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Traction electric motor for battery-powered electric vehicles

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Abstract: Paper deals with a newly designed three-phase asynchronous electric motor with an application as a traction motor for driving compact battery-powered electric vehicles mainly in urban environments. The main characteristics of the motor are presented. The problems and solutions related to the sizing and optimization of the motor in the design according to various criteria and conditions are analyzed, with energy efficiency being the main determining factor.

Keywords: INDUCTION MOTORS, BATTERY-POWERED ELECTRIC VEHICLES, TRACTION MOTORS, ENERGY EFFICIENCY

1. Introduction

Recently, the use of electric vehicles (EVs) has been updated - the future of our world will be influenced by the electrification of vehicles, which is one of the main goals for generating the so-called "new power". Electric vehicles have a number of advantages over classic cars with internal combustion engines (ICE) in urban conditions, mainly related to reducing harmful emissions [1].

Electric vehicles are receiving ever-greater attention from vehicle manufacturers, governments, regulators and consumers and the pressure is increasing on vehicle designers to deliver on the technology's promise [2].

Global warming and pollution as well as international carbon emission targets initiated a process to reduce car emissions. The automotive industry pushes to improve fuel efficiency and reduce emissions, also by increasing the vehicle electrification. Automotive manufacturers constantly seek improved overall performance: higher conversion efficiency, reduced cost, lower weight, higher power density. Enhancement of energy efficiency reduces the energy expense and battery capacity required to travel a given distance [2].

Motors and drives are becoming more and more a hot topic, as they are literally everywhere. Efficiency (in the sense of reducing the losses in the motor and control unit) and reliability, as well as improving the acoustic characteristics of the drive train are key characteristics. Currently, it is possible to implement modern control systems with all their advantages and of course disadvantages. For instance, utilizing high switching frequencies without output filters can result in high voltage slope rates (dV/dt), resulting in motor insulation breakdown. Furthermore, higher switching frequencies can cause undesired capacitive couplings and electromagnetic interference (EMI) issues [2].

Battery-powered electrical vehicles (BEVs), plug-in hybrid electrical vehicles (PHEVs) and mild hybrid electric vehicles (MHEVs) all contain several important systems directly related to energy efficiency and performance – electric drive, mechanical system and control unit [2].

The operation of the most important component in an electric drive – the electric motor – is sometimes associated with various breakdowns and malfunctions. After failures in bearing elements, electrical faults are the second most common cause of electric motor failures. According to the US Electric Power Research Institute (EPRI), nearly 48% of all failures of such equipment are due to problems related to the electrical system. These can be faults in the rotor (12%) or windings (36%). In the remaining 52% of cases, mechanical damage to the components is proven. Defects in windings, for example, occur due to moisture, pollution, aging of the insulation, thermal overload, electric shocks, damage to the wires, etc. In these, energy is observed passing through the insulation, which causes an increase in the operating temperature and stress on the system until a fault occurs in the winding. When the motor suffers any of the damage described above, most often the damage is irreversible and leads to a progressive deterioration of its efficiency [3].

The research thesis defended in the present paper is formulated as follows: прилагането на високоефективни електрически двигатели в EV directly correlates with issues of energy efficiency and environmental protection.

2. Some considerations

The all electric vehicles (BEV, PHEV and MHEV) have been developed using several different traction technology. Today, mainly three types electrical machines are applied for vehicle propulsion: permanent magnet synchronous motor (PMSM), induction motor (IM) and switched reluctance motor (SRM). The stators and inverters of the first two kinds are identical. Research on electric drives of electric vehicles with IMs has been carried out and presented in [4, 5].

IM have a significant advantage over PMSM motor. The flux could be adjust by control of the ratio between voltage and frequency in field weakening domain. The IM have best efficiency at low load and high speed [6].

The traction induction motor differ from the conventional one. A traction motor must remain small and light. To operate with high current density level the stator coils must contain much more copper in the slots than a traditional motor of its size. Special technologies of the stator windings for achieving a higher fill factor and optimum heat transfer are applied.

The precise determination of the equivalent circuit parameters is important. The resistances are dependent on the winding dimensions and temperature. The stator and rotor leakage reactance are function of the frequency. The magnetizing reactance varies along with the air-gap flux and is dependent on the magnetic circuit saturation. All these parameters are needed in the performances research as well as by implementation of the control.

Caproni JSC, Bulgaria is a leading manufacturer of hydraulic elements and systems with application in mobile and stationary industrial equipment. One innovation of the company is the development of AC motors for BEVs with possible application of frequency regulation and vector control [7, 8].

The advantages of adjustable AC drives in EVs are well known over the behavior of DC collector motors. These include: higher efficiency and level of reliability, longer motor and battery life, longer range between two charges, lower service costs, lower vibration and noise. Important features are also the smooth variation of the speed, the high overload capacity, the quick action and the accuracy in steady-state and dynamic modes. The braking process with energy recovery to the battery is very effective. The advantage is that for the same nominal power and speed, induction motors have smaller mass and overall dimensions compared to DC collector motors [7].

The designed induction motor for electric vehicles is intended for conversion and installation in conventional cars by replacing the ICE. Its application is limited to short-distance traffic in urban environments. Some more important data values and parameters for the considered IM, produced by Caproni JSC, Bulgaria, are given in the Table 1.

Table 1: Induction motor data and electric equivalent circuit parameters.

