshwater should not be transported through brick and stone ducts to avoid leaks.

Pipe networks, water pumps, storage areas, fire hydrants, house service connections, metres, and other accoutrements are the primary components of the water supply system, as depicted in Figure 1 [11]. The piping systems have nodes and links (pipes). A transmission network's effectiveness is not just determined by the difference between supply and demand [12]. The performance depends on how reliable the system is and satisfies the demand with a minimal loss. Additionally, the network must always be able to meet needs under reasonable pressure. A water supply service's poor performance can be attributed to various factors. The essential causes are pipe failures, low pressure and flow rate in pipes, and shortage of pumping stations, valves, and appurtenances [13].

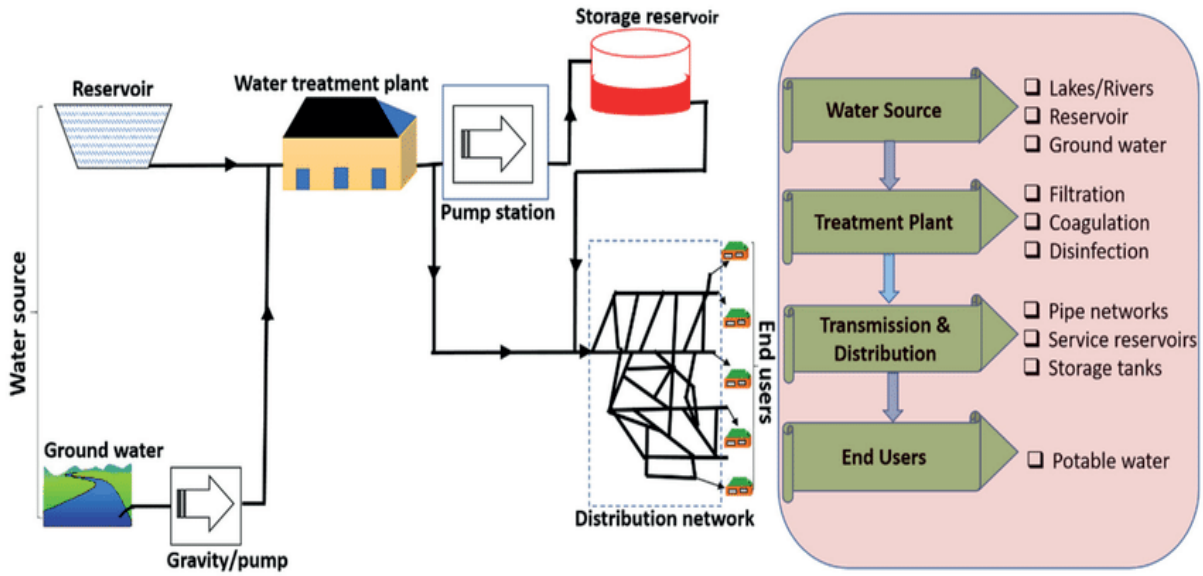

Figure 1 *Architecture of water distribution system [11]*

The distribution of hydraulic characteristics and flow rates in pipes, including pressures (leftover heads) at nodes, are estimated using the simulation software for specific loading and operational circumstances groups. The hydraulic simulation models EPANET help in calculating water distribution piping systems. With the support of hydraulic models, it is difficult to predict the performance of a water supply method. The main contribution of this research paper is as follows: the dependability of water supply is analyzed by the selected benchmark model.

This study paper's format is set up this way: Section 2 examines the current dependability of the water distribution systems. After that, part 3 describes the procedures and materials, and section 4 presents the findings and a commentary. Section 5 brings this paper to a close.

2 Literature survey

The dependability study of current water supply systems is covered in this section. Each Water Distribution System (WDS) element is prone to mechanical malfunction. Still, because of the high level of susceptibility in pipes, the authors Gheisi et al. [14] focused on pipeline breakage (often called mechanical malfunction or pipe failure). The article [14] thoroughly investigates the WDS reliability analysis literature. The research aimed to categorize the appropriate literature and distinguish between various failure kinds and reliability analysis approaches. The three criteria utilized to classify WDS failures were mechanical/physical and hydraulic, as well as the quality of water problems. The main elements affecting the WDS's reliability are the probability of occurrence or failure rates in pipes, pipe disaster groupings, and criteria to quantify consistency. However, this research does not cover the complete network of practical concerns regarding the maintenance of dependability and reliability-based design of WDSs.

Redundancy and surrogate reliability approaches for water distribution systems have been examined by Tanyimboh et al. [15]. Flow entropy, resilience index, network resilience, and excessive power factor were the metrics that were evaluated. The essential objective is to demonstrate that, for water distribution systems, only flow entropy appears to have the attributes of an appropriate indicator of hydraulic dependability and redundancy. One of the main drawbacks is that the flow entropy model it examined was created for a specific operating scenario. Investigating potential expansions to various operational conditions would be desirable.

Additionally, according to Duan et al. [16], the analysis method can be divided into three categories: pipe analysis, node effect analysis, and system stability. The simulation study findings and discussion show that the EPANET is a reliable computation tool for the pipe impact assessment and system reliability tests, including pipe type analysis and pipe network adjustment. The critical pipe sections, most likely to cause widespread cascade breakdown, must be eliminated during the pipe network repair to increase the disaster resilience. The water supply piping system, as well as the breakdown features of the cascade, should also be considered when analyzing the pipe network's dependability.

Jeong et al. [17] examined the relationship between the representative reliability indices with hydraulic processes to provide the maximum suitable reliability index considering the desired organism's effectiveness under numerous circumstances. Six hydraulic measurements, that characterize system performance, were established from redundancy, robustness, and serviceability perspectives. Future research should consider the needs of water managers when creating

scenarios that represent actual operational situations and when determining the dependability indices and hydraulic measurements.

Berardi et al. [18] demonstrated a two-level mechanical reliability assessment process appropriate for large authentic Water Distribution Networks (WDNs). The most important scenarios are effectively processed using a path/connectivity-based technique to establish dependability indicators for global-level investigation. The advanced hydraulic model features robust modelling of the water amount in tanks consuming the widespread global gradient approach and automatic topological change detection. An essential test bed for demonstrating the effectiveness of the technique indicated on a practical organization challenge of substantial scale, in addition to the difficulty, was the usage of an actual WDN, with unprecedented difficulty demonstrated.

3 Methodology description

In a water supply system, reliability is "the capacity of a distribution system to meet the demands that are made on it where demands are stated in terms of 1) the flows to be distributed, and 2) the range of pressures at which those flow rates must be provided." This research's primary goal was to determine the effectiveness of a water supply method. The objectives were to (a) analyze the total effectiveness of the water distribution structure using reliability analysis and (b) suggest/recommend needed modifications for the effective operation of the WDS. Following are the steps involved in a water distribution network simulation: (i) distribution system's network representation, (ii) updating object properties in the system, (iii) system operation, (iv) selecting a list of analysis options, (v) executing a hydraulic analysis, and examining the research outcome. Equation (1) is used to determine the reliability analysis.

$$R_i(h) = \left\{ \frac{Q_i}{Q_{i,req}}, \right. \tag{1}$$

where $R_i(h)$ = *Hydraulic reliability at node i*,

$$Q_i = \begin{cases} Q_{req}, & if\ H_i \geq H_{i,req} \\ Q_{i,req}\sqrt{\dfrac{H_i - H_{\min}}{H_{i,req} - H_{\min}}}, & H_{\min} < H_i < H_{i,req}, \\ 0, & H_i \leq H_{\min} \end{cases} \tag{2}$$

where H_i = *Evaluated pressure an node i,* Q_{req} = *required outflow an node i,* Q_i = *evaluated outflow at node i,* $H_{i,req}$ = *required pressure at node i,* H_{min} = *Minimum pressure at node at i*.

3.1 Benchmark data

In this research, the Wolf-Cordera Ranch (WCR) Model was taken as the benchmark data shown in Figure 2 [19]. The modest WCR advancement spans 2,400 km^2, but its current mean demand is predicted to be 3.7 million gallons. The WCR design has five pumps and 372 hydrants, with 1981 pipelines. The pipe density per is 0.825 pipes. The majority of pipes in the system have a 0.2032 m diameter. The network must simultaneously open several hydrants to meet significant fire needs of 5250 gpm to 8000 gpm with multiple residential fire demands of 2500 gpm to 2750 gpm. Multi-objective optimization could be applied to satisfy all the physical

Figure 2 *Wolf-Cordera Ranch (WCR) data [19]*

restrictions and achieve overall design goals. Node pressures, fire streams, and overall performance of the model if one of the essential malfunctions are the bare minimum. Pressure at 544 nodes, fire flow at 544 hydrants, concurrently fire flow at 33 business locations and 45 residential sites, pump discharge capacity, and energy life cycle costs for typical day and peak day needs were all assessed for the WCR water system. Removing the hydrants deemed to achieve design specifications with the lowest pipe widths decreased the 625 objective assessments to 40 accurate evaluations.

3.2 Water distribution network

The water circulation grid comprises pipes of diameters of 0.15 m, 0.2 m, 0.3 m, 0.4 m, and 0.6 m. The total length of the 0.15 m diameter pipeline is 5491 m, the entire length of the 0.2 m diameter pipeline is 85837 m, the whole length of the 0.3 m diameter pipeline is 18429 m, the total length of the 0.4 m diameter pipeline is 2193 m, and total length of the 0.6 m diameter pipeline is 5056 m. Finally, the cumulative length of the pipeline network is 117 km. Figures 3 - 6 show the layout

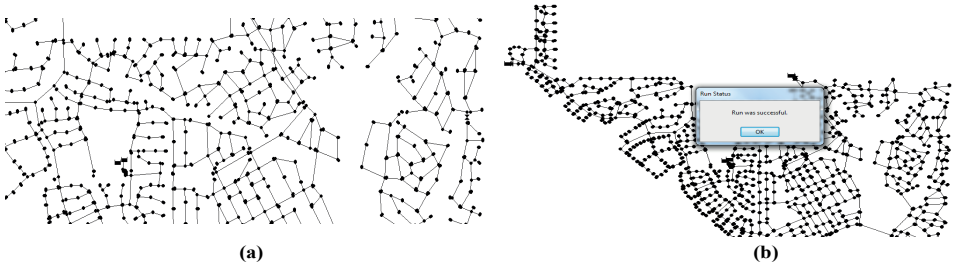

Figure 3 *Network simulation with 0.6 m diameter (a) Network before simulation, (b) Network with 40 % of pipe damage*

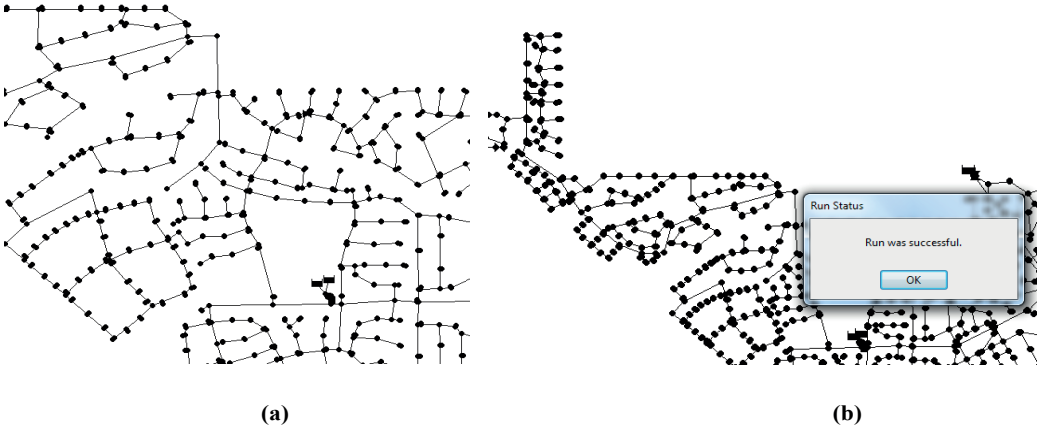

Figure 4 *Network simulation with 0.4 m diameter (a) Network before simulation, (b) Network with 71 % of pipe damage*

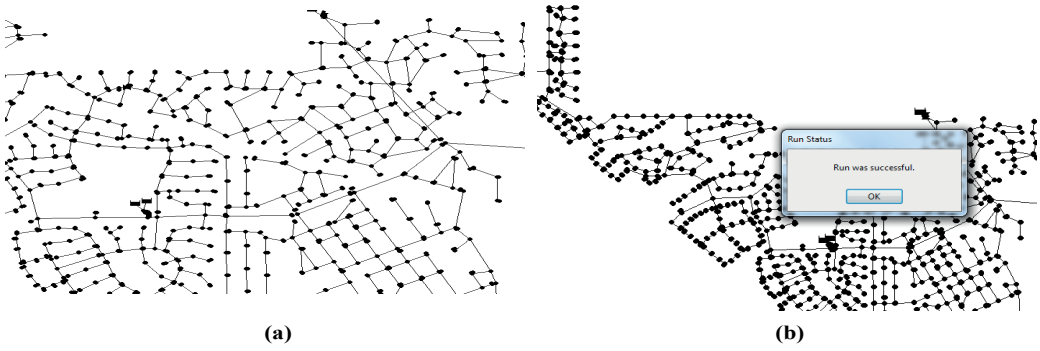

Figure 5 *Network simulation with 0.3 m diameter (a) Network before simulation, (b) Network with 13 % of pipe damage*

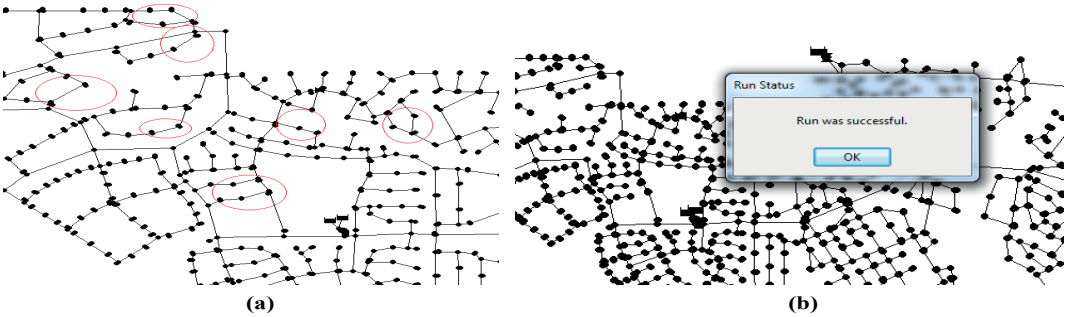

Figure 6 *Network simulation with 0.2 m diameter (a) Network before simulation, (b) Network with 4% of pipe damage*

Table 1 *The Network statistics*

Parameters	Quantity
Sum of Junctions	1782
Quantity of Reservoirs	4
Amount of Tanks	0
Amount of Pipes	1985
Number of Pumps	6
Number of Valves	4
Flow Units	GPM

Table 2 *Analysis of data*

Sl No	Diameter of pipe (m)	Friction Factor	No. of pipes used	Total length of pipes (m)	Cumulative length
1	0.15	0.005	670	5491 m	117 km
2	0.2	0.036	1033	85837 m	
3	0.3	0.030	235	18429 m	
4	0.4	0.024	14	2193 m	
5	0.6	0.012	33	5056 m	

distribution from the EPANET before and after the simulation for various diameters.

4 Result and discussion

Tool: EPANET
OS: Windows 7 (64 bit)
Processor: Intel Premium
RAM: 8 GB RAM

4.1 Statistics of a network

The parameters employed in this study, including overall junctions, reservoirs, tanks, pipelines, pumps, and valves, are described in this section along with their corresponding quantities, which are explained in Table 1.

4.2 Criteria for the pipe selection

Susceptible to damage: Pipes with the highest flow rate and higher pressures are more prone to damage.

Critical pipes: Pipes connecting the reservoir to the main header and pump discharge lines to the reservoir are essential pipes that must be incorporated into the simulation for the better use.

4.3 Data analysis

From the EPANET analysis, this research provides the % of damage for the various diameters of pipe, such as 0.6 m, 0.4 m, 0.3 m, 0.2 m, and 0.15 m. Moreover, the friction factor, the number of pipes used, and the total length of the pipe for various diameters are described in Table 2.

4.3.1 The failure simulation of a 0.6m diameter pipe

The EPANET analysis provides a pipe failure simulation of a 0.6m diameter pipe, results of which are presented in Table 3. The total number of pipes used for 0.6m pipe is 33. To analyze the system reliability, 5 pipes are initially considered as damaged out of 33 pipes, where the obtained damage is 15%; thus, the system is reliable. Moreover, the 10 pipes are regarded as damaged out of 33 pipes, where the acquired damage is 30%; thus, the system is reliable. Then, 13 pipes are considered as damaged out of 33 pipes, where the obtained damage is 40%; thus, the system is reliable. Finally, the 14 pipes are regarded as damagedout of 33 pipes, where the acquired damage is 42% and the system has failed. Hence, the system is reliable with a number of 13 damaged pipes.

The diamter of 0.6m is the largest diameter of pipes used in the entire network. The system is reliable, with 40% of damaged pipes. The system could deliver water to the entire network with 60% of pipes of a 0.6m diameter. The average pressure difference observed was 234 kPa, as shown in Figure 7. System reliability failed above 40% of damage.

4.3.2 The failure simulation of a 0.4m diameter pipe

The EPANET analysis provides a pipe failure simulation of a 0.4m diameter pipe described in Table 4. The total number of pipes of a 0.4m diameter used is 14. To analyze the system reliability, the 3 pipes are initially considered damaged out of 14 pipes, where the obtained damage is 21%; thus, the system is reliable. Moreover, the 5 pipes are regarded as damaged out of 14 pipes, where the acquired damage is 36% thus, the system is reliable. Then, 10 pipes are considered as damaged out of 14 pipes, where the obtained damage is 71%, thus the system is reliable; Finally, the 11 pipes are considered as damaged out of 14 pipes, where the acquired damage is 78%, and the system is failed. Hence, the system is reliable with 10 damaged pipes.

The 0.4m diameter is the second-largest diameter of pipes used in the entire network. Number of pipes used is smaller when compared to the other diameter pipes. The system is reliable, with 71% of damaged pipes. The system could deliver water to the entire network with 29% of pipes of 0.4m diameter. The average pressure difference observed was 20.6 kPa, shown in Figure 8. System reliability failed above 71% of damage.

Table 3 *The failure simulation of a 0.6m diameter pipe*

Sl No	Total no. of pipes	No. of pipes damaged	% of damage	Remarks
1.	33	5	15	The system is reliable, with 5 damaged pipes
2.	33	10	30	The system is reliable, with 10 damaged pipes
3.	33	13	40	The system is reliable, with 13 damaged pipes
4.	33	14	42	System failed

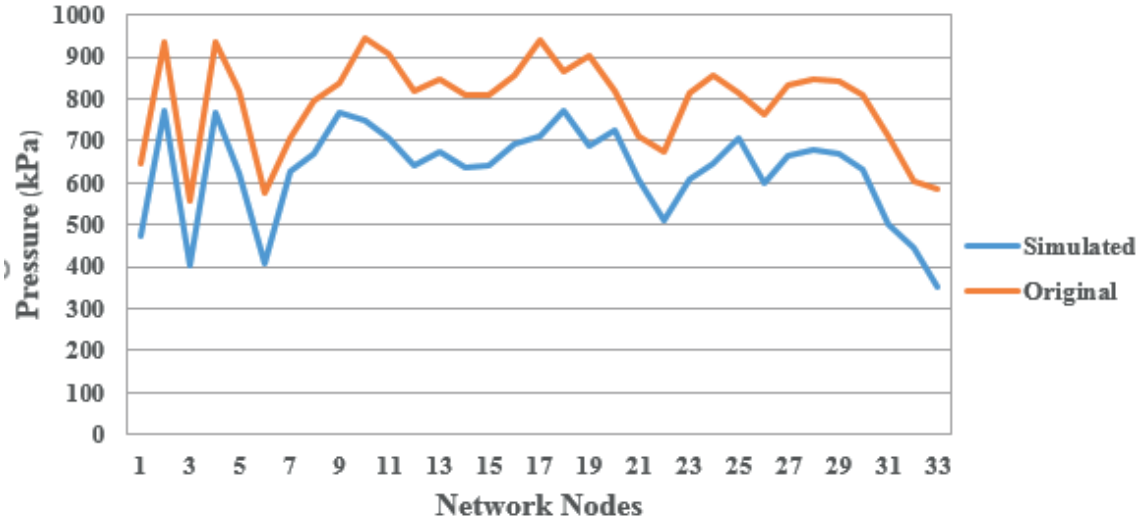

Figure 7 *The pressure difference of a system showing 40% of damaged pipes (∅ 0.6m) vs the original network*

Table 4 *The failure simulation of a 0.4 m diameter pipe*

Sl No	Total no. of pipes	No. of pipes damaged	% of damage	Remarks
1.	14	3	21	The system is reliable with 3 damaged pipes
2.	14	5	36	The system is reliable with 5 damaged pipes
3.	14	10	71	The system is reliable with 10 damaged pipes
4.	14	11	78	System failed

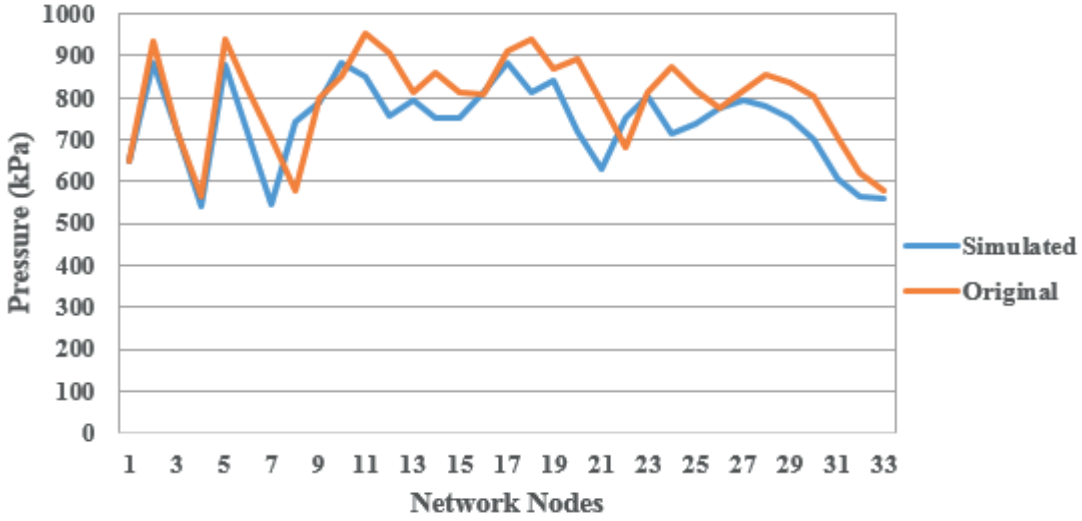

Figure 8 *The pressure difference of a system showing 71% of damaged pipes (∅ 0.4 m) vs the original network*

4.3.3 The failure simulation of a 0.3 m diameter pipe

The EPANET analysis provides a pipe failure simulation of a 0.3 m diameter pipe, illustrated in Table 5. The total number of pipes of a 0.3 m diameter was 235. To analyze the system reliability, initially, the 10 pipes are considered as damaged out of 235 pipes, where the obtained damage is 4%; thus, the system is reliable. Moreover, the 25 pipes are considered as damaged out of 235 pipes, where the acquired damage is 11%; thus, the system is reliable; Then, 31 pipes are considered as damaged out of 235 pipes, where the obtained damage is 13% thus the system is reliable; Finally, the 32 pipes are considered as damaged out of 235 pipes, where the acquired damage is 14%, and the system is failed. Hence, the system is reliable with 31 damaged pipes.

The 0.3 m diamter pipes cover around 18 km of the total network, and 235 pipes are used, as well. The system is reliable, with 13% of damaged pipes. The system could deliver water to the entire network with 87% of pipes of a 0.3 m diameter. The average pressure difference observed was 8.5 kPa, which is shown in Figure 9. System reliability failed above 13% of damage.

4.3.4 The failure simulation of a 0.2 m diameter pipe

The EPANET analysis provides a pipe failure simulation of a 0.2 m diameter pipe as shown in Table 6. The total number of pipes of a 0.2 m diameter is 1033. To analyze the system reliability, the 15 pipes are initially considered damaged out of 1033 pipes, where the obtained damage is 1.4%; thus, the system is reliable. Moreover, the 35 pipes are considered damaged out of 1033 pipes, where the obtained damage is 3.4%; thus, the system is reliable. Then, 42 pipes are considered as damaged out of 1033 pipes, where the acquired damage is 4%; thus, the system is reliable. Finally, 43 pipes are considered damaged out of 1033 pipes, where the obtained damage is 4.1%, and the system fails. Hence, the system is reliable with 42 damaged pipes.

The 0.2 m diameter pipes cover the major area of the network (86 km of the total network and 1033 pipes are used, as well). The system is reliable, with 4% of damaged pipes. The system could deliver water to the entire network with 96% of pipes of a 0.3 m diameter. The average pressure difference observed was 0.95 kPa, as wshiown in Figure 10. System reliability failed above 4% of damage.

Table 5 *The failure simulation of a 0.3 m diameter pipe*

Sl No	Total no. of pipes	No. of pipes damaged	% of damage	Remarks
1.	235	10	4	The system is reliable, with 10 damaged pipes
2.	235	25	11	The system is reliable, with 25 damaged pipes
3.	235	31	13	The system is reliable, with 31 damaged pipes
4.	235	32	14	System failed

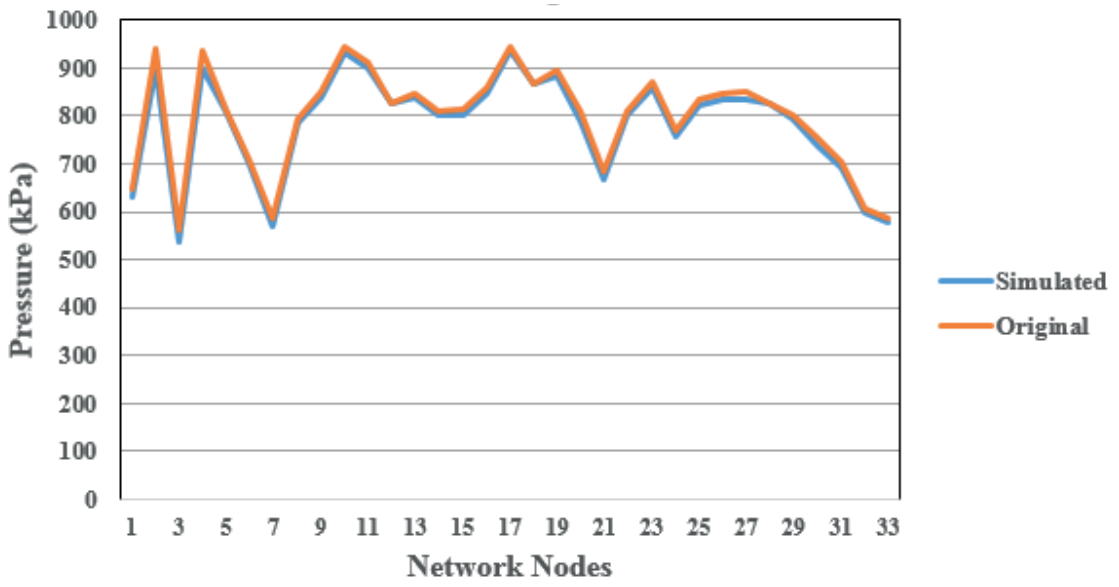

Figure 9 *The pressure difference of a system showing 13 % of damaged pipes (∅ 0.3 m) vs the original network*

Table 6 *The failure simulation of a 0.2 m diameter pipe*

Sl No	Total no. of pipes	No. of pipes damaged	% of damage	Remarks
1.	1033	15	1.4	The system is reliable with 15 damaged pipes
2.	1033	35	3.4	The system is reliable with 35 damaged pipes
3.	1033	42	4	The system is reliable with 42 damaged pipes
4.	1033	43	4.1	System failed

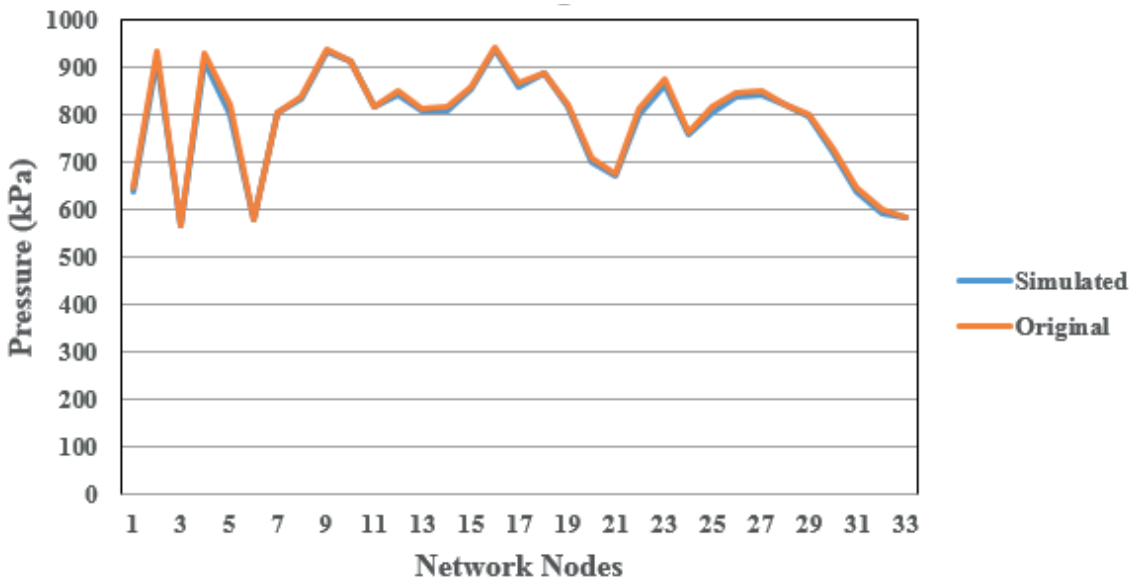

Figure 10 *The pressure difference of a system showing 4 % of damaged pipes (∅ 0.2 m) vs the original network*

Table 7 *Final analysis of data*

Sl No	Diameter of pipe (m)	No. of pipes used	Minimum no. of pipes to be healthy	Allowed % of the damage	Pressure difference (kPa)	Network status
1	0.15	670	670	0	0	Reliable
2	0.2	1033	991	4	0.95	
3	0.3	235	204	13	8.5	
4	0.4	14	4	71	20.6	
5	0.6	33	19	40	234	

4.3.5 The failure simulation of a 0.15 m diameter pipe

The 0.15 m diameter is the smallest diameter of all the pipes in the network. It is the end connection pipe to the consumers, and if one pipe fails, supply to that consumer/s will be stopped, and system reliability will fail. Howevere, that will not affect the other consumers or the total network. For the above four failure cases (0.6 m, 0.4 m, 0.3 m, and 0.2 m), a single consumer was not affected by a supply failure, and system reliability was intact during a limited % of failure.

4.4 Final data analysis

The allowed % of damage and their pressure difference for various pipe diameters are presented in Table 7. From the EPANET analysis, this research provides reliability for the various pipe diameters such as 0.6 m, 0.4 m, 0.3 m, 0.2 m, and 0.15 m.

5 Conclusions

This study provides a systematic approach for evaluating the WDS's reliability using the EPANET because the WDS's functionality is crucial for a consistent water supply. Moreover, the benchmark data such as WCR are used as inputs, and its findings can be used to measure any network's dependability after testing and validation. This research evaluates the % of acceptable damage for various pipe diameters such as 0.15 m, 0.2 m, 0.3 m, 0.4 m, and 0.6 m from the EPANET simulation. The system reliability failed above 40 % for 0.6 m, 71 % for 0.4 m, 13 % for 0.3 m, and 4 % for 0.2 m. As a result, this study indicates that reliability testing can be done using this data on every network since it depends on the diameter, length, and number of pipes used in a network and since almost every water distribution network has a consistent ratio of pipes. The benchmarking ratio acquired by comparing various types of networks will be tested and validated in the future. In addition, we may establish a hypothesis with benchmarking ratios/safe damage limit for any water distribution network.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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PERCEPTION BASED LEVEL OF SERVICE FOR SPEED HUMPS IN MIXED TRAFFIC CONDITIONS - A CASE STUDY IN INDIA

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Resume

Speed humps are used to reduce vehicle speeds and enhance the road safety. However, there has been very limited study that discusses the Level of Service (LOS) that a speed hump provides to its road users. The present study attempts to designate LOS for movement on speed humps based on user perception. A perception-based survey in google forms was collected to assess the opinions of daily commuters while moving over speed humps along their regular routes to work which comprised various socio demographic and technical factors along with recommendations and suggestions. The study employed clustering technique to determine the Level of Service range. The results offer valuable insights into the effectiveness and acceptance of speed humps as a traffic calming measure for enhancing the road safety and could serve as a basis for potential improvements in speed hump design and implementation.

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1 Introduction

The speed hump, commonly known as the ”sleeping policeman” plays a crucial role in ensuring road safety and reducing vehicle speeds. Nowadays, traffic calming devices can be found extensively on roads, particularly in densely populated areas. These devices have been proven to be highly effective in controlling vehicle speeds. There are more than 20 types of traffic calming devices, each offering its unique set of advantages and disadvantages [1]. Excessive speed remains a major cause of road fatalities, leading to thousands of deaths and permanent injuries from traffic accidents each year. It has been demonstrated that by reducing the speed, the frequency of accidents decreases significantly. Among various speed reduction measures, speed humps have proven to be the most effective way to reduce speed and lower accident rates [2-6].

The significant decrease in vehicle speeds brought about by traffic calming measures can effectively discourage through traffic and enhance pedestrian safety. However, this reduction in speed may lead to an increase in traffic noise and air pollution levels, creating a controversial situation. Traffic emissions are recognized as a primary contributor to air pollutants such as carbon dioxide (CO_2), nitrogen oxides (NOx), volatile organic compounds (VOC), and particulate matter (PM). In fact, traffic emissions are responsible for up to 80 % of the total PM emissions. [7]. Speed humps can occasionally result in noise, cause back injuries, and damage vehicles when drivers attempt to traverse them at excessive speeds [8]. In the context of India, where heterogeneous and mixed traffic is prevalent, the effectiveness of speed humps was briefly discussed by [5]. It was noted that the incorrect placement and improper design of speed humps have been causing challenges in maintaining smooth traffic flow [3].

According to [9], the level of service represents a quality measure that reflects the operational traffic characteristics and how they are perceived by road users. It provides valuable insights into the efficiency and effectiveness of the traffic conditions and the level of satisfaction experienced by the users. The research conducted by [10] devised a level of service measure for fundamental expressway segments through an empirical approach. Their approach involved incorporating

customer satisfaction as a critical parameter to determine the level of service. Clustering can be used to classify the level of service criteria for urban streets [11]. Levels of service at median openings were quantified through the application of cluster analysis [12-13]. Authors of [14] applied clustering techniques as an analytical tool to assess the performance of two-lane highways under conditions of heterogeneous traffic. The k-mean algorithm was employed for the clustering analysis and to establish varying levels of service ranges through calibration. However, even after many searches, no results yielded that have calculated the LOS for speed humps.

In this study, K-means clustering was employed to group data points and establish the Level of Service criteria. The cluster analysis was conducted using SPSS software. In this study, the determination of the number of clusters (k) was carried out using the silhouette plot. In developing countries like India, where heterogeneous traffic conditions are prevalent, there is a lack of extensive research conducted on the impact of speed humps on road users, particularly in terms of effectiveness and user satisfaction. Hence, the primary objective of this study was to evaluate the effectiveness of speed humps based on perception-based survey and to develop the appropriate Level of Service range for speed humps on arterial roads under Indian conditions. The study mainly concentrated on assessment of speed humps focusing on road users' perception and their level of satisfaction with these traffic calming measures.