Quantities	
Description	Data
Type	ACM 15-8-5-30
Connection (stator)	delta
Rated power	15 kW
Rated stator voltage	49 V
Operating frequency	102.5 Hz
Pole pair number	2
Airgap	0.4 mm
Synchronous speed	3075 rpm
Shaft speed	2971 rpm
Rated slip	0.03392
Rotor moment of inertia	0.028778 kgm ²
Rated torque	48.218 Nm
Breakdown shaft torque	126.1 Nm
Line stator current	121.21 A
Ratio locked rotor/on load current	5.26 p.u.
Stator phase resistance	0.01197 Ω
Referred rotor resistance	0.014 Ω
Stator leakage reactance	0.01677 Ω
Referred rotor leakage reactance	0.005648 Ω
Magnetizing reactance (saturated)	1.624 Ω

3. Results obtained

The traction motor is designed for operation mode S2 - 60 min according to IEC 60034-1, self-ventilation cooled - code IC01 according to IEC 60034-6, equipped with a 64 pulse encoder for speed feedback, integrated in the rear bearing, thermal protection is implemented with a Pt1000 thermistor in the stator winding (standard equipment), and the insulation of the stator winding has heat resistance class H (180°C).

The design was carried out with specified internal and external diameters of the sheets, with a certain number and dimensions of the stator and rotor channels. The main difficulties encountered in the design are related to the low value of the voltage and the significant value of the current. This necessitates the use of the maximum number of parallel branches and elementary wires. On the other hand, the number of windings in a section is relatively small. The possibilities for varying the independent variables are

also limited by the conditions for minimum dimensions and mass, as well as by technological factors.

Partial optimization tasks are solved under the criterion of maximum efficiency and current density limitations in the stator and rotor windings. These limits are imposed to achieve allowable winding temperatures. The efficiency values of the motor are at the level of class IE2 (high efficiency) according to IEC 60034-30. The parameters of the equivalent circuit, currents in the windings, losses, powers, etc. are determined. Models have been created for different load levels, as well as for the lower and upper limits of the frequency range. The obtained results allow to estimate the distribution of the magnetic induction in the sections of the magnetic circuit, to determine the magnetic flux through the air gap and the electromagnetic torque.

For the rated speed, the overload capability of the motor is determined by the multiple of the maximum torque. The multiple of the maximum torque is usually greater than 2, where the stator current is more than twice the rated motor current. The short-term overload of the drive also depends on the maximum current of the inverter, which is 2 times greater than its rated current. For starting with a larger moment, the voltage and electromotive force (emf) are increased at the same frequency. The magnetic flux, the magnetizing current and the currents in the stator and rotor windings increase. Greater starting torque at relatively lower starting current is an important advantage.

The air gap has the greatest influence on the magnetizing current value of induction motors. In turn, the magnetizing current determines the current and losses in the stator winding and the power factor. Manufacturing induction motors with optimum air gap depends on the bearing design and the level of the manufacturing process. The selected construction scheme and the precision in the machining of the stator and rotor packages, the bearing shields and the shaft create the possibility of achieving a small and uniform air gap of the motors.

The machine winding and laying of the sections, the channel filling factor and the impregnation quality of the stator winding largely determine the heat dissipation and temperature condition of the winding. The resistance of the winding, the losses in it and the efficiency depend on the temperature.

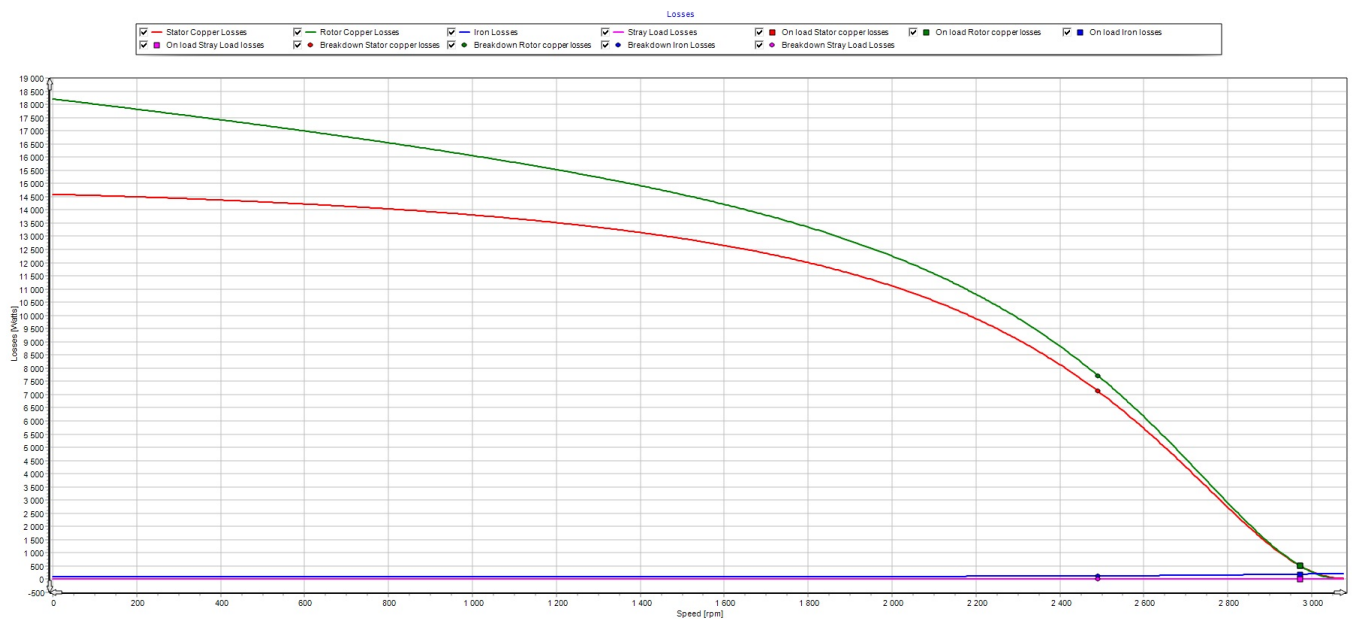


Fig. 1 Losses versus speed for a 15 kW traction motor.