2 LOS and clustering technique

The LOS assesses the performance and effectiveness of speed humps in managing the traffic speed, enhancing road safety, and minimizing vehicle discomfort. The LOS evaluation encompasses multiple factors, including speed reduction achieved by speed humps, vehicle response (e.g., smooth passage or discomfort), user satisfaction, and impact on traffic flow. Achieving an optimal LOS involves striking a balance between speed reduction and minimizing discomfort to vehicle occupants. Proper design and placement play a key role in ensuring passenger comfort. While speed humps enhance safety, they can also impact the traffic flow by requiring vehicles to slow down or come to a complete stop. This can affect overall road capacity and travel times. Different road users, such as drivers, pedestrians, and passengers, may have varying perceptions of speed humps' effectiveness. Their viewpoints contribute to a comprehensive understanding of LOS. The LOS analysis related to speed humps provides a comprehensive view of their impact on road safety and traffic operations. This assessment guides decision-making in designing, implementing, and managing speed hump strategies to create safer and more efficient road environments. The assessment of Level of Service in relation to speed humps has provided valuable insights into their impact on road users and overall traffic conditions. Through a comprehensive analysis of various factors, including user perceptions, preferences, and vehicle-related considerations, this study aimed to determine the effectiveness and implications of speed humps. The findings underscore the multifaceted nature of speed humps' influence on road safety, vehicle comfort, and traffic flow. The evaluation of LOS through factors, such as speed reduction, vehicle response, and user satisfaction has allowed for a holistic understanding of their role in enhancing road safety measures.

Clustering techniques are a fundamental part of data analysis. They aim to group similar data points together based on certain characteristics or attributes. Cluster analysis involves the grouping of objects based on the information present in the dataset that describes their relationships. The primary goal of clustering techniques is to form groups of data where the data points within each group exhibit similarity and differ from data points in other groups. Within a cluster group, the data points are closer to the center of that particular group than to the center of other cluster groups. K-means, k-medoid, and hierarchical agglomerative are among the commonly utilized clustering algorithms suitable for defining the Level of Service criteria.

The K-means clustering is a type of unsupervised hard partitioning method used to address classification problems [13]. The K-means method utilizes the variation within each cluster as a measure to create homogeneous clusters. Its primary goal is to segment the data in a manner that minimizes the variation within each cluster. The process of clustering begins with random assignment of objects to a certain number of clusters. Subsequently, objects are iteratively re-assigned to other clusters to minimize the within-cluster variation, which is calculated as the squared distance from each observation to the center of its associated cluster. If reallocating an object to another cluster reduces the within-cluster variation, the object is re-assigned to that cluster [15]. In the K-means clustering, the number of clusters must be predetermined by the researcher. However, the optimal number of clusters can be determined through hierarchical clustering and then specified in the K-means clustering. Despite this, K-means is generally considered superior to hierarchical methods due to its robustness against outliers and irrelevant clustering variables, which can have a stronger impact on the performance of hierarchical clustering [15]. Additionally, K-means is well-suited for handling large datasets since its computational requirements are lower compared to hierarchical methods [15]. The study's conducted by [16] suggests that the silhouette method is a viable approach for determining the optimal number of clusters (k) in clustering analysis. In various comparative experiments, the silhouette width index demonstrated effective performance [14, 17-18]. The clustering process continues either until a predefined number of iterations

are completed, or until the convergence is achieved [15]. Convergence is a crucial aspect of the K-means clustering technique. It signifies that there are no further changes in cluster affiliations, implying stability in the clustering process. Achieving convergence is facilitated through a series of iterations. Lloyd's algorithm is commonly employed in K-means clustering to reach convergence by iteratively updating and refining the cluster centers. It is a widely used heuristic for K-means clustering [19-20]. The Lloyd's algorithm can be described in two straightforward phases. In the first phase, k centroids are chosen randomly, where k represents the number of specified clusters. In the second phase, each data point in the dataset is assigned to the nearest centroid based on the Euclidean distance. If a data point is closer to another cluster's centroid than the initially assigned one, the centroid is updated until all the data points within a cluster are closest to the centroid of that specific cluster. This process ensures that each data point is associated with the most appropriate cluster center, leading to convergence [21].

2.1 Two step clustering technique

The two-step clustering, a data mining technique, involves a process of grouping data into clusters using the two-stage approach. In the first stage, a preliminary clustering is performed to create a set of initial clusters. In the second stage, these initial clusters are merged or refined to create the final clusters. This method is particularly useful for handling large datasets and is aimed at discovering underlying patterns and relationships within the data. The two-step clustering technique exhibits its effectiveness by demonstrating the quality of the clusters it forms. This technique is designed to showcase how well the data points are grouped into clusters, helping to reveal meaningful patterns and relationships within the dataset.

The silhouette measure of cohesion and separation is a metric used to evaluate the quality of clusters formed in a clustering analysis. It combines two aspects: cohesion, which measures how close the data points are within the same cluster, and separation, which gauges how distinct clusters are from each other. The silhouette measure provides a value between -1 and 1, where the higher values indicate well-separated and cohesive clusters, while negative values suggest that data points might have been assigned to the wrong clusters.

2.2 K-Means clustering to classify the clusters

The K-means method utilizes the variation within each cluster as a measure to create homogeneous clusters. Its primary goal is to segment the data in a manner that minimizes the variation within each cluster. The process of clustering begins with random assignment of objects to a certain number of clusters. Subsequently, objects are iteratively re-assigned to other clusters to minimize the within-cluster variation, which is calculated as the squared distance from each observation to the center of its associated cluster. If reallocating an object to another cluster reduces the within-cluster variation, the object is re-assigned to that cluster.

K-Means clustering is employed to check the convergence and to determine the cluster range. K-Means clustering is utilized for the two specific purposes: convergence checking and determining the cluster range.

2.2.1 Convergence checking

In K-Means clustering, convergence refers to the point where the iterative process of reassigning data points to clusters stabilizes. It ensures that the further iterations do not significantly alter the assignment of data points to clusters. By employing the K-Means clustering for convergence checking, the study is likely monitoring the iterative process to ensure that it reaches a stable state, indicating that the algorithm has effectively assigned data points to their appropriate clusters.

2.2.2 Determining the cluster range

The "cluster range" likely refers to the optimal number of clusters for the given data. The K-Means clustering requires the number of clusters to be specified beforehand. Determining the appropriate number of clusters can be challenging, but it significantly influences the quality of clustering results. By utilizing K-Means clustering for determining the cluster range, the study is likely experimenting with different numbers of clusters to find the one that results in the most meaningful and accurate clustering structure for the data.

3 Research methodology

A well-designed research methodology is crucial for generating reliable and valid results, ensuring that the research findings contribute meaningfully to the body of knowledge in a particular field. The current study utilized the study approach presented in Figure 1.

4 Data collection and extraction

In the research process, particularly in studies and projects requiring empirical data, data collection and extraction hold significant importance. Since the present study involves the collection of road user

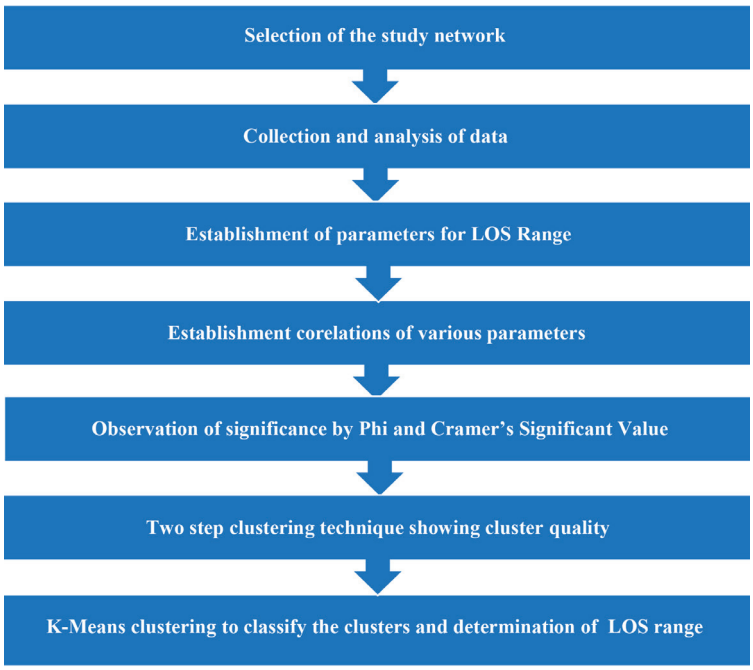

Figure 1 *Flowchart depicting the methodology*

Figure 2 *Snapshots of improperly designed speed hump*

perception while moving on speed humps, therefore their responses in form of questionnaire survey were adopted. The survey was performed among the residents of Bhubaneswar, a smart city in India. The city was selected for the survey since it was noted that most of the speed humps in the city, even on major arterial roads are not adhering to IRC guidelines (IRC 99-2018), despite being a smart city. The average chord length of the speed humps (Mohanty et al., 2021 [3]) in the city was found to be 1.88 meters as opposed to minimum 3 meters as per IRC guidelines. Figure 2 shows one of those speed humps where the chord length is too small. This results in jerky deceleration behaviour leading to negative and unsatisfactory driving experience for the road users.

Therefore, the road user perception survey was carried out among the residents of Bhubaneswar to inquire about their daily commuting patterns to their workplaces, the frequency of encountering speed humps during their daily travels, and their perceptions of these speed humps. The survey encompassed eleven aspects of consideration and requested participants to assign a score to the effectiveness of speed humps. These eleven factors are:

1. Age
2. Gender
3. Category of vehicle
4. Number of speed humps encountering
5. Requirement of speed humps
6. Effectiveness in reducing speeds below 20 km/h
7. Contribution to increase road safety
8. Speed over speed humps
9. Suggestions for speed hump modification
10. Irritation due to excess reduction of speed
11. Vehicle life affected due to too many speed humps

The responses to prepared questionnaire were collected via google forms, direct interview and through hard copies by visiting workplaces. Around 750 number of responses were collected, out of which the partially completed forms were not considered for analysis. A sample questionnaire is provided in the Appendix and a screenshot of the extracted data on excel spreadsheet is presented in Figure 3. The coding (0,1,2,3,4,5…) has been used based on the severity of lowest to highest

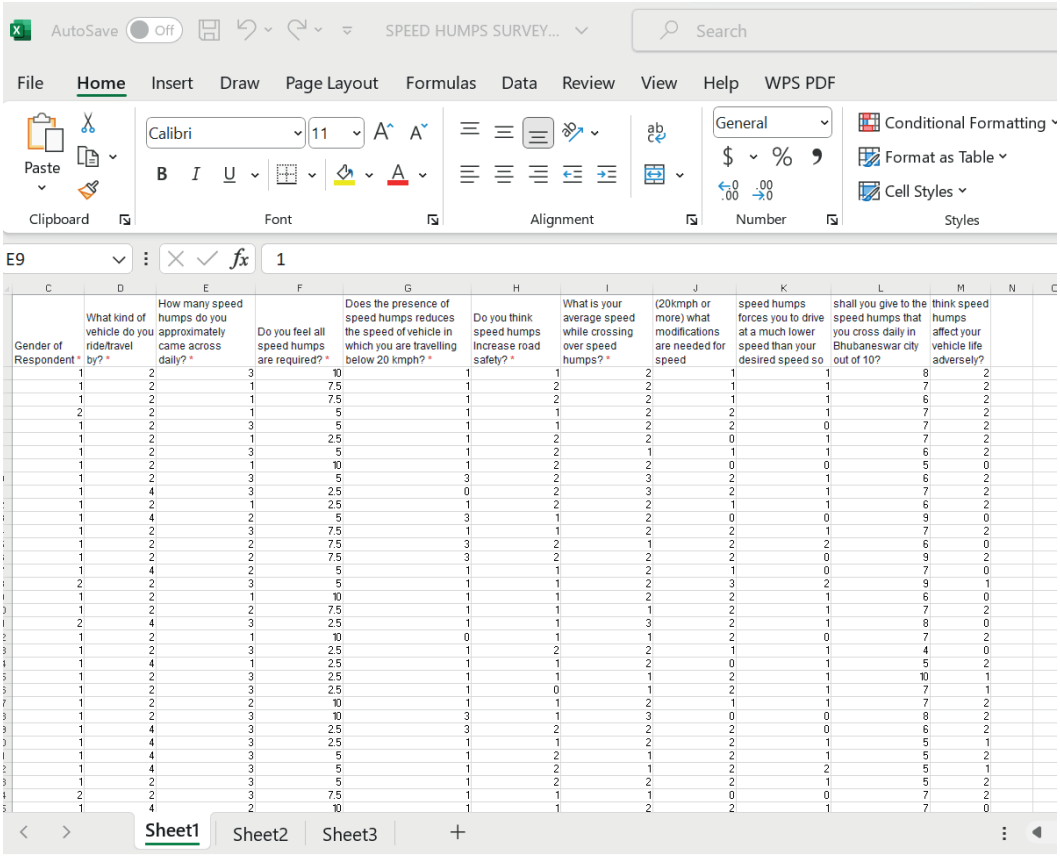

Figure 3 *Screenshot of the extracted data*

for qualitative answers and for various genders and category for quantitative answers. The coding was required for the Statistical Package for the Social Sciences (SPSS) analysis.

The extracted data was entered into the SPSS software for analysis. The research employed Phi and Cramer's statistics to identify the levels of significance for the factors. Factors with significant values below 0.05 were regarded as meaningful, while those with significant values exceeding 0.05 were deemed as not having statistical significance.

5 Results and discussion

The factors utilised for questionnaire survey were correlated with the average scores to understand their importance and impact on the perception of road user for evaluation of speed humps. Phi and Cramer's V are both statistical measures used to measure the strength and significance of associations between categorical variables. These statistics help researchers and analysts to determine whether there is a significant relationship between variables and to what extent they are associated. The results of Phi and Cramer's V are presented in Table 1. It can be observed that 6 factors are found to be significantly affecting the scores provided by road users. These six factors will now be taken into consideration for subsequent analysis.

As can be seen from Table 1, the following factors were found significant to be affecting the perception of road users with regards to travelling on speed humps.

a. Category of a vehicle
b. Number of speed humps encountering
c. Requirement of speed humps
d. Contribution to increase the road safety
e. Suggestions for the speed hump modification
f. Vehicle life affected due to speed humps

According to the provided scores, Table 2 presents the assessment of six distinct factors influencing the road users' perceptions, while traversing over speed humps. These factors have been further categorized into various sub-components, and Table 2 presents the average scores associated with each of them. As exemplified, the "Category of a Vehicle" factor has been segmented into sub-components that reflect distinct vehicle categories. To illustrate, 2-wheelers were assigned an average score of 6.5, whereas cars and jeeps garnered an average score of 6.1, and heavy vehicles obtained a score of 7. The details for each factor and their respective scores are explained in the following paragraph with graphs (Figure 4 to 9) for pictorial representation.

Notes:

Category of a vehicle: This factor is divided into sub components representing different types of vehicles. For instance, the average score given to 2-wheelers is 6.5, while cars and jeeps received an average score of 6.1, and heavy vehicles scored 7.

Table 1 *Phi and Cramer's Significant Value of all the factors*

Contributing Factors	Phi and Cramer's Significant Value	Remarks
Age	0.518	Not Significant
Gender	0.729	Not Significant
Category of vehicle	0.042	Significant
Number of speed humps encountering	0.000	Significant
Requirement of speed humps	0.000	Significant
Effectiveness in reducing speeds below 20 kmph	0.424	Not Significant
Contribution to increase the road safety	0.000	Significant
Speed over speed humps	0.106	Not Significant
Suggestions for the speed hump modification	0.037	Significant
Irritation due to excess reduction of speed	0.221	Not Significant
Vehicle life affected due to speed humps	0.000	Significant

Table 2 *Factors that contribute to the average scores assigned to speed humps*

Contributing Factors	Sub components	Average
Category of a vehicle	2 Wheeler	6.5
	Cars and Jeeps	6.1
	Heavy Vehicle	7
Number of speed humps encountering	1 Number	6.7
	2 Number	7
	3 Number	6.1
Requirement of Speed Humps	No Speed Humps Required	3.3
	< 40 %	5.6
	40-50 %	6.4
	> 50 %	6.9
	All Speed Humps Required	7.3
Contribution to increase the road safety	Yes	7.3
	No	3.8
	Not Always	6.0
Suggestions for the speed hump modification	Increase Width of Speed Humps	6.4
	Reduce Height of Speed Humps	6.2
	No Change in Design Required	7.1
	Any Other Suggestions	7.1
Vehicle life affected due to speed humps	Yes (To a higher extent)	5.7
	Yes (But manageable)	6.5
	No	7.2
	Can't Say	7.8

Number of speed humps encountering: This factor is divided by the number of speed humps encountered. The average scores for encountering 1, 2, and 3 speed humps are 6.7, 7, and 6.1, respectively.

Requirement of Speed Humps: This factor considers the respondents' perception of speed hump necessity. Different levels, ranging from "No Speed Humps Required" to "All Speed Humps Required," are presented along with their corresponding average scores.

Contribution to increased road safety: This factor explores whether respondents believe speed humps contribute to increase the road safety. The options "Yes," "No," and "Not Always" are included, along with their average scores.

Suggestions for the speed hump modification: This factor indicates the suggestions provided by respondents to modify speed humps. Different modification suggestions are listed, along with their average scores.

Vehicle life affected due to speed humps: This factor examines whether vehicle life is impacted by speed humps. Respondents' answers range from "Yes

(To a higher extent)" to "Can't Say," with corresponding average scores.

Overall, Table 2 along with Figures 4 to 9 offers a comprehensive overview of how different factors and sub components influence the average scores attributed to speed humps in the survey.

The assigned score for speed humps appears to be influenced by the respondents' age. Younger individuals might have given higher scores, while older respondents may have given relatively average scores. Alternatively, it could be interpreted that older age groups might have provided favorable scores, perceiving speed humps as effective measures for enhancing road safety. In contrast, younger respondents might have deemed speed humps less necessary.

When investigating the correlation between the number of encountered speed humps and the perceived requirement for them, an assumption can be made. If an individual faces an excessive number of speed humps daily, it is plausible that they might express a lesser need for these humps. The rationale behind this assumption is that encountering a significant number of speed humps daily could lead to irritation over time. People who traverse numerous speed humps daily are likely more acquainted with them, enabling them to better determine whether any modifications to the speed humps are necessary.

Drawing insights from both the necessity of speed humps and the irritation resulting from excessive speed reduction, it is evident that improperly designed speed humps and their overabundance can lead to frequent speed reduction, causing annoyance to vehicle occupants. Such irritation could lead to individuals assigning lower scores to speed humps and even expressing the opinion that speed humps are unnecessary in certain situations. In the case of individuals who perceive speed humps as significantly enhancing the road safety, they are more likely to provide higher scores. Conversely, those who feel that speed humps occasionally pose issues might assign more moderate scores.