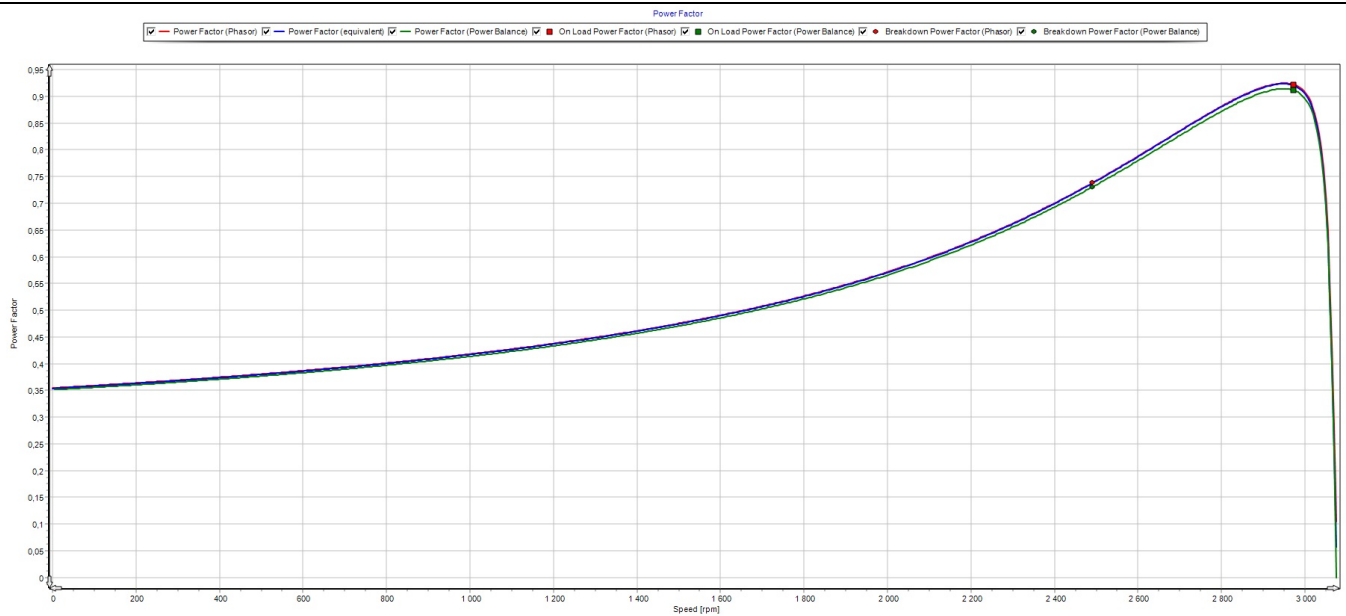


Fig. 2 Power factor versus speed for a 15 kW traction motor.

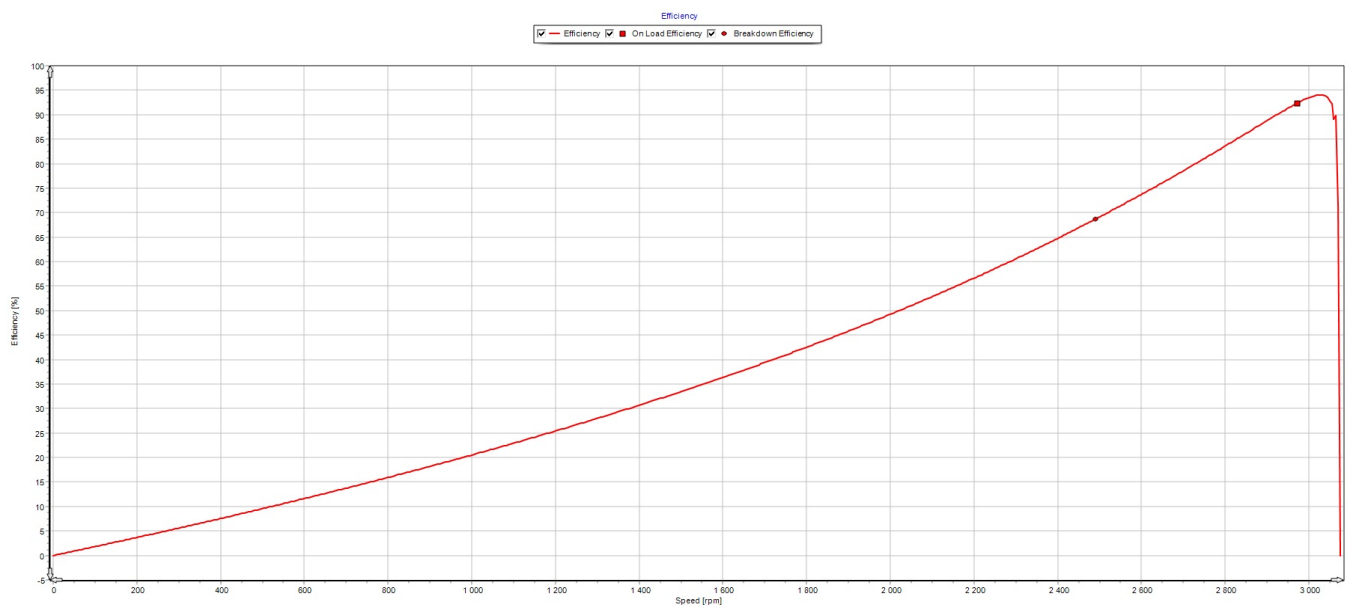


Fig. 3 Efficiency versus speed for a 15 kW traction motor.

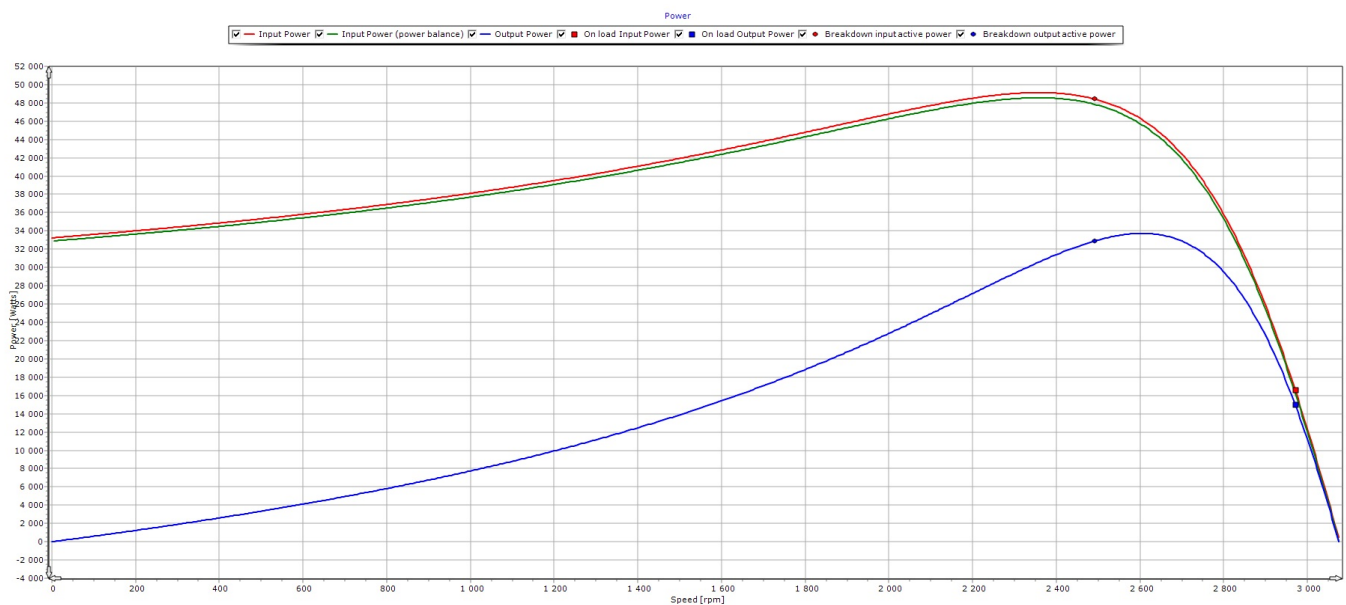


Fig. 4 Power versus speed for a 15 kW traction motor.