Category of vehicle - Individuals driving heavy vehicles such as trucks have assigned an average score of seven out of ten. This is likely due to their vehicles having wide tires, which allows for a more comfortable experience when driving over speed humps of various heights and widths. Additionally, passengers traveling in buses generally do not encounter discomfort when crossing speed humps. In contrast, those using 2-wheelers, cars, and jeeps have given lower scores. This is potentially because they might have encountered speed humps with substantial height and width that are not well-suited for their vehicles, resulting in uncomfortable situations for them.

Number of speed humps encountering - Individuals encountering two speed humps on a daily basis have provided an average score of seven. This can be attributed to their familiarity with these two specific speed humps, along with the observation that traversing two speed humps does not significantly affect their vehicle or cause discomfort for the driver or rider. In contrast, individuals who face three or more speed humps daily have given lower scores, potentially due to irritation caused by frequent interactions with these obstacles. They may also believe that encountering numerous speed humps impacts their vehicle's longevity. Notably, there are respondents who claim not to encounter

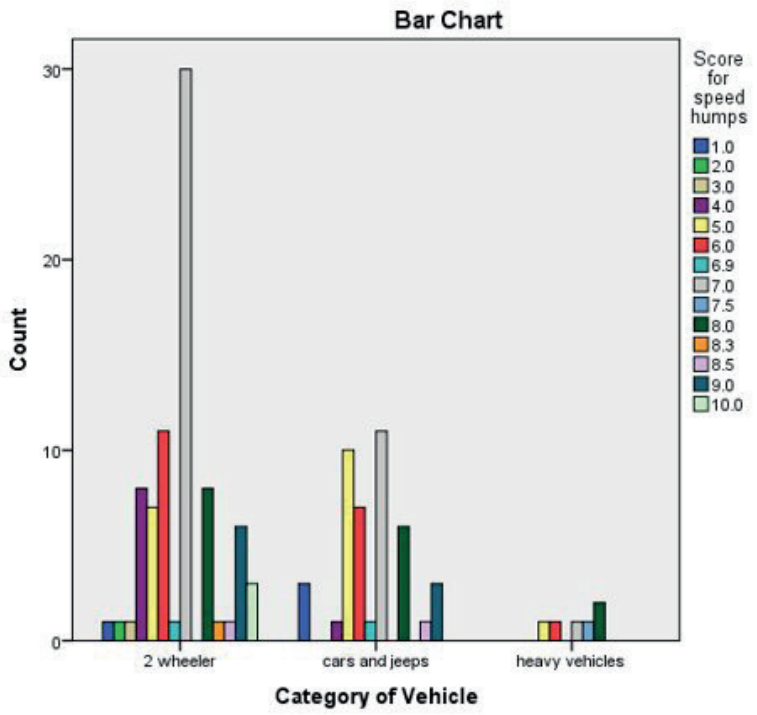

Figure 4 *Scores given by the drivers of various category of vehicles*

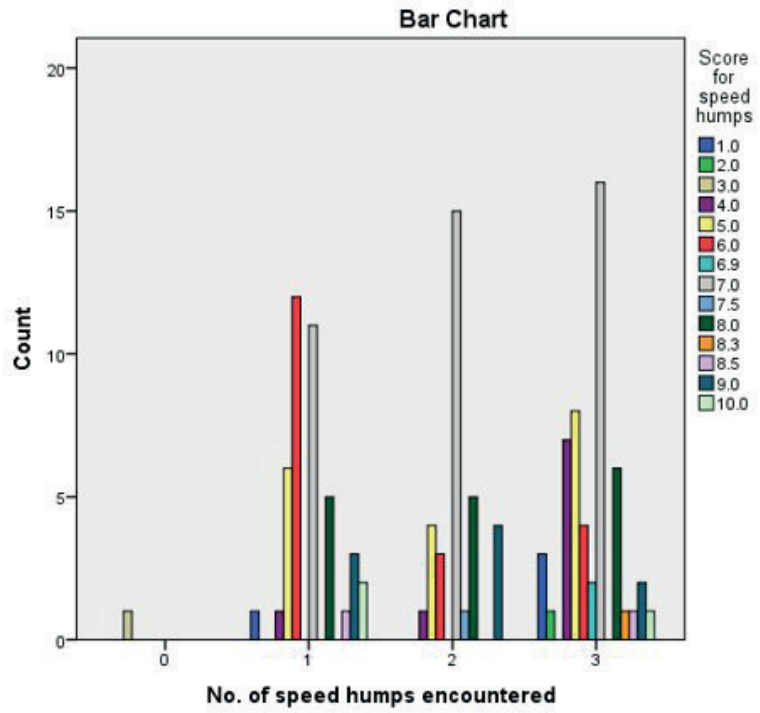

Figure 5 *Scores given by the road users encountering the number of speed humps*

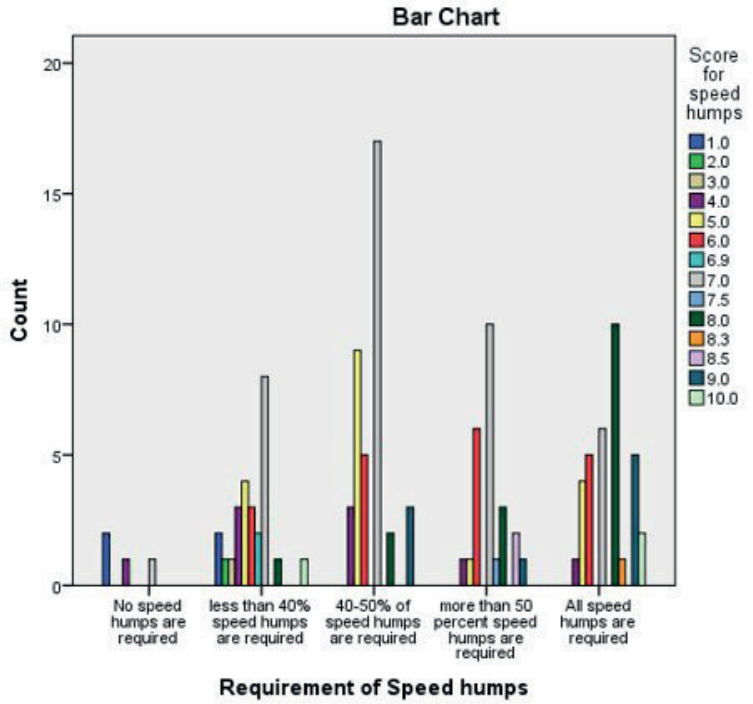

Figure 6 *Scores given by the road users on the basis speed of requirements*

any speed humps in their daily travels, yet they have still assigned a score. This situation raises questions about the validity of their scoring, thus rendering their viewpoint unreliable. As a result, their scores have been disregarded in the analysis.

Requirement of speed humps - Individuals who perceive the necessity for all s the peed humps to be in place have assigned an average score of 7.3. This group might prioritize road safety over any potential discomfort experienced while crossing speed humps. They likely believe that the speed humps foster driver and rider alertness, leading to an overall increase in road safety. Conversely, those who feel that fewer than 40 % of speed humps are required have given an average

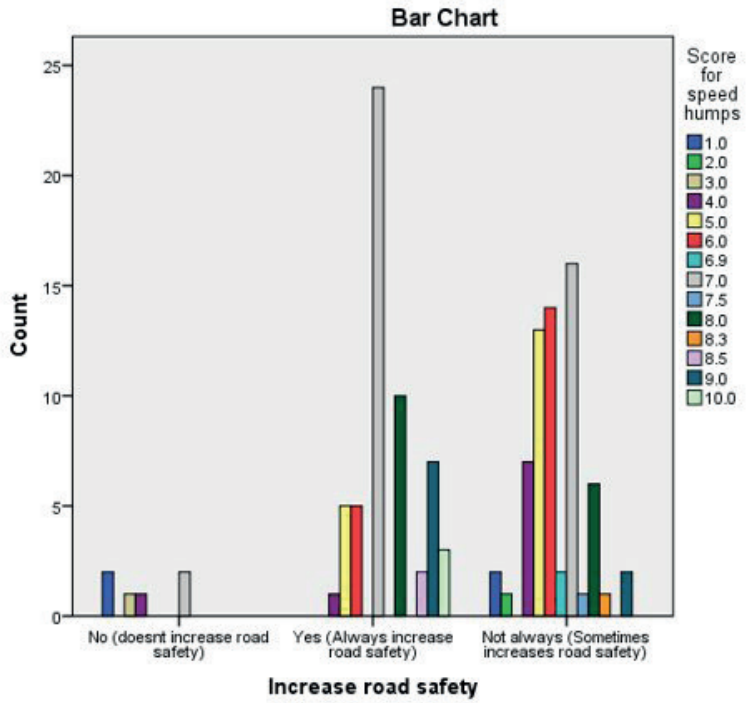

Figure 7 *Scores given by the road users on the basis of road safety*

score of 5.6. This group might find speed humps to be bothersome and detrimental to their vehicle's lifespan. They may also advocate for modifications to speed hump design and a reduction in their numbers. Furthermore, there exists a segment of individuals who deem no speed humps necessary. For these individuals, the primary emphasis might be on speed and comfort rather than the road safety.

Contribution to increase the road safety - A significant proportion of individuals hold the belief that the speed humps indeed enhance the road safety, as evidenced by their average score of 7.3. For them, prioritizing people's safety during road travel takes precedence over other considerations. These respondents likely support the idea of implementing the speed humps universally, viewing them as a means to bolster the road safety. This perspective implies that an increased number of speed humps could contribute to heightened road safety. However, a substantial portion of respondents have assigned scores suggesting that speed humps do not consistently amplify road safety. This group might consider additional factors beyond just speed humps - such as the proper usage of road signs and adhering to speed limits - as crucial contributors to road safety.

Suggestions for speed the hump modifications - Individuals who believe that no modifications are necessary for speed humps have assigned an average score of 7.1. This group perceives speed humps as adequately fulfilling their intended purpose. They find the existing dimensions of the speed humps to be comfortable and devoid of any adverse impacts on both them and their vehicles. Conversely, scores ranging from 6.2 to 6.4 have been given by individuals who advocate for alterations in speed hump dimensions, whether it be in terms of width, height, or both. These respondents have likely encountered issues that prompt them to suggest modifications.

Vehicle life affected due to speed humps - Individuals who hold the view that the speed humps do not impact a vehicle's lifespan have assigned an average score of 7.2. Their assessment might stem from the perception that the dimensions of the speed humps encountered daily are well-suited, posing no problems for their vehicles. Furthermore, these respondents might navigate speed humps at a reduced pace, minimizing external stress on their vehicles and thereby averting any negative effects. Another noteworthy group comprises those who cannot definitively ascertain whether the speed humps affect their vehicle's lifespan. These respondents have provided scores that reflect their uncertainty on the matter.

The two-Step clustering was employed in the study to assess the cluster quality, and the Silhouette value was utilized as shown in Figure 10. The research categorized the scores into six distinct clusters, resulting in an impressive Silhouette value of 0.9, indicating a high level of cluster separation and cohesion. A Silhouette value of 0.9 signifies a remarkably strong level of clustering quality. Such a high value indicates that the data points within each cluster are well-separated from other clusters, and the clustering itself is cohesive and meaningful. Such a value suggests that the clustering results are robust and reliable, portraying

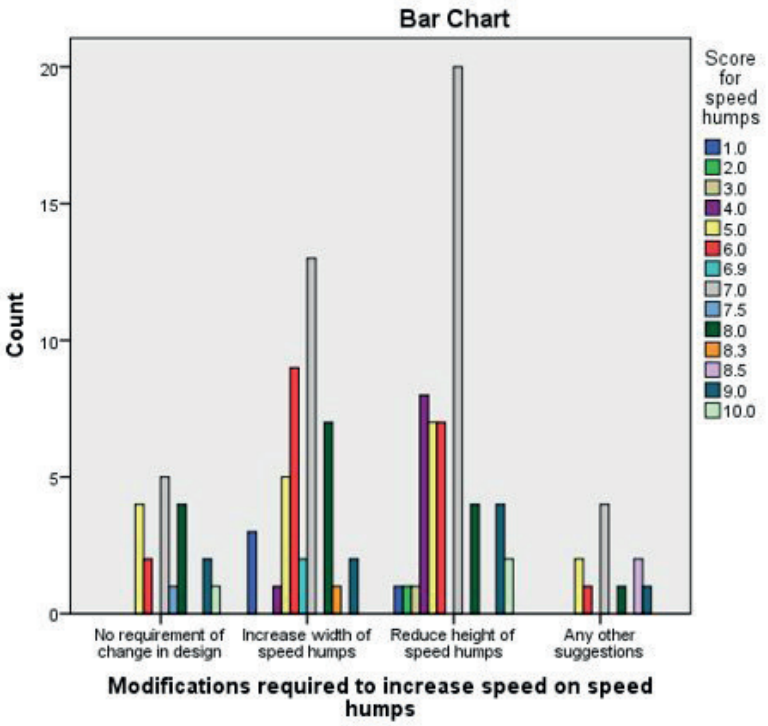

Figure 8 *Scores given by the road users for modification*

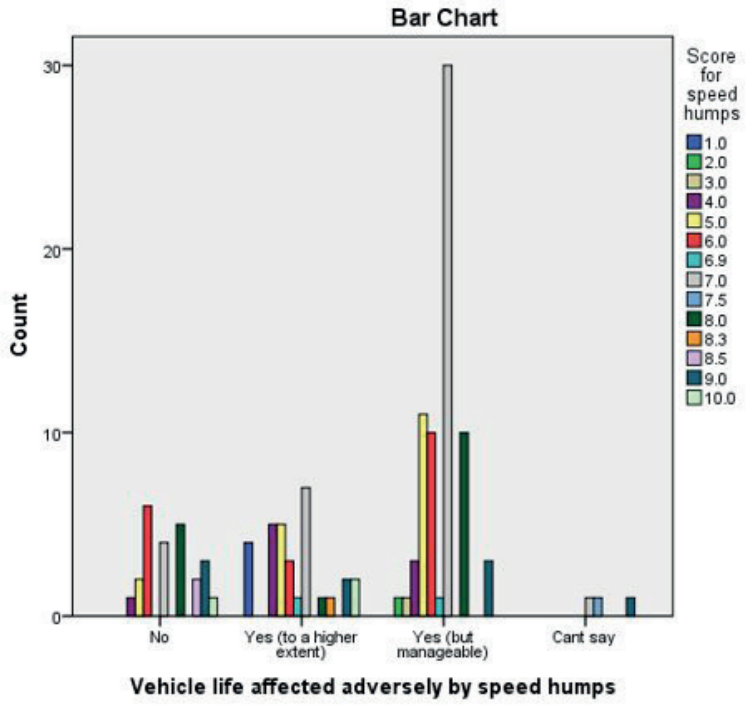

Figure 9 *Scores given by the road users based on vehicle affected*

distinct and accurately separated clusters. Table 3 presents the assignment of those scores to various clusters.

Table 3 categorizes different perceptions of speed humps into clusters based on the assigned scores and is graphically presented by Figure 11. These clusters help identify patterns in how individuals perceive the effectiveness and necessity of speed humps.

Cluster 1: This cluster corresponds to a score of 8.4

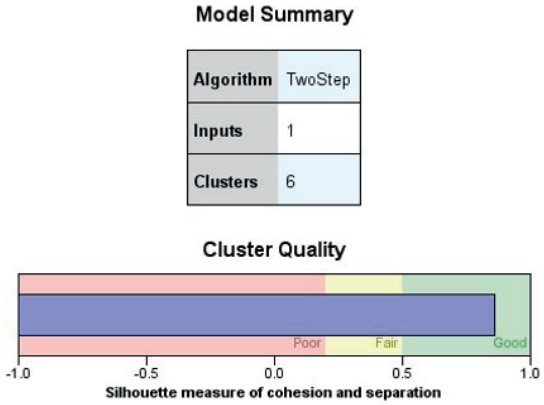

Figure 10 *The two-step clustering technique showing cluster quality*

Table 3 *Assignment of clusters to different scores for the speed humps*

	Cluster					
Score for speed humps	1	2	3	4	5	6
	8.4	6.7	1.2	4.7	10.0	3.0

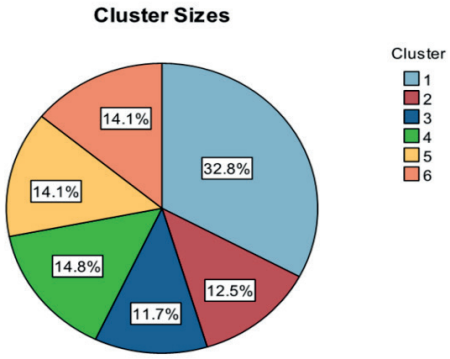

Figure 11 *Details of the clusters*

for speed humps. Individuals in this cluster likely have a positive perception of speed humps and rate them as effective or necessary.

Cluster 2: This cluster is associated with a score of 6.7 for speed humps. People in this cluster might have moderate views about speed humps, indicating that they perceive them as somewhat effective or acceptable.

Cluster 3: This cluster pertains to a score of 1.2 for speed humps. Individuals in this cluster seem to hold a negative perception of speed humps, possibly indicating strong dissatisfaction with their presence o purpose.

Cluster 4: This cluster is linked to a score of 4.7 for speed humps. People in this cluster might have a relatively neutral or balanced view of speed humps, implying that they consider them to have some degree of effectiveness but that there is a room for improvement, as well.

Cluster 5: This cluster is associated with a high score of 10.0 for speed humps. Individuals in this cluster likely have a very positive opinion of speed humps, potentially viewing them as highly effective and essential for road safety.

Cluster 6: This cluster corresponds to a score of 3.0 for speed humps. People in this cluster might have a lower opinion of speed humps, suggesting that they perceive them as less effective or unnecessary.

5.1 Level of service (LOS) range of the speed humps

The LOS (Level of Service) of the speed humps refers to the overall effectiveness and performance of these traffic calming devices. It is a measure of how well the speed humps fulfil their intended purpose of reducing vehicle speeds and enhancing road safety. The LOS is typically evaluated based on several factors, including the design, placement, and impact on traffic flow and user experience.

Different LOS categories indicate varying levels of effectiveness and user satisfaction. A high LOS indicates that the speed humps are well-designed and

achieve their intended goals without causing significant inconvenience to road users. Conversely, a low LOS suggests that the speed humps may be ineffective, leading to potential issues such as traffic congestion, discomfort to drivers and passengers, or even damage to vehicles.