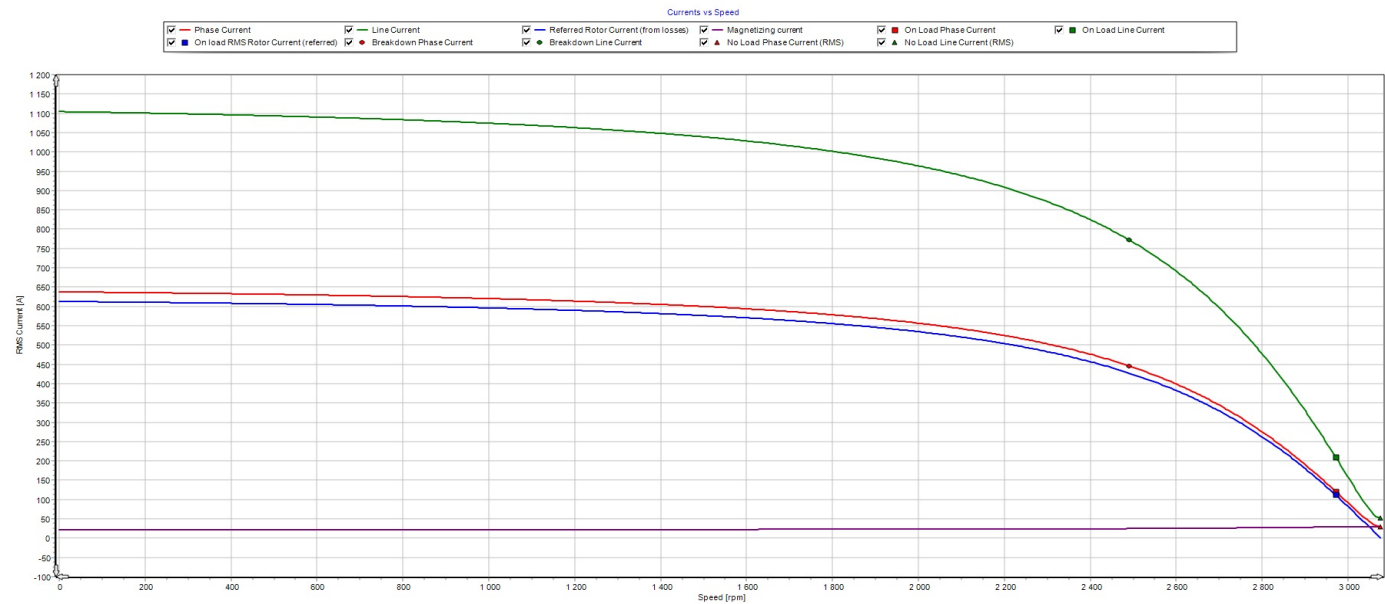


Fig. 5 RMS current versus speed for a 15 kW traction motor.

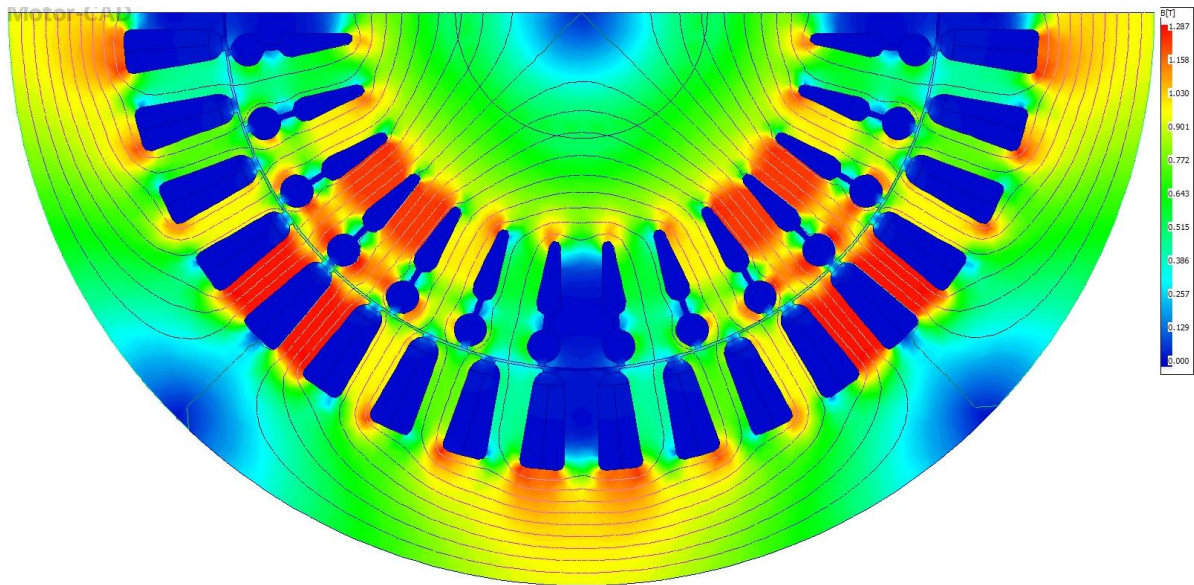


Fig. 6 Magnetic field picture for a 15 kW traction motor at rated load.

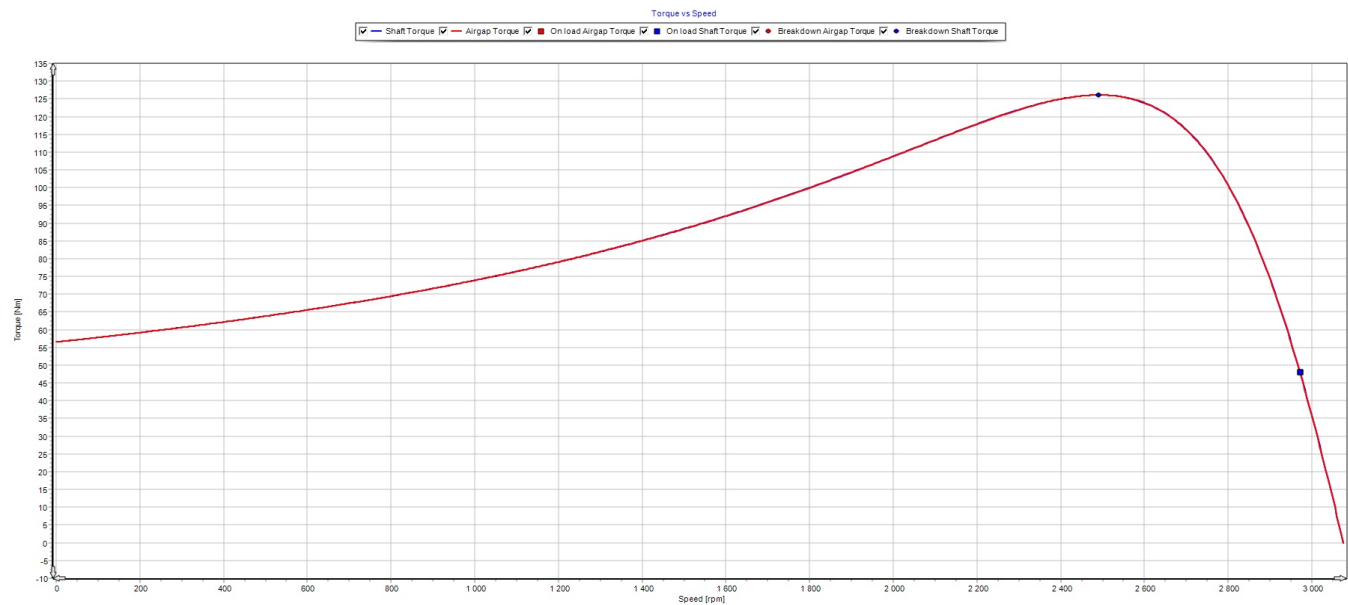


Fig. 7 Mechanical characteristics of a 15 kW traction motor at constant parameters.

4. Conclusions

The positive results of the prototype test are a confirmation of the efforts in the development of competitive, energy-efficient induction motors for BEV. The design, construction, production and testing activities are aimed at the implementation of the set motor indicators and the provision of high efficiency. and level of reliability. An AC motor has been proposed for driving electric vehicles. The adventurous stage made it possible to gain experience, speed up implementation and realize sales, create a base that will serve in subsequent developments. Upcoming tasks include expanding and supplementing motor series, taking customer suggestions into account. Work on the implementation of asynchronous motors with a higher degree of protection is also a priority.

Along with efforts to develop competitive, high-energy-efficiency asynchronous motors for BEV, theoretical model studies are also needed, as well as field tests of electric motor prototypes mounted on EV, which are conducted under a specific program containing cycling of work and type of load. This would give a more complete and clear picture of the overall behavior of the electric drive.

As a summary - there is a clear interest in cleaner, greener energy, and hence also for such a world. This implies actions to support energy optimization, environmental protection and resource saving both at the design stage and in operation of electric propulsion systems.

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Monitoring of changes in the roughness of the metal surface after the application of the conversion layer

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Abstract: The article is focused on the study of the integrity of the material that is used in the automotive industry in process of creating joints by combined technology. The article describes the study of the properties of chemically pretreated surfaces by phosphating technology. When creating new surfaces by phosphating, a new type of phosphate layer was used using modern conductive compounds of polyaniline salts. The pretreated surfaces were investigated in terms of structure, 2D and 3D microgeometry, contact angle in relation to the determination of surface wettability and surface energy. The experiment was realized in order to identify the connections between individual factors of the process and roughness characteristics.

Keywords: surface integrity, microgeometry, roughness, contact angle

1. Introduction

In automotive industry, when constructing cars, they also emphasizes the use of increasingly progressive steel materials that have improved properties, in order to achieve better efficiency in the operation of cars. This fact contributes to the development and acceleration of adhesive bonding technologies, but this pace cannot be at the expense of the quality of the given joints. Therefore, constant precise testing of the joints and the quality of the surfaces that the joints create is necessary to ensure reliability at the required quality. The quality of the materials to be joined is increased by the conversion layers representing the chemical pretreatment of metal materials, which are created by the chemical reaction between the metal and the applied coating. In the final phase of a given chemical reaction, a surface layer is formed – conversion layer.

Phosphate layers are often used as conversion layers in the automotive industry. The primary advantages of phosphate layers include, for example: improved corrosion resistance, increased surface functionality and support for adhesion of organic coatings or adhesives. [1]

Usually, these phosphate layers are made of zinc or iron phosphate. Application of phosphates can be carried out by spraying or immersion. Phosphating technology is constantly evolving. The paper deals with the possibility of creating such phosphate layers by applying polyaniline salts and their influence on changes in surface properties.

2. Material and method and results

2.1 Used material

Uncoated deep-drawn steel DC04, thickness 0.8 mm (abbreviation designation DC). The chemical composition of the materials is in Table 1.

Table 1: Chemical composition of used steel DC04

Material	C	Mn	P	S
DC	0,04%	0,25%	0,009%	0,008%

The tested samples were pre-treated by a new approach to creating the conversion layer by chemical pre-treatment using modern conductive compounds of polyaniline salts – polyaniline phosphate and polyaniline citrate.

2.2 Used pre-treatment

a) Exclusion of polyaniline salt (PANI-H₃PO₄) by precipitation polymerization (conc. H₃PO₄ = 0.8 M) - Sample (DC_1)

Polyaniline is prepared by oxidation of aniline with ammonium peroxodisulphate in an acidic environment. The reaction takes place in air at room temperature. This is an exothermic reaction. In the practical version, 9 ml of aniline was dissolved in a beaker in 250 ml of distilled water acidified with phosphoric acid in an amount of 13.6 ml. In the second beaker, a solution of ammonium peroxidizate was prepared by dissolving 28.5 g of the substance in 750 ml of distilled water.

After complete dissolution, the prepared solutions were mixed and stirred with a glass stirrer for the entire time of polymerization due to increased diffusion of reaction substances. After mixing the solutions, panels were inserted into the beaker, on which the polyaniline salt was secreted.

The course of polymerization was accompanied by color changes. From the initially clear reaction mixture through blue to the final deep green color of polyaniline. [2, 3]

b) Exclusion of polyaniline salt (PANI-Citr) by precipitation polymerization (conc. citric acid = 1.6 M) Sample - (DC_4)

In this part, the pre-preparation of the phosphate was carried out as follows: in a beaker, 9 ml of aniline was dissolved in 250 ml of distilled water acidified with citric acid in the amount of 84 g.

In the second beaker, a solution of ammonium peroxidizate was prepared by dissolving 28.5 g of the substance in 750 ml of distilled water, and both were mixed throughout the polymerization.