To ensure the optimal performance and acceptance of speed humps, it is crucial to carefully consider their design and placement, considering factors such as traffic volume, road type, and user feedback. Regular evaluations of the LOS can help to identify areas for improvement and ensure that speed humps continue to contribute positively to road safety and traffic management.

5.2 Analysis of the cluster and determining the LOS range

Determinations of Range
(Cluster (6) - Cluster (3))/2
= (3.0-1.2)/2
=1.8/2
= 0.9
Now Range = 0 to 1.2 + 0.9 = **(0-2.10)**
(Cluster (4) - Cluster (6))/2
= (4.7-3.0)/2
=1.7/2
= 0.85
Now Rang e= 2.10 to 3.0 + 0.85 = **(2.10-3.85)**
(Cluster (2) - Cluster (4))/2
= (6.7-4.7)/2
= 2/2
= 1
Now Range = 3.85 to 4.7 + 1 = **(3.85-5.70)**
(Cluster (1) - Cluster (2))/2
= (8.4-6.7)/2
= 1.7/2
= 0.85
Now Range = 5.70 to 6.7 + 0.85 = **(5.70-7.55)**
(Cluster (5) - Cluster (1))/2
= (10.0-8.4)/2
= 1.6/2
= 0.8
Now Range = 7.55 to 8.4 + 0.8 = **(7.55-9.2)**
Cluster (6) Range = **(9.2-10)**

5.3 Grouping of the cluster range

The present study attempted to classify the cluster range into six level of grouping like LOS ranging from LOS A to LOS F, table 4.

LOS A means the cluster range is between 9.2 to 10, that means if the score given by road user was in the range of 9.2 to 10, it will be consider as LOS A, which indicates the operational efficiency of the speed humps is in a good condition. Likewise other scores are categorized into different groups. LOS F indicates the operational efficiency of speed humps is the worst condition and it needs an improvement.

From the above grouping it can be said that Group A, a range of which is between (9.2-10) depicts very good LOS. That means people that have given a score lying in the above range find speed humps to be perfect in all the aspects and they do not face any problem while travelling over them. Now Group B, a range of which is between (7.55-9.2) depicts good LOS. That means people who have given a score lying in the above range find that the speed humps are good but they might have faced a little problem while crossing speed humps or their vehicle while travelling over them. Subsequently, the ranges are grouped. For the last group, which is Group F, a range of which is between (0-2.10), depicts a very poor LOS. This means that the people, who have given a score lying in the above range, find the speed humps to be annoying, and as a result affect them and their vehicle adversely, while travelling over the speed hump. They think that a heavy modification is required to the speed humps.

6 Conclusions

Everyday road users do come across at least one or two speed humps while travelling to their destination place. Speed humps take an important role in road safety and traffic management.

The assessment of Level of Service, in relation to speed humps, has provided valuable insights into their impact on the road users and overall traffic conditions. Through a comprehensive analysis of various factors, including user perceptions, preferences, and vehicle-related considerations, this study aimed to determine the effectiveness and implications of speed humps. The

Table 4 *Grouping of the cluster*

Level of service (LOS)	Cluster Range (based on score by the road user)
LOS A	(9.2-10)
LOS B	(7.55-9.2)
LOS C	(5.70-7.55)
LOS D	(3.85-5.70)
LOS E	(2.10-3.85)
LOS F	(0-2.10)

findings underscore the multifaceted nature of speed humps' influence on road safety, vehicle comfort, and traffic flow. The evaluation of LOS through factors such as speed reduction, vehicle response, and user satisfaction, has allowed for a holistic understanding of their role in enhancing the road safety measures. It is evident that the speed humps serve as a significant tool for traffic calming, particularly in areas where the excessive speed poses risks to pedestrians and road users. However, the effectiveness of the speed humps also hinges on their proper design, placement, and maintenance. Striking a balance between the speed reduction and minimizing discomfort to vehicle occupants remains crucial.

This study emphasizes the importance of considering diverse perspectives when assessing the impact of speed humps. Different user groups, such as drivers of various vehicle types, pedestrians, and passengers, have distinct viewpoints that contribute to a comprehensive understanding of the LOS. From the above results and discussions, the study concluded that the speed humps, which are of perfect and standard dimensions, are those in which people do not face any problem while travelling over them. At the same time according to some people's score and response it can also identified that there are also few speed humps that are causing problems to road users. Those speed humps are either affecting them or their vehicle life and are also irritating them. They think that few modifications to the speed humps can make them better and easy to travel. The application of the K-Means clustering, to assess the Level of Service pertaining to speed humps, has provided valuable insights into the perceptions and preferences of the road users. Through the utilization of this clustering technique, we were able to group individuals into distinct clusters based on their responses and scores related to various factors associated with the speed humps. The K-Means clustering analysis unveiled several distinct clusters, each representing a unique perspective on speed humps. Those clusters allowed to categorize respondents based on their perceptions of the speed humps' impact on road safety, vehicle comfort, and overall effectiveness. By examining the cluster assignments and associated scores, we gained a deeper understanding of the diverse viewpoints within the sample. This study's findings demonstrated that the K-Means clustering effectively discerns patterns and nuances in the responses, allowing for a more nuanced understanding of road users' preferences and concerns. This approach not only helps identify varying levels of satisfaction with speed humps but offers insights into the potential improvements that could enhance both the road safety and user experience, as well.

So, the speed humps can be made more carefully and by following strictly to the standard codes so that everyone can travel across speed humps easily. For an effective traffic calming management it is essential to have a carefully planned process which includes clear strategies, goals, and guidelines. In essence, the utilization of the K-Means clustering for analyzing the Level of Service of the speed humps has proven to be a valuable analytical tool. It enables us to comprehensively evaluate the diverse viewpoints of road users, providing a basis for making informed decisions regarding the design, placement, and management of the speed humps. This methodology offers a structured and data-driven approach to enhancing the road safety and traffic management, ultimately contributing to a safer and more efficient road environment for all stakeholders. The evaluation of Level of Service of speed humps sheds the light on the crucial role they play in promoting the road safety and traffic management. This assessment highlights the need for well-planned and well-implemented speed hump strategies that prioritize both safety and user experience. As road infrastructures continue to evolve, a thoughtful approach to incorporating speed humps can contribute significantly to creating safer and more efficient roadways for all. Being the first of its kind, and a unique study for assessing the satisfaction level of the road users while moving on speed humps, the present study could act as a foundation for numerous future studies in this field, including various types of speed humps, different types and configuration of roads, and the acceleration behaviour of vehicles after leaving the speed humps. The future studies can collectively contribute to a specific guideline for the LOS assessment on speed humps in various codes.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

QUESTIONNAIRE SURVEY FOR PERCEPTION WHILE MOVING ON SPEED HUMPS

This survey is solely for the purpose of research. It won't be used for any other purpose and the identity of the participants will be kept anonymous under all circumstances.

Age of Respondent -
Gender of Respondent -
Origin and destination (from home to workplace/education institute) -

1. What kind of vehicle do you ride/travel by?
   a. 2W
   b. 3W
   c. Personal Car
   d. Public car (Ola, Uber, etc.)
   e. Public transit (Bus)

2. How many speed humps do you approximately came across daily?
   a. No speed humps
   b. 1 to 3
   c. 3 to 5
   d. More than 5

3. Do you feel all speed humps are required?
   a. Yes, all are required.
   b. Yes, but most of them are required (> 50%)
   c. Yes, but not all (40 - 50%)
   d. Yes, but very few are required (< 40%)
   e. None of them are required.

4. Does the presence of speed humps reduces the speed of vehicle in which you are travelling below 20 kmph?
   a. Yes
   b. No
   c. Can't Say
   d. Not always

5. Do you think speed humps Increase road safety?
   a. Yes
   b. No
   c. Yes, but not always (50-50)
   d. Can't say

6. What is your average speed while crossing over speed humps?
   a. 0-10 km/h
   b. 10-20 km/h
   c. > 20 km/h

7. For better speed (20 km/h or more) what modifications are needed for speed humps??
   a. Increase width of speed humps
   b. Decrease height of speed humps
   c. Any other suggestions
   d. No changes are required

8. Do you think speed humps forces you to drive at a much lower speed than your desired speed so much so that you feel irritated on seeing speed humps?
   a. Yes
   b. No
   c. Can't say

9. How much mark shall you give to the speed humps that you cross daily in Bhubaneswar city out of 10?

10. Do you think speed humps affect your vehicle life adversely?
    a. Yes, to a much higher extent
    b. Yes, but its manageable
    c. No
    d. Can't say

ANALYSIS OF THE TECHNICAL CONDITION OF THE ROAD INFRASTRUCTURE OF THE GREATER POLAND VOIVODSHIP FROM THE ASPECT OF ROAD TRAFFIC SAFETY IN 2010-2021

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Resume

Every year a large number of vehicles travel on Poland's roads. The technical condition of vehicles largely depends on the technical condition of the road infrastructure. For this reason, the purpose of the article was to analyze the technical condition of the road infrastructure. The analysis was carried out with the help of a questionnaire survey on a random group of 380 people living and using roads in the Wielkopolska province.

Based on the survey, it appears that drivers of the Wielkopolska province perceive changes in the state of road infrastructure in Poland. According to the respondents, these are changes for the better, and this is true regardless of whether they were asked about the road surface, signage, parking lots, toilets or the road network. They see the biggest positive changes over the past 10 years in pavement, while the smallest changes in infrastructure.

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1 Introduction

People are changing their habits on a yearly basis. The need for the constant movement and the advancement of technology are two reasons for this. Due to increased transportation and traffic congestion, the state of the road infrastructure deteriorates.

According to the article by Hoy, shopping, following others, such as children to school, and helping with administrative duties are some of the things that motivate women to travel. The fact that "motivations to travel are not fixed, but rather depend on specific life situations and change with the stages of a person's life, [1]" should also be emphasized. The major life transitions that affect travel behavior include getting a job, having children, and retiring. The report also mentions that women are more likely to take public transit while men are more likely to drive a car. Women make up 18% of respondents in the article below, while men make up 82%.

Leaning into road safety is important. However, as the author Racynska-Bulawa noted, improving road safety necessitates changes to numerous public policy facets [2]. A forward-looking road safety policy should be taken into consideration in other EU policy areas, while also taking into account the goals of other policy areas, according to the European Commission's instructions for road safety policy for the years 2011 to 2020. Policy in the areas of energy, environment, employment, education, youth, public health, research, innovation, and technology, as well as in the areas of justice, insurance, trade, and international relations, are all directly related to road safety.

Humans unquestionably hold the top spot among the variables that have a significant impact on the road safety (human-road-vehicle as a causal component in accidents). According to [3], the behavior of specific groups of road users overall has an impact on the frequency of traffic accidents. There are a number of laws and norms that must be followed when driving on the road [4]. Numerous factors play a role in enhancing the road safety, including encouraging safe driving practices [5-7], as well as efficient traffic management and maintaining the technological efficiency of roads and cars [8-11].

Future drivers' education and testing should also

be taken into account. The above-mentioned elements of the road safety are studied by scientists, together with issues pertaining to traffic control, emergency medical services, and transport psychology [12]. Authors of [13-23] explore the issue with using the road for transportation in terms of safety.

The European Commission's initiatives to further enhance the road safety are founded on the established long-term EU objective of attaining zero fatalities and serious injuries in the road transport by 2050, often known as "Vision Zero" and "Safe System." The paper, which was made public on the website of the European Commission, aims to cut traffic fatalities and serious injuries by 50% by 2030 as compared to 2020 [24].

2 Research

2.1 Purpose and methodology of the survey

The subject of the research is the analysis of the technical condition of the road infrastructure in Greater Poland from the aspect of road traffic safety with special consideration of the years 2010-2018. In connection with the chosen research topic, the aim is to gain knowledge by means of studying the technical condition of the road infrastructure in Greater Poland from the aspect of road traffic safety. Taking into account the above objective, the following hypotheses were adopted:

MAIN HYPOTHESIS: In the period 2010-2021, the technical condition of road infrastructure in the Greater Poland had a positive impact on the road safety.

H1. The condition of road surfaces, road infrastructure and its elements in the Greater Poland has improved over the last 10 years.

H2. Do road managers care enough about development of the road infrastructure in Wielkopolska?

H3. The condition of the road infrastructure affects the road traffic safety.

H4. Road users feel safe in road traffic in the Greater Poland voivodship.

H5. Roads should be monitored.

To obtain answers to the questions and hypotheses posed, the survey covered 380 people residing in the Greater Poland who travel on Greater Poland roads on a daily basis by both private cars and public transport. The diagnostic survey was conducted on a group representative of the general population. The survey was conducted online using a questionnaire made available on the Internet and in a paper version. Participation in the survey was voluntary.

The actual survey was preceded by a pilot (pre-survey) to verify the community's good understanding of the questions in the survey questionnaire; the reason for conducting the pre-survey was to get to know the community better, as well. The minimum and required number of respondents for the survey was calculated using the formula below, with a confidence level of 95% and a maximum error of 5%, resulting in a representative sample of 380 people [25].

The responses of respondents to metric questions were also examined. Gender, age, driving experience, whether the driver is a professional, how frequently they use a vehicle, and the type of a vehicle they use. In addition, two analyses (by age and gender) were taken into account in the Chi-square context. To create hypotheses for random variables, this statistical test is employed. The common pattern of the outcomes can be used to determine whether the variables are related to one another. There is a significant link between the variables if the theoretical Chi-square was lower than the calculated one. The following form [25] is the formula for the chi square test of concordance:

$$x^2 = \sum_r^{i=1} \frac{(f_i - np_i)^2}{np_i} \quad (1)$$

where: χ^2 - Chi-square test,
f_i - how many values from a specific interval were seen,
n_{pi} - number (n) of units that should be present in an interval supplied (intervals' expected values).

2.2 Results

There were 217 women (57%) and 163 men (43%) who took part in the survey. However, the result is quite similar. Women tend to be more willing to participate in this type of survey on social media as well. Those in the 21-30 age bracket were the most likely to take part in the survey, with 228 respondents, giving a response rate of

Table 1 *Respondents' place of residence*

No.	Village	Town between 5000 and 50000 inhabitants	Town between 50001 and 100000 inhabitants	Town with more than 100000 inhabitants	Sum
women	35	25	50	107	217
men	22	20	45	76	163
sum	57	45	95	183	380
%	15.00	11.84	25.00	48.16	100

Table 2 *Results of the chi-square test of compatibility*

df	p	chi^2	theoretical chi^2
3	0.05	1.39	7.8147

Table 3 *Length of time respondents have held a driving licence by gender*

No	Women	Men	Sum	%
I do not	7	0	7	1.84
Up to 2 years	16	4	20	5.26
2-10 years	52	51	103	27.11
11-18 years	101	48	149	39.21
19-26 years	20	41	61	16.05
27-34 years	4	4	8	02.11
35-42 years	8	8	16	4.21
43-50 years	7	5	12	3.16
Over 50 years	2	2	4	01.5
Sum	217	163	380	100

Table 4 *Results of the chi-square test of compatibility*

df	p	chi^2	theoretical chi^2
8	0.05	30.92	15.5073

Table 5 *Frequency of motor vehicle driving by gender*

No	daily	several times a week	once a week	seldom	not applicable	Sum
Women	35	71	58	49	4	217
Men	33	73	56	1	0	163
Sum	68	144	114	50	4	380
%	17.89	37.89	30.00	13.16	1.05	100

Table 6 *Results of the chi-square test of compatibility*

df	p	chi^2	theoretical chi^2
4	0.05	43.4	9.4877

60%. Respondents aged under 20 (13%) and those aged 31-40 (17%) gave a similar response rate. Respondents aged over 50 were represented by a group of 30 (8%). In contrast, the smallest group of respondents were those aged 41-50 (2%). Almost half of the respondents indicated that they live in a city with more than 100 000 inhabitants (48%), both among men and women aged 21-40. 25% of people indicated a city of between 50 001 and 100 000 inhabitants as their answer. On the other hand, a rural area and a smaller city, i.e., between 5 000 and 50 000 inhabitants, were marked by 15% and 12% of respondents respectively. These were mainly people aged under 20 years and over 50 years. The chi-square test showed that there was a relationship between the place of residence and gender (Tables 1 and 2).

As the largest group of respondents is made up of those aged 21 to 30 and 31 to 40, the largest group holding a driving licence is made up of those had it for 11 to 18 years (40%). In similar percentage groups are respondents holding a driving licence for 2 to 10 years (27%) and 19 to 26 years (16%). The smallest group of respondents are those aged over 50, so this is also the smallest group in the driving licence holding period question, accounting for 1%. Only 2% of respondents have held a driving licence for 27 to 34 years, 4% of respondents have held a driving licence document for 35 to 42 years and 3% for 43 to 50 years. In addition, % of respondents do not hold a driving licence at all, and up to 2 years of entitlement is held by 5% of respondents. The chi-square analysis shows that there is no correlation between the gender and the duration of holding a driving licence. Both women and men hold a driving licence at similar intervals (Tables 3 and 4). In this case, hypothesis 0 is not rejected.

Only 69 respondents (18%) drive a motor vehicle every day. Respondents who drive a motor vehicle only a few times a week are most likely to travel to work with other company employees in one vehicle or use public transport - 144 respondents (38%). Total of 114 (30%) respondents use a motor vehicle once a week, 49 respondents (13%) rarely use a motor vehicle and 4 respondents (1%) did not select any of the following answers. A chi-square analysis shows that there is correlation between gender and frequency of driving (Tables 5 and 6). Currently, both women and men are drivers, and the number of women working as drivers is increasing.

The next question of the survey concerns the form in which the respondents travel in traffic. The largest group, 171 people (45%), are passengers in a private

Table 7 *Form of traffic by gender*

No	Bicycle	Electric scooter	Public transport	Passenger in a private car	Company car driver	Private car driver	Pedestrian	Sum
Women	20	5	38	102	9	38	5	217
Men	3	10	26	70	21	26	7	163
sum	23	15	64	172	30	64	12	380
%	6.05	3.95	16.84	45.26	7.89	16.84	3.16	100

Table 8 *Results of the chi-square test of compatibility*

df	p	chi^2	theoretical chi^2
6	0.05	22.6	12.5916

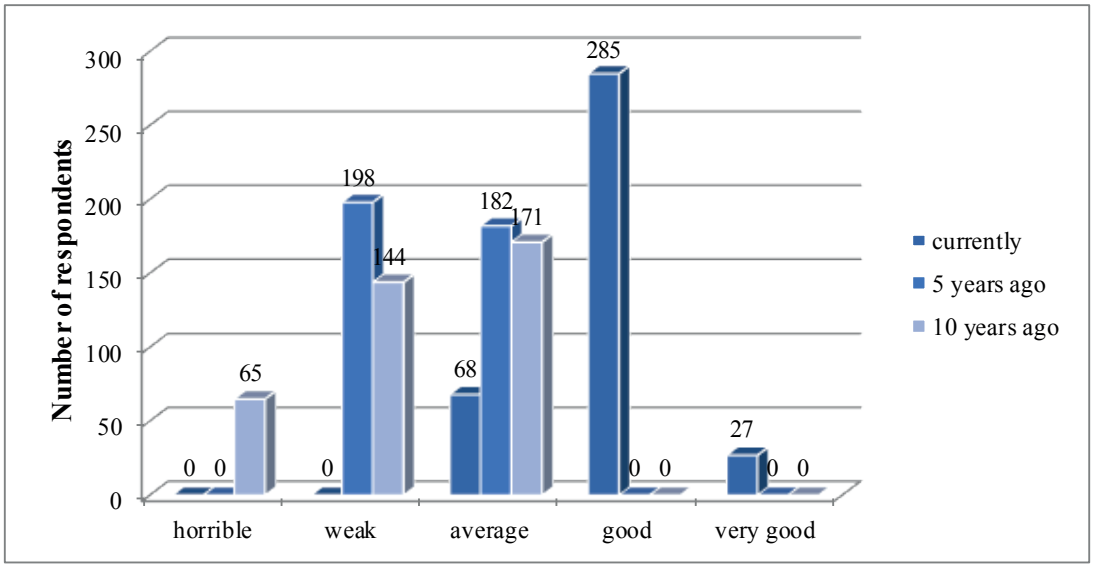

Figure 1 *Scale for evaluating the road surface in Greater Poland*

Table 9 *Pavement condition over the last 10 years according to respondents (in%)*

	horrible	weak	average	good	Very good
currently	0	0	18	75	7
5 years ago	0	52	48	0	0
10 years ago	17	38	45	0	0

car. In relation to this answer, the assumption that respondents move, for example, several people to work, is verified. Sixty-five (17%) respondents each indicated that they are most often the driver of a private car, but they take the public transport, as well. Thirty respondents (8%) get around in a company car and only 11 (3%) walk. Respondents were also given the opportunity to mark their own answer 15 of them (4%) indicated that one of the more common forms of mobility is the electric city scooter, which is however more common in larger cities. Unfortunately, only 23 respondents (6%) get around by bicycle. The chi-square test shows that there is correlation between the form of mobility and gender. Both men and women use different forms of transport (Figure 1, Tables 7 and 8)

The next part of the questionnaire concerns the whole road infrastructure in Greater Poland. These are questions not only about the condition of the road surface and network, but about the road signs, stopping places (car parks, toilets, petrol stations), etc. as well. In this section, respondents were also asked about safety on the roads of Greater Poland and whether roads should be continuously monitored.

According to the respondents, the condition of the road surface is currently good (75% of the answers given). Only 18% of respondents (68 people) indicated that the condition of the road surface is average and 7% (27 people) assess it as very good. Respondents think that 5 years ago the condition of the road surface was bad - 52% of responses and average - 48% of responses. In contrast, 10 years ago almost half of respondents - 45% rated the condition of the pavement as average, 38% (144 people) rated the condition of the pavement as bad and 17% rated the condition of the pavement as terrible (see Figure 1 and Table 9 for details).

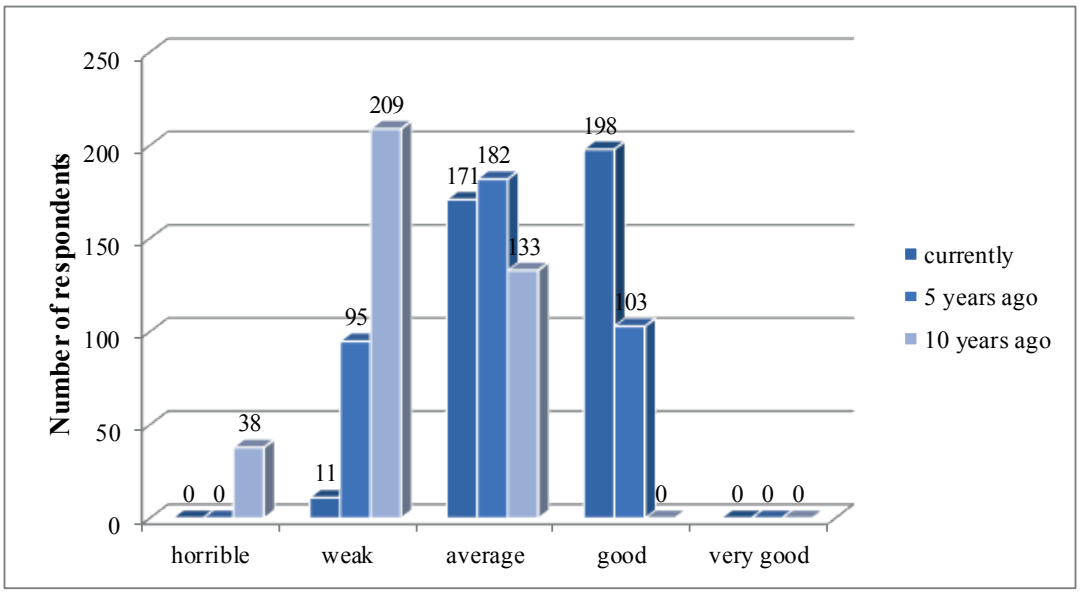

Figure 2 *Signposting of road infrastructure in Greater Poland over the last 10 years according to respondents*

Table 10 *Signage over the last 10 years according to respondents (in%)*

	horrible	weak	average	good	Very good
currently	0	3	45	52	0
5 years ago	0	25	48	27	0
10 years ago	10	55	35	0	0

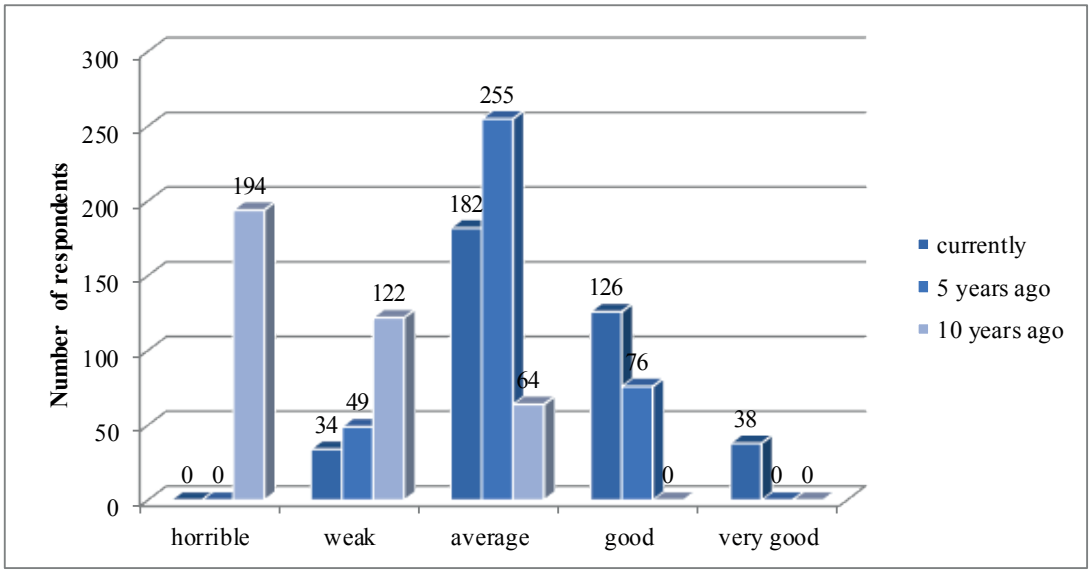

Figure 3 *Accessibility to point infrastructure in Greater Poland over the last 10 years according to respondents*

Table 11 *Availability of point infrastructure of Greater Poland province over the last 10 years according to respondents (in%)*

	horrible	weak	average	good	Very good
currently	0	9	48	33	10
5 years ago	0	13	67	20	0
10 years ago	51	32	17	0	0

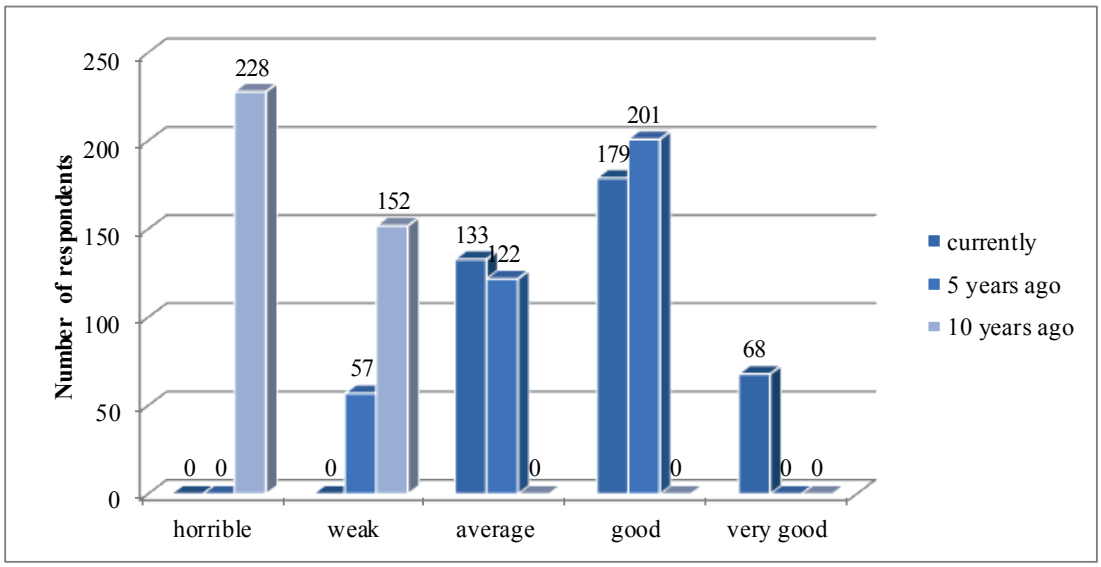

Figure 4 *The road network of Greater Poland province conditions over the last 10 years according to respondents*

Table 12 *The road network conditions over the last 10 years according to respondents (in%)*

	horrible	weak	average	good	Very good
currently	0	0	35	47	18
5 years ago	0	15	32	53	0
10 years ago	60	40	0	0	0

Table 13 *Whether Greater Poland should care about infrastructure development by gender*

No	Yes, especially about high-traffic roads	Yes, about all roads	Rather not	Definitely not	Sum
women	68	146	1	2	217
men	54	105	2	2	163
sum	122	251	3	4	380
%	32.11	66.05	0.79	1.05	100

Table 14 *Results of the chi-square test of compatibility*

df	p	chi^2	theoretical chi^2
3	0.05	0.98	7.8147

Figure 2 and Table 10 show respondents' answers regarding road signage over the last 10 years in the Greater Poland. According to the respondents, signage is currently at a good (52%) and average (45%) level. Only 3% of respondents felt that signposting in Greater Poland is poor. Five years ago, according to respondents, signage was average (48%), which is similar to today. A further 27% and 25% of respondents indicated signage was at a good and poor level, respectively. In contrast, a decade ago, 55% of respondents (209 people) rated signage as poor, 35% (133 people) as medium and 10% (38 people) as terrible.

According to respondents, road infrastructure (car parks, toilets, petrol stations, etc.) has improved significantly over the last decade. More than half of the respondents (51%) felt that 10 years ago the road infrastructure was terrible and 32% described it as poor. Only 17% considered it to be average. On the other hand, already 5 years ago a significant part of respondents (67%) described road infrastructure as average, 20% (76 people) as good and only 13% (49 people) as poor. In technical terms, both the Greater Poland and Poland have moved forward. Currently only 9% of respondents considered road infrastructure as poor; 48% (182 respondents) as average, 33% (126 respondents) as good and 10% (38 respondents) as very good. Detailed results are shown in Figure 3 and Table 11.

Regarding the expansion of the road network in Greater Poland over the past 10 years, almost half (47%) of respondents indicated that the road network is currently good, 35% average, and 18% of respondents consider it very good. Five years ago, 53% of respondents (201 people) described the road network as good, 32% (122 people) as average, and 15% (57 people) as poor. In

Table 15 *Influence of infrastructure condition on traffic safety by gender*

No	Yes	No	I have no opinion	Sum
Women	165	29	6	200
Men	158	20	2	180
Sum	323	49	8	380
%	85.00	12.89	2.11	100

Table 16 *Results of the chi-square test of compatibility*

df	p	chi^2	theoretical chi^2
2	0.05	15.37	5.9915

Table 17 *Sense of the road safety by gender*

No	definitely yes	rather yes	Yes	definitely not	rather not	Not	Sum
Women	2	79	90	12	32	2	217
Men	0	51	70	7	35	0	163
Sum	2	130	160	19	67	2	380
%	0.53	34.21	42.11	5.00	17.63	0.53	100

Table 18 *Results of the chi-square test of compatibility*

df	p	chi^2	theoretical chi^2
5	0.05	6.44	11.0705

contrast, 10 years ago, as many as 60% of respondents indicated that the road network was terrible, and 40% indicated that it was poor. The results are shown in Figure 4 and Table 12.

Total of 258 (66%) respondents believe that Greater Poland should take more care of all roads, not just expressways. 122 (32%) respondents marked the answer "yes, especially with heavy traffic," 3 marked the answer "rather not," and 4 marked the answer "definitely not." "The chi-square concordance test shows that there is a no correlation between the gender and assessment of care for the road infrastructure development (Tables 13 and 14). Women are more likely to pay attention to such factors.

When asked whether the condition of the road infrastructure affects traffic safety, as many as 323 respondents (85%) answered in the affirmative. Only 49 respondents (13%) answered in the negative, and 8 respondents (2%) had no opinion on the subject. It seems that the answer to this question is obvious. It is true that there are times when, for example, a worse road surface forces vehicle drivers to reduce their speed, but this is not the rule. The chi-square test shows that there is a correlation between the gender and the assessment of the impact of infrastructure condition on traffic safety. Both men and women have similar opinions (Tables 15 and 16).

In the question about the feeling of safety in traffic in Greater Poland, although opinions were divided, it can be considered that a significant proportion of respondents have such a feeling of safety. The above analysis shows that 160 respondents representing 42% marked the answer "yes" and 130 (34%) respondents marked "rather yes," for a total score of 76%. This is a significant majority. Sixty eight respondents, representing 18%, feel rather not safe on the road, and 5% or only 19 respondents definitely do not feel safe. It is worth noting that negative answers were marked by more women, which also coincides with the chi-square test conducted, which shows that there is a no correlation between the gender and feeling safe on the road (Tables 17 and 18).

Is monitoring on the roads a good idea? It should be noted that respondents are almost unanimous 266 respondents, or as many as 70%, answered in the affirmative, 64 respondents, or 17%, in the negative, and only 50 or 13% of respondents did not express an opinion. Certainly, monitoring would facilitate the investigation.

In many cases, especially in accidents involving vulnerable road users, the unprotected road users are the least attentive. Cyclists often forget to signal a turn with their hand, and young people often cross lanes while looking at their phones or listening to music. Monitoring would certainly help settle the dispute over who was the perpetrator of the incident. A chi-square test shows that there is correlation between gender and the answers given, with both women and men thinking the same (Tables 19 and 20).

The last question in the survey questionnaire was an open-ended question, so respondents had the opportunity to type in many of their own suggestions for improving the road infrastructure to increase safety.

Table 19 *Assessment of the need for monitoring by gender*

No	Yes	No	I have no opinion	Sum
Women	140	37	40	217
Men	126	27	10	163
Sum	266	64	50	380
%	70.00	16.84	13.16	100

Table 20 *Results of the chi-square test of compatibility*

df	p	chi^2	theoretical chi^2
2	0.05	12.8	5.99146

Table 21 *Suggestions for improving road infrastructure to increase safety according to respondents*

Respondents' proposals	Number of responses	Percentage of responses*,%
construction of sidewalks and bicycle paths	304	80
reconstruction of intersections into „traffic circle" type intersections	247	65
improvement of visibility conditions at intersections and entrances to roadways, including entry and exit lanes	152	40
installation of lighting or illumination especially in particularly dangerous places	133	35
improvement of roadway performance	122	32
construction of left turns	87	23
construction of pedestrian bridges	65	17
more frequent renewal of horizontal signs	30	8
use of barriers separating sidewalks from the roadway	27	7

*% responses do not add up - there was an opportunity to write many suggestions for improving road infrastructure to increase the road safety.

Table 22 *Average rating of the road condition in the last decade by respondents*

Assessment of the condition of roads in the Greater Poland province in terms of:	Fatal	Poor	Average	Good	Very good
pavement	0.16	0.90	1.12	0.75	0.06
marking	0.10	0.83	1.28	0.78	0
infrastructure	0.51	0.53	1.31	0.53	0.10
road network	0.60	0.55	0.66	1.0	0.18

The vast majority of respondents (80%) said that more sidewalks and bicycle paths should be built along roads connecting large cities with smaller towns and villages. The next most frequently mentioned suggestion was the reconstruction of ordinary intersections into "traffic circle" type intersections - 65% of responses. The following responses were on a similar level: improved visibility conditions at intersections and road inlets, including entry and exit lanes - 40%, installing lighting or illumination especially in particularly dangerous places - 35%, and improving roadway parameters 32%. Respondents also noted that the construction of left turn lanes (23%), construction of pedestrian bridges (17%), more frequent renewal of horizontal signs (8%) and the use of barriers separating sidewalks from the roadway (7%) would have an impact on traffic safety (Table 21).

To find out the respondents' opinions on the state of infrastructure in Greater Poland in 2010-2021, respondents were asked questions assessing the state of roads in terms of pavement, signage, infrastructure (parking lots, gas stations, toilets, etc.) and road networks. Respondents answering the above questions were allowed to select only one answer from the following: horrible, poor, average, good, very good. In addition, to get an indication of whether their opinion had changed over the past decade, they were asked to refer to their condition now, 5 years ago and 10 years ago. For each response, the average of each time interval was determined (Table 22).