2.3 2D surface roughness measurement method

The surface roughness of the evaluated samples was measured by the touch measurement method with a profilometer type SurfTest SJ-201, Mitutoyo (Japan). The measurement was carried out in accordance with the ISO 21920-2 standard. For the purpose of the experiment, parameters were chosen that could accurately describe the differences in the roughness of the evaluated surfaces.

The following parameters were chosen:

Ra [μm] – mean arithmetic deviation of the surface

Rz [μm] – average value of the largest profile heights

RPc [-/cm] - number of profile elements per cm of length

RSm [μm] - average width of profile elements

2.4 Measured values of roughness parameters

According to the mentioned methodology, individual surface roughness parameters were evaluated, Table 2. The sample marked DC_0 presents the measured values of the unprepared surface.

Table 2: Average values of measured roughness parameters

Sample	Average values of measured roughness parameters			
	Ra [μm]	Rz [μm]	RPc [-/cm]	RSm [μm]
DC_0	$1,08 \pm 0,09$	$6,01 \pm 0,59$	$56,07 \pm 10,65$	$187,3 \pm 30,27$
DC_1	$2,07 \pm 0,56$	$14,44 \pm 5,78$	$56,941 \pm 12,58$	$172,5 \pm 62,39$
DC_4	$2,60 \pm 0,45$	$15,55 \pm 2,12$	$32,95 \pm 3,81$	$284,5 \pm 39,73$

On the basis of the achieved values, we can conclude that the application of phosphate layers resulted in an increase in the average values of the observed roughness parameters compared to the original surface. Sample DC_4, phosphate with polyaniline salt (PANI-Citr) by precipitation polymerization (conc. citric acid = 1.6 M) has the highest and the most appropriate values in all selected roughness parameters. [4,5] In the attached profilograms of individual surfaces of materials Fig. 1a – Fig. 1c we recorded a change in the surface roughness of tested materials and on the basis of this fact we can state that the chemical surface pretreatment has an effect on the individual roughness parameters of the monitored samples.

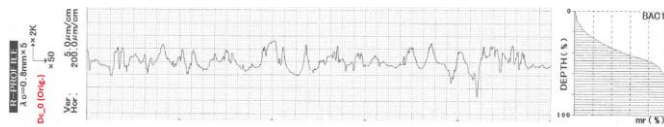


Fig. 1a Profilogram + Firest-Abbot curve for the sample DC_0

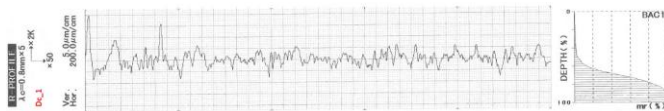


Fig. 1b Profilogram + Firest-Abbot curve for the sample DC_1

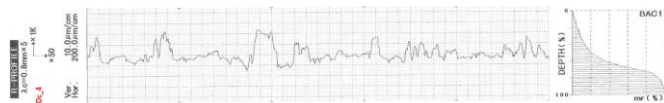


Fig. 1c Profilogram + Firest-Abbot curve for the sample DC_4

The geometric state of the surfaces has a decisive influence on its function. The requirements for the accuracy of the geometry of individual surfaces that are in contact with others are very high. Since it is assumed that the studied surfaces will interact with others, e.g. in the case of adhesive bonding, these were also subjected to a spatial evaluation of the surface in order to obtain a comprehensive image that tells about the character of surface. This measurement was carried out in a non-contact way using a ZEISS Smartproof 5 confocal microscope. 3D representation of the surfaces is in Fig.2a– Fig. 2c.