The average was calculated by dividing each response by the number of people surveyed. Averaging across all the survey periods, respondents gave the best rating to the current road infrastructure. Respondents consider it to be at least average. In terms of pavement, signage, parking lots, gas stations, etc., the state of infrastructure was rated as average by respondents. In contrast, the road network was rated as good by respondents. Signage in Greater Poland was rated by

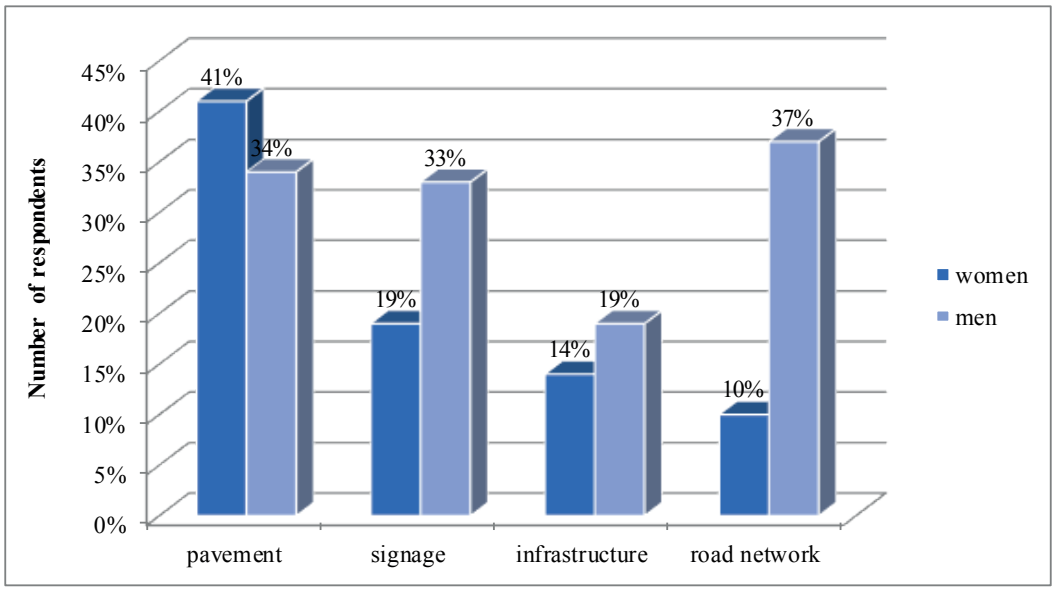

Figure 5 *Percentage of respondents who answered that the current state of infrastructure in Greater Poland province is good, by gender*

respondents at a similar level now and 5 years ago. When asked about the condition of the pavement, signage, infrastructure and road network now, respondents most often answered well. Figure 5 shows the responses of respondents by gender who rated the current state of infrastructure in Greater Poland as good.

Leaning into the specific problems posed, the first question, which complements the main research problem, can be considered confirmed. Although, among the respondents, women are more convinced only about the condition of sidewalks in Greater Poland - 41%. More men rate signage (33%), infrastructure (19%) and the road network (37%) as good. It is worth noting that no matter what the respondents were asked about, i.e., sidewalk, signage, infrastructure or road network, their opinion changed for the better over time. An upward trend can be observed. At the same time, specific hypothesis one was confirmed.

The second specific research problem was: "Should the road managers care more about the development of road infrastructure in Greater Poland?". Respondents - 68% in question 11 of the survey questionnaire - felt that the Greater Poland region should care more about the development of road infrastructure on all the roads, not just those with heavy traffic. The remaining respondents said Greater Poland should also take care of roads with heavy traffic. The second specific hypothesis was disproved. None of the respondents believe that there is no need for further infrastructure development.

At the same time, the third specific research problem

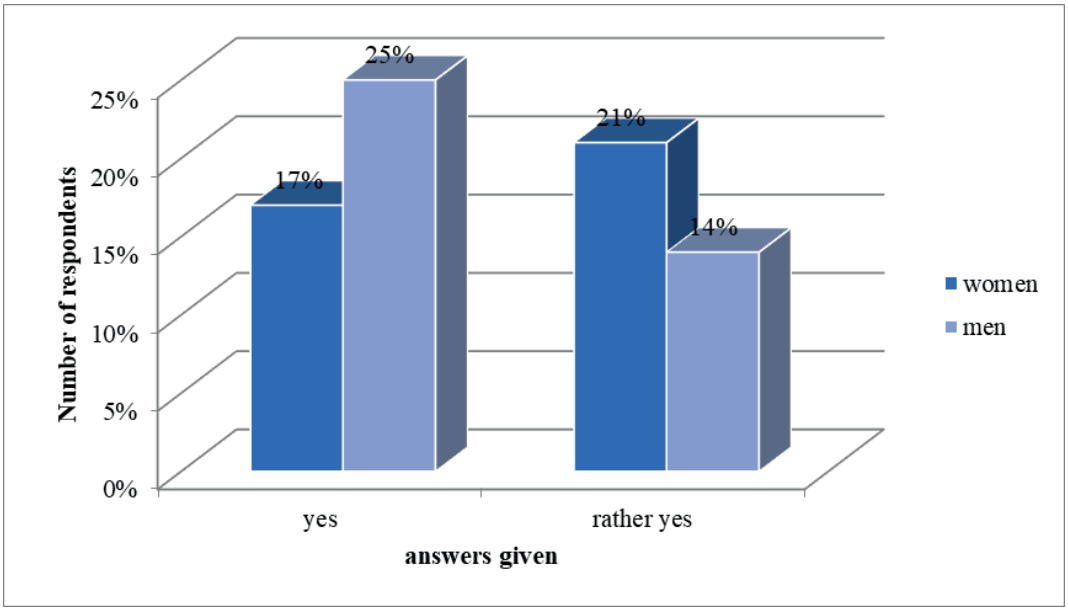

Figure 6 *Percentage of respondents who feel safe on the road in Greater Poland province by gender*

should be addressed. To the question "Does the condition of road infrastructure affect traffic safety?" respondents answered to question 12 of the survey questionnaire. Total of 85% of respondents believe that well-maintained and developed infrastructure has an impact on the traffic safety. Furthermore, only one in four respondents does not feel safe in traffic in Greater Poland (question 13 of the survey). Figure 6 shows the percentage distribution of respondents who feel safe in traffic in Greater Poland by gender.

Figure 6 shows that men are more decisive and 25% of them answered without hesitation that they feel safe in traffic in Greater Poland. Only 14% of them answered "rather yes." Women, on the other hand, are not so decisive, as a higher percentage - 21% - marked the answer "rather yes." It can be seen from the above that hypotheses three and four are confirmed. Respondents from Greater Poland believe that the state of road infrastructure influences the traffic safety and that they feel safe (77% of responses).

The last specific question was about monitoring roads. Respondents believe that roads should be monitored (70%). The results of affirmative responses by gender are similar. Both 140 women (51%) and 126 men (49%) believe that all roads in Greater Poland should be continuously monitored. They have in mind, among other things, sectional speed measurements, a network of speed cameras and the use of unmarked police cars with recording devices. In connection with such a response, the fifth specific hypothesis is confirmed. A negative answer was given by 17% of respondents, and 13% of respondents evaded answering.

3 Summary

Transportation infrastructure is one of the most important factors in a country's economic development. As already written, Poland's road infrastructure improved after Poland's accession to the European Union in 2004, as well as before 2012, when Poland began hosting the Euro 2012 European Football Championships. This event necessitated the expansion of the national road network and the modernization of existing roads to enable fast connections to neighboring countries, airports and stadiums where the soccer matches were to be played.

The development of the road infrastructure plays an important role in society. It is worth noting that Poland is striving to bring this infrastructure up to European Union standards. The road transport in EU countries plays an important role, and the adaptation of Polish roads to European requirements promotes international exchange. The development of highways and expressways positively influences the inflow of foreign investment and promotes the development of industry and services. The mobility of the labor force is also increasing, and thus unemployment is falling. The consequence is an improvement in the competitiveness of the Polish economy. All this allows to conclude that investment in the road infrastructure is a key element, ensuring the socio-economic development of the country.

The considerations undertaken, unfortunately, do not exhaust the entire issue of the road safety, but identify some of the most important factors affecting this level. The analysis of the level of the state of road infrastructure in Greater Poland, carried out and compiled in this article, indicates its upward trend. However, its further development is advisable, of course. The EU funds obtained by the Greater Poland region are only a supplement to national outlays, it is also necessary for local authorities to act. Increase their activity to obtain additional funds for the road infrastructure.

In conclusion, the analysis shows that drivers in Greater Poland recognize the changes taking place in the state of road infrastructure in Poland. According to respondents, these are the changes for the better, and this is true regardless of whether they were asked about pavement, signage, parking lots, toilets or the road network. They see the biggest positive changes over the past 10 years in pavement, and the smallest in infrastructure. Respondents also believe that the state of the road infrastructure affects the traffic safety and that they feel safe on the road. A significant number of respondents also believe that all roads in the Greater Poland province should be monitored, which may be a rather difficult task to accomplish. The only specific hypothesis that was not confirmed is hypothesis two. Residents of Greater Poland believe that road managers should not stop developing and improving road infrastructure. In addition, a large group of respondents, moved by motor vehicle only a few times a week, most likely to travel to work with other company employees in one vehicle or use public transportation. The largest group, 171 people (45%), are passengers in a private car. In connection with this answer, the posed idea was that the respondents move, for example, to work in several people is verified.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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AN ESTIMATE OF THE NUMBER OF ACCIDENTS ON POLISH HIGHWAYS BASED ON THE KIND OF ROAD

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Resume

A surprising number of people die on Polish highways every year. Despite the fact that number is decreasing year after year, it is still rather considerable. Due to the epidemic, the costs of the road accidents were significantly lowered, but they still remain fairly large. Understanding the roads where the majority of accidents happen and the anticipated number of accidents in the next years are necessary to lower this number. The purpose of the article was to forecast the number of accidents that would happen on Polish roads based on the kind of roads. To do this, annual accident statistics from the Police's statistics for the years 2001-2021 were reviewed, and a forecast for the years 2022-2031 was produced. It is clear that either the accident rate is increasing or it is steady. Predictions also suggest that a large increase in accidents on Polish roads may be expected given the current situation.

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1 Introduction

The road accidents are situations that result in both property damage and injury or death to other motorists. According to the WHO Every year, 1.3 million people worldwide die in car accidents. Road accidents cause a 3% GDP loss in the average nations. Children and teenagers between the ages of 5 and 29 die most frequently from traffic accidents [1]. By 2030, the UN General Assembly wants to see a 50% decrease in traffic accident fatalities and injuries.

A traffic collision's size is a factor in evaluating how serious it is. For the responsible authorities to develop the road safety legislation with the intention of preventing accidents, minimizing injuries, fatalities, and property damage, it is critical to quantify the severity of accidents [2-3]. Before implementing countermeasures to prevent and minimize accident severity, it is vital to identify the critical components that influence it [4]. A multi-node Deep Neutral Network (DNN) architecture is provided by Yang et al. for forecasting various degrees of injuries, fatalities, and property loss. It makes it possible to fully and accurately assess how serious traffic incidents are [5].

The accident numbers come from a number of sources. Typically, government representatives use the pertinent government agencies to obtain and evaluate them. Numerous sources, including hospital files, insurance company databases, and police reports, are used to collect data. As a result, the transportation industry is conducting more extensive analyses of data related to traffic accidents [6].

Currently, the most significant information source for the analysis and forecasting of traffic events is intelligent transportation systems. The GPS equipment mounted on moving vehicles may be used to process these data [7]. Roadside microwave vehicle detection systems may continually capture information about moving vehicles, such as speed, traffic volume, and vehicle type [8]. Additionally, a lot of traffic data may be gathered over a predetermined period of time using a license plate recognition system [9]. Social media is another possible source for information on traffic and accidents, albeit the accuracy of the reports may not be sufficient due to the inexperience of the reporters [10].

Work with various data sources need to be properly questioned in order for accident data to be of any use. Analytical outcomes can be more precise by integrating

many data sources and combining diverse traffic accidents data [11].

To determine the severity of the situation and establish a connection between the traffic participants and accidents, Vilaca et al. [12] carried out a statistical analysis. The study's findings include raising the bar for traffic safety rules and implementing more traffic safety precautions.

Based on the quantity of traffic accidents, which serves as a barometer for the investigation into accident causes, Bak et al. [13] conducted a statistical analysis of traffic safety in a chosen Polish area. The study examined the safety factors of persons who cause accidents using multivariate statistical analysis.

The type of traffic problem being addressed determines the source of accident data to be used for analysis. The accuracy of accident prediction and accident elimination is increased by combining statistical models with additional data from the real driving or other information collected from intelligent traffic systems [14].

The literature contains a number of techniques for predicting the probability of accidents. The most popular methodologies for forecasting accident frequency [15-16] have the drawback of not allowing for evaluation of forecast accuracy based on previous forecasts and the frequent residual component of autocorrelation [17]. While Sunny et al. [18] employed the Holt-Winters exponential smoothing method, Prochazka et al. [19] used a multi-seasonality model. One of the model's drawbacks is that exogenous variables cannot be included [20].

The frequency of traffic accidents has been predicted using the curve-fitting regression models of Al-Madani [21] and Monedero et al. [22] for analyzing the number of fatalities, as well as the vector autoregressive model, which has the disadvantage of requiring many observations of variables to accurately estimate their parameters [23]. Assuming the series are already stationary, these only require an order of autoregression [24] and a few straightforward linear connections [25].

Random Forest regression was used by Biswas et al. [26] to forecast the frequency of traffic accidents. The approach and peak prediction are unstable [27], the data comprise groups with associated features that are as important to the original data, and in this case the smaller groups are preferred over the bigger ones [28]. For the proposed forecasting problem, Chudy-Laskowska and Pisula [29] used an autoregressive quadratic trend model, a univariate periodic trend model, and an exponential smoothing model. The problem at hand might potentially be anticipated using a moving average model, however, this approach has the poor forecast accuracy, data loss within a sequence, and is unable to take into account trends and seasonal fluctuations [30].

The GARMA approach, which restricts the parameter space, was employed by Prochazka and Camej [31] to ensure that the process is stationary. Forecasting frequently uses the ARMA model for stationary systems [19, 32-33] and the ARIMA or SARIMA model for the non-stationary phenomena. The benefit of these models is that they give the models under investigation a considerable deal of flexibility; nevertheless, the drawback is that they demand more advanced research skills from the researcher than, for instance, the regression analysis [34]. The linearity of the ARIMA model is another drawback [20].

In their study [35], Chudy-Laskowska and Pisula employed an ANOVA to forecast the frequency of traffic accidents. This approach's drawback is that it makes additional assumptions, most notably the assumption of sphericity, the failure of which could result in incorrect conclusions [36]. The frequency of auto accidents is also predicted using neural network approaches. Since neural networks are frequently referred to as "black boxes" where input is data and the model outputs the results without being aware of the analysis, the disadvantages of neural networks include the need for prior expertise in the field [35, 37-38], the dependence of the final result on the initial conditions of the network, and the inability to interpret the results conventionally.

Kumar et al. [39] used the Hadoop model as a cutting-edge prediction technique. This strategy's drawback is that it is unable to handle small data sets [40]. The Garch model was employed by Karlaftis and Vlahogianni [33] to provide predictions. This strategy's intricate model and complicated shape are a problem [41]. However, McIlroy and his team's usage of the ADF test [42] has the drawback of not having sufficient power to detect the autocorrelation of the random component [43].

To make predictions, authors of publications have also utilized data-mining algorithms, which frequently struggle with having a lot of broad descriptions [44-46]. Sebego et al.'s collection of models [47], which is another example of a model combination, are one more. Bloomfield's work [48] also suggests parametric models. Additionally, topics linked to forecasting and transportation safety are covered in [49].

The authors projected the number of accidents on Polish roads using the aforementioned data. The number of accidents was predicted using a few exponential models.

2 Materials and methods

On Polish roads, there is an increasing number of modern automobiles. Currently, there are about 750 cars per 1000 persons in Poland. As a result, the number of traffic accidents either increases or stabilizes (Table 1). An occurrence, involving a moving vehicle on the road that causes fatalities or significant injuries, damage to movable things like equipment or products, or other sorts of material harm, is referred to as a road traffic accident. Poland has the following varieties of roadways,

Table 1 *Number of accidents in Poland from 2007 to 2021, broken down by the kind of road [50]*

Date/type of road	Motorway	Expressway	2 one-way carriageway	Single carriageway	1 carriageway 2 directions
2007	3699	1468	55379	21427	324332
2008	3873	1371	56257	23507	326965
2009	3828	1508	57539	23063	329335
2010	4253	1845	68557	26827	353425
2011	3902	1692	63292	24645	313109
2012	4454	1725	58536	23175	288645
2013	5443	2444	60769	24671	298432
2014	6369	3114	62871	25364	285259
2015	7011	3751	64476	27481	292457
2016	8646	4739	71175	28791	326927
2017	9836	5882	71568	32326	349604
2018	9775	6542	72656	33386	345698
2019	10559	8082	73960	35680	357460
2020	8632	7856	59077	29680	300413
2021	10593	9999	65029	35254	324560

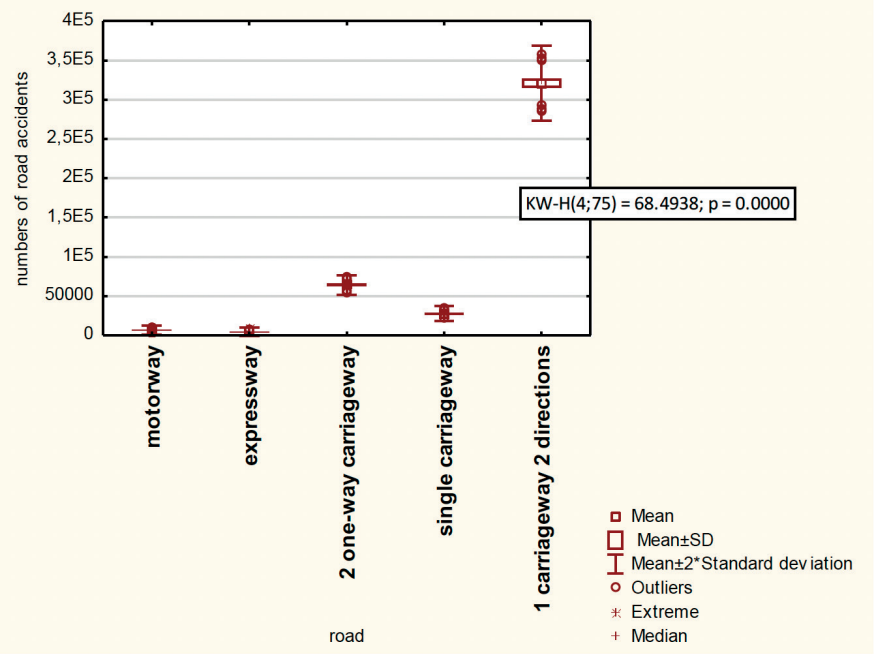

Figure 1 *The average number of accidents on Poland's roads compared by the kind of road for the period 2007 to 2021*

per police statistics [50]:

- Motorway,
- Expressway,
- 2 single carriageways,
- single carriageway,
- 1 carriageway 2 directions.

Selected time series models were used in the investigation in Statistica software.

The Kruskalla-Wallis test was used to examine the relationship between the kind of road and the frequency of accidents. The test probability is p = 0.000 and the test statistic has a value of 68 (Figure 1). The resulting statistics implies that it is best to abandon the presumption of an equal mean level of traffic accidents.

3 Estimating the number of accidents on the road

Using certain exponential equalization models, the frequency of accidents was forecasted for each type of the road. The key distinction between the two methods is that the weights are selected using an exponential function, while the forecast variable's time series is

provided by a weighted moving average. These weights were carefully chosen by the Statistica program, which was utilized to carry out the applied analysis.

The number of accidents, for each type of route under consideration, was predicted using a weighted average of recent and historical information. The results of forecasts created using these methods depend on the model chosen and the ideal values for its parameters. Predictions of the number of accidents on Polish roads by kind of road were made using specific time series models.

Measures of analytical forecasting perfection were calculated using the errors of forecasts that had expired, which were calculated using Equations (1)-(5):

- ME - mean error

$$ME = \frac{1}{n}\sum_{i=1}^{n}(Y_i - Y_p), \quad (1)$$

- MAE -mean average error

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|Y_i - Y_p|, \quad (2)$$

- MPE -mean percentage error

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\frac{Y_i - Y_p}{Y_i}, \quad (3)$$

- MAPE - mean absolute percentage error

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|Y_i - Y_p|}{Y_i}, \quad (4)$$

- MSE - mean square error

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - Y_p)^2, \quad (5)$$

where: n - the length of the forecast horizon,
Y - observed number of the road accidents,
Y_p - forecasted number of the road accidents.

The mean absolute percentage error was reduced to compare the number of accidents during a pandemic and when a pandemic is not included in the study.

For the study's route categories, annual police records from 2007 to 2021 were utilized to project the number of accidents. The projected results for the roads are shown in Figures 2 to 6. The study's numerous forecasting methods are identified by the codes M1, M2,..., Mn. The forecasting techniques used in the study are as follows:
M1 - moving average method 2-points,
M2 - moving average method 3-points,
M3 - moving average method 4-points,
M4 - exponential smoothing no trend seasonal component: none,
M5 - exponential smoothing no trend seasonal component: additive,
M6 - exponential smoothing no trend seasonal component: multiplicative,
M7 - exponential smoothing linear trend seasonal component: none HOLTA,
M8 - exponential smoothing linear trend seasonal component: additive,
M9 - exponential smoothing linear trend seasonal component: multiplicative WINTERSA,
M10 - exponential smoothing exponential seasonal component: none,
M11 - exponential smoothing exponential seasonal component: additive,
M12 - exponential smoothing exponential seasonal component: multiplicative,
M13 - exponential smoothing fading trend seasonal component: none,
M14 - exponential smoothing fading trend seasonal component: additive,
M15 - exponential smoothing fading trend seasonal component: multiplicative)

Based on the research conducted for the highway (Figure 2), regardless of the research method used, one can conclude that one can still expect an increase in the number of traffic accidents in Poland in the coming years. This is mainly due to the increase in the number of kilometers of highways in Poland. In the case analyzed, the smallest MAPE error occurred when using the M13 method - exponential smoothing fading trend seasonal component: none.

The situation is similar for expressways, which are increasing year by year. As can be seen (Figure 3), the largest increase is observed with the M11 method, and the smallest with M3. In the case analyzed, the smallest MAPE error occurred with the M8 method - exponential smoothing linear trend seasonal component: additive.

Another of the analyzed roads is a dual carriageway (Figure 4). Based on the analyzed data, one can further expect stabilization and minimal increase in the number of traffic accidents during the analyzed period. In the analyzed case, the smallest MAPE error occurred using the M9 method - exponential smoothing linear trend seasonal component: multiplicative WINTERSA.

Another of the analyzed roads is a one-way road (Figure 5). In this case, one can still expect an increase in the number of traffic accidents. This is particularly evident with the M15 method. In the case analyzed, the smallest MAPE error occurred with the M12 method - exponential smoothing seasonal multiplicative component.

The last of the analyzed roads is the road 1 roadway 2 directions (Figure 6). In this case, there is a large change in the amplitude of the input data. For this reason, large differences in the data can still be expected. In the case analyzed, the smallest MAPE error occurred with the M14 method - exponential smoothing fading trend seasonal component: additive.

The aforementioned information leads to the conclusion that not all the approaches utilized in the case study were successful. The best forecasting

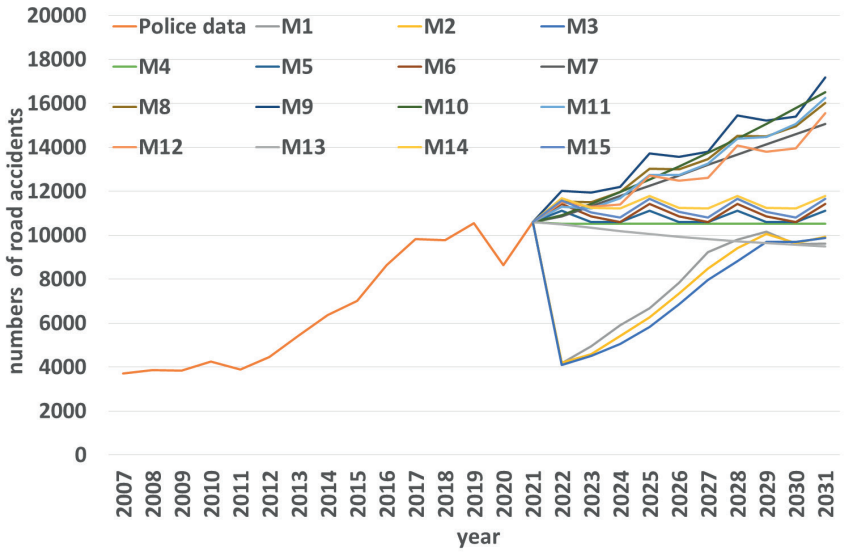

Figure 2 *Forecasting the number of road accidents for the motorway between 2022 and 2031*

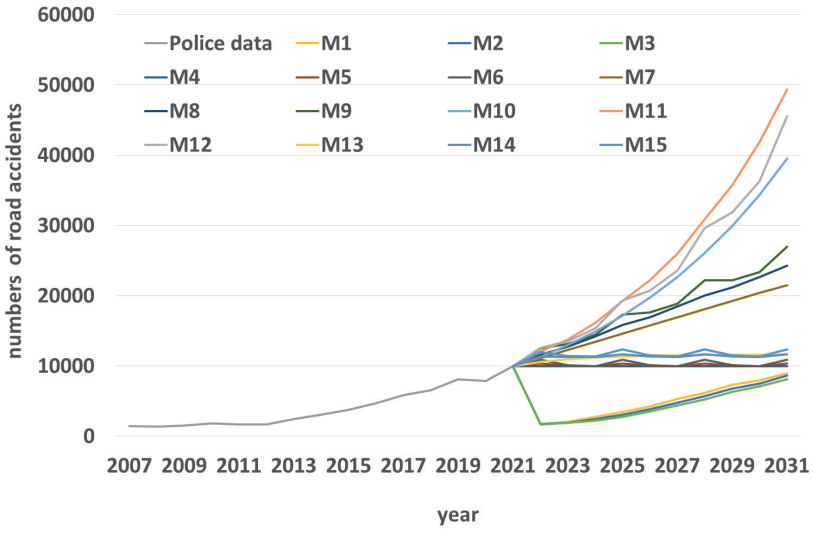

Figure 3 *Forecasting of the number of road accidents for the express road between 2022 and 2031*

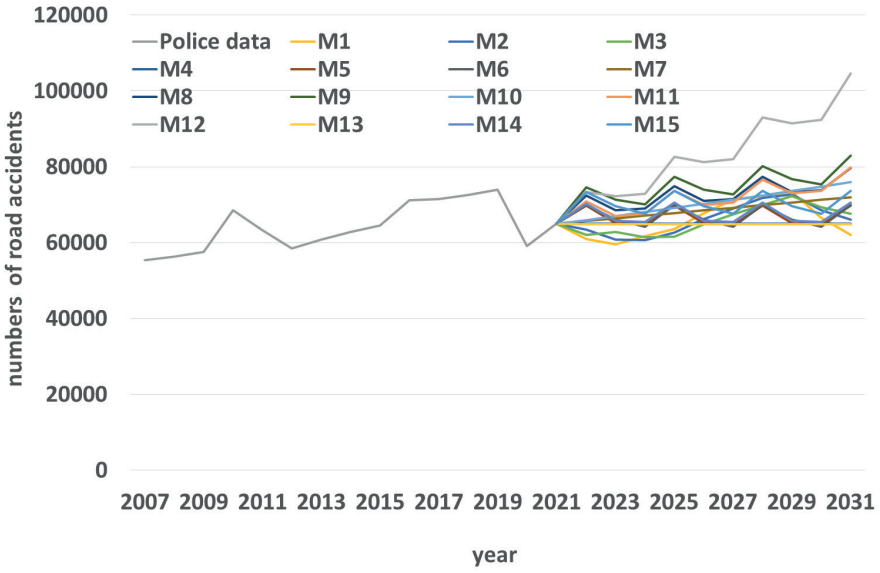

Figure 4 *Forecasting the number of road accidents for a 2 carriageway road from 2022 to 2031*

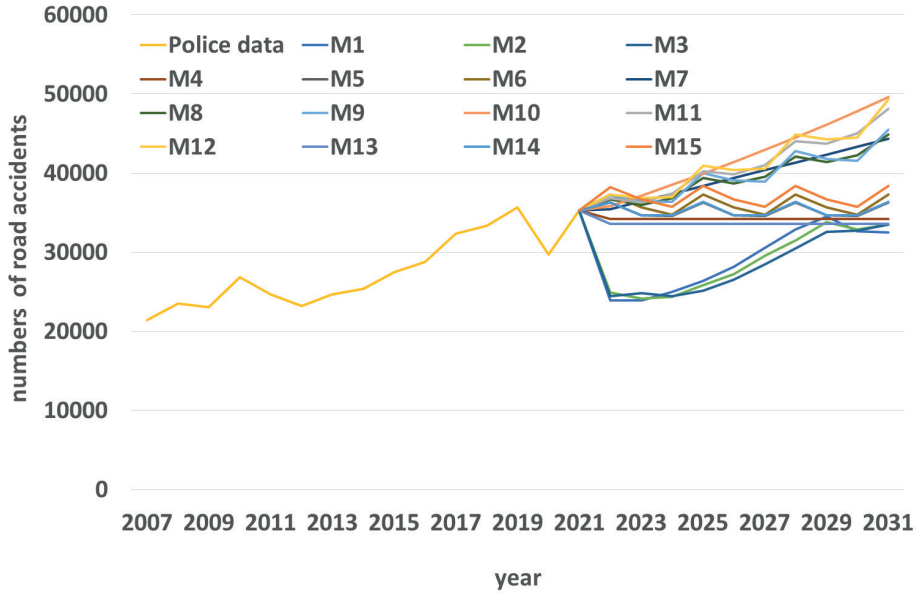

Figure 5 *Forecasting the number of road accidents for a one-way road from 2022 to 2031*

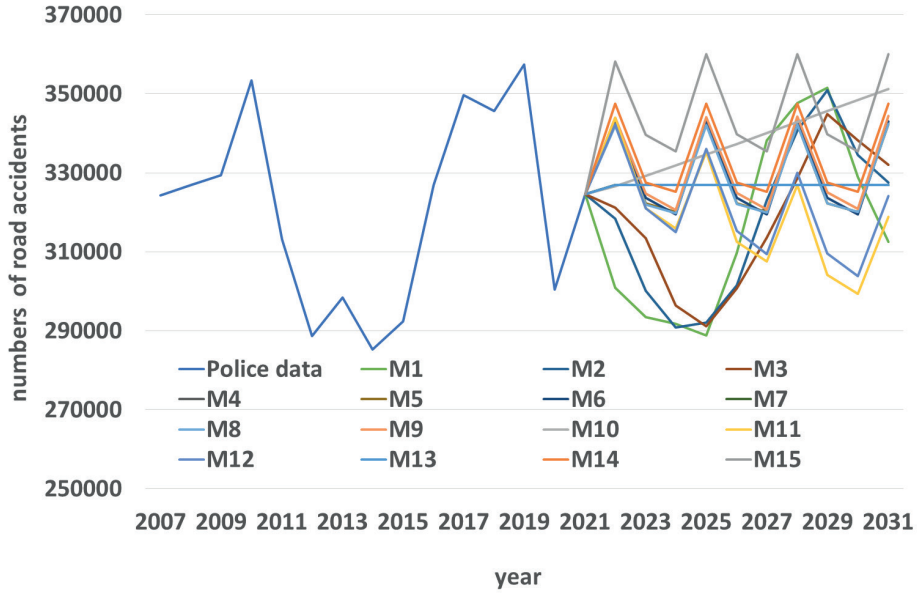

Figure 6 *Projected number of road accidents for road 1 carriageway 2 directions in 2022-2031*

techniques for each road were determined to be the following:

- Motorway - M13
- Expressway - M8
- 2 single carriageway road - M9
- Single carriageway - M12
- 1 carriageway 2 directions - M14

The information gathered makes it possible to conclude that the technique picked is dependent on the kind of route being researched. The MAPE error was consistently the minimum when using the linear trend and fading trend strategies. Figure 7 illustrates a forecast of the number of accidents on the roads that were examined based on this information.

Table 2 presents the outcomes of the forecasting blunders. According to the findings, there will probably be more accidents in the future. This is particularly crucial for highways. It is important to note that the epidemic has affected the outcomes. With the exception of highways, where the error value is 3.5 %, the choice of an effective forecasting approach is demonstrated by a maximum error value of 1 %. The smallest MAPE error on the analyzed roads, at 0.03 %, occurred for single carriageway road 1 with 2 directions of travel. The next largest error was for single carriageway road 2 (0.31 %), expressway (0.69 %) and single carriageway road (0.76 %). During the survey, the largest error occurred when predicting the number of accidents on highways (3.56 %)

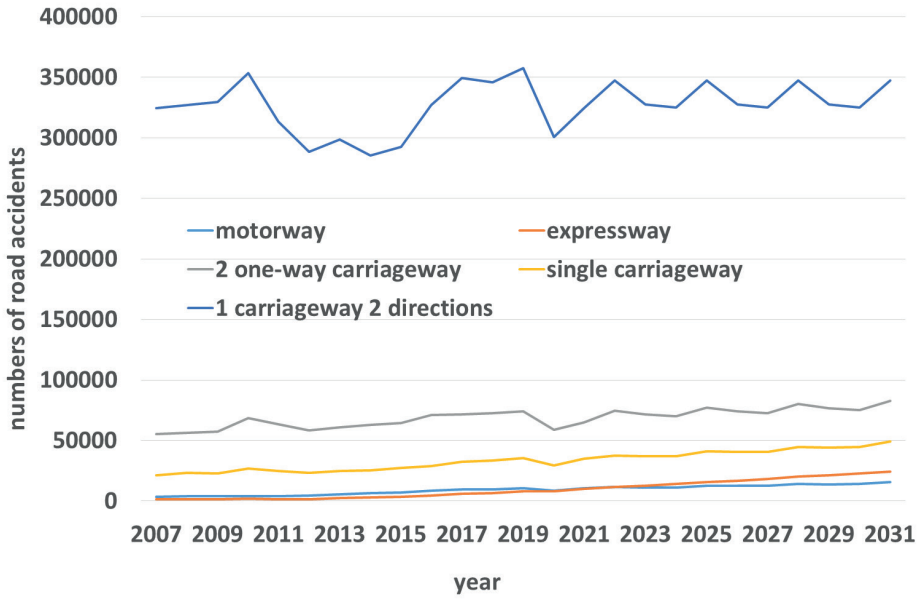

Figure 7 *Projected number of road accidents by analyzed road types in 2022-2031*

Table 2 *Forecasting errors for the best forecasting methods*

Road type/forecast error	ME	MPE	MSE	MAPE [%]	MAE [%]
Motorway	296.02	678.91	781259.3	3.56	9.39
Expressway	99.86	410.92	406005.5	0.69	10.22
2 single carriageway road	471.47	3832.82	23170378	0.31	5.98
Single carriageway	8.33	1922.17	5491637	0.76	6.86
1 carriageway 2 directions	0.41	16.51	410.1266	0.03	5.19

4 Conclusions

The number of accidents in Poland was predicted using an exponential equalization method using the Statistica application. The method found the weights that would be the most useful in lowering the mean absolute error and the mean absolute percentage error.

According to the study's conclusions, the number of traffic accidents would probably be similar to what it was before the epidemic. The exception is that as the number of highways increases, so does the number of accidents that take place on them. It is important to note that the epidemic has affected the outcomes. An error value of no more than 3.5% can serve as evidence that one has chosen a reliable forecasting method. The smallest MAPE error on the analyzed roads, at 0.03%, occurred for single carriageway road 1 with 2 directions of travel. The next largest error was for single carriageway road 2 (0.31 %), expressway (0.69%) and single carriageway road (0.76 %). During the survey, the largest error occurred when predicting the number of accidents on highways (3.56%)

The estimated number of road accidents found in this article can be used to create future strategies to lower the number of accidents on roads, especially on motorways. For example, the measures took effect on January 1, 2022, with the application of tougher penalties for moving violations on Polish roadways.

The authors plan to explore additional factors influencing accident rates in Poland in the subsequent study. The volume of traffic, the day of the week, or the age of the accident's perpetrator are a few examples of these. In the subsequent investigations, the authors also intend to examine how the quantity of cars, traffic volume, and vehicle type affect the frequency of road accidents.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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