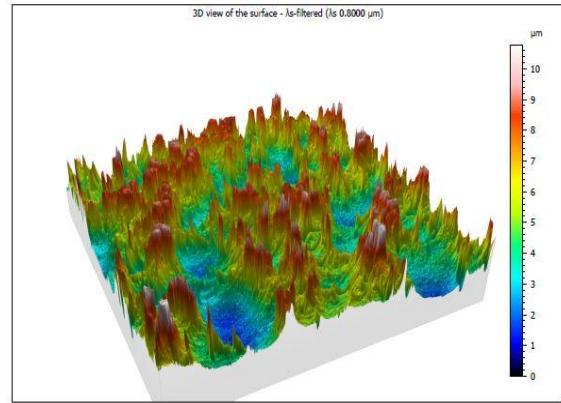


Fig. 2a 3D surface of the sample DC_0

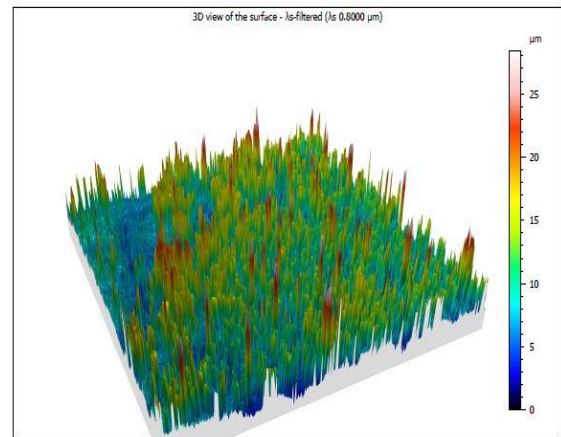


Fig. 2b 3D surface of the sample DC_1

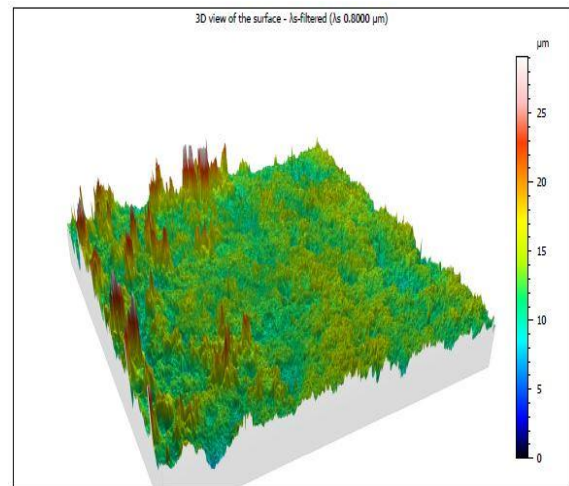


Fig. 2c 3D surface of the sample DC_4

2.5 Measurement of the contact angle of the samples

The next step was to compare the contact angle. The contact angle of the surface of the materials was measured by a direct optical method. See System E Advex Instruments was used as the device. The method consists in placing a small drop of liquid on the measured surface, photographing it and determining the contact angle from the photograph, Fig. 3. Table 3 represents the values of the measured contact angles of the observed samples with an average value.

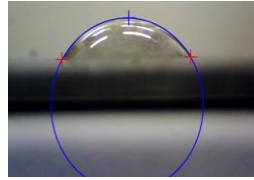
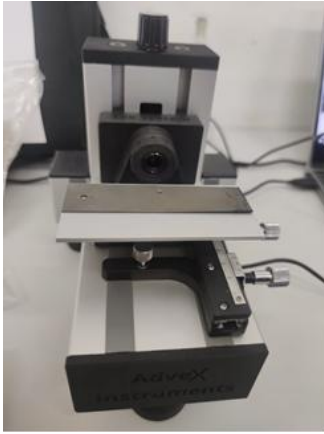


Fig. 3 The principle of contact angle measurement

Table 3: Values of measured contact angle values

Measurement number	DC_0	DC_1	DC_4
1.	70,2°	77,5°	75,1°
2.	68,5°	77,6°	81,3°
3.	65°	68,8°	79,2°
Average	67,9°	74,6°	78,5°

2.6 Morphology of films of polyaniline salts (PANI.H₃PO₄ and PANI – Citr)

The morphology of the samples with films of polyaniline salts was evaluated using the AFM method. The mean square thickness of the surface of the excluded film of polyaniline salts was measured. The root mean square thickness value provides information about the distribution of the polymer film on the material on which the film was deposited. [2]

The applied film of polyaniline salt PANI.H₃PO₄, which was formed in an environment of 0.8M phosphoric acid, reached a mean square thickness of the film surface up to 68 μm, while the film of polyaniline salt PANI – Citr, which was formed in an environment of 0.8M citric acid, reached mean square thickness of the film surface with a value of up to 0.82 μm.

Microscopic images of synthesized polyaniline salts are shown in Fig 4a and Fig. 4b.

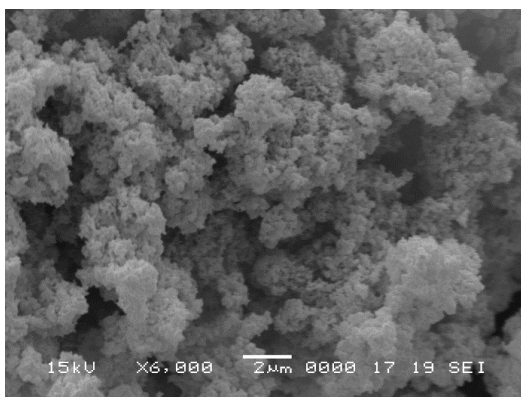


Fig. 4a Microscopic image of synthesized polyaniline salts H₃PO₄

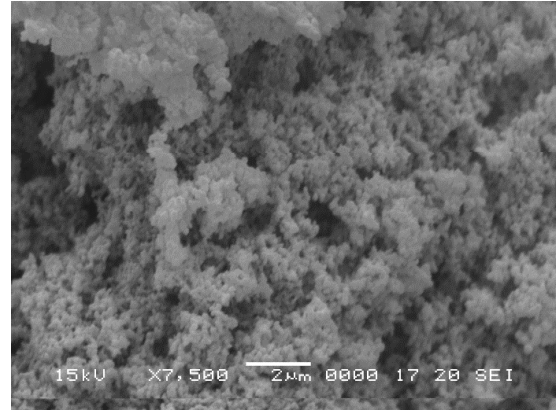


Fig. 4b Microscopic image of synthesized polyaniline salts polyaniline citrate (PANI-Citr.)

From the comparison of the morphology of the polyaniline salts, it is possible that there was an increase in thick layers of the applied coating film on the surface of the sample DC_04 (PANI-Citr). This means that, despite the relatively large contact angle, good anchoring of the glue is a prerequisite. Contact angle values can be improved in future research by correcting the parameters during the phosphating process.

3. Conclusions

Based on the presented results of experimental measurements, it is possible to state the following conclusions:

- when measuring and evaluating the 2D roughness parameters, it was demonstrated that the DC_4 sample has more favorable results for the further application of the adhesive coating or glue.
- the samples that were phosphated in polyaniline salts in this experiment showed satisfactory values of contact angles. It is necessary in future research to focus on the optimization of technological parameters during phosphating.

Experimental verification of the use of specific compounds of polyaniline salts in the phosphating process from the point of view of their applications for adhesive bonding is promising, but attention needs to be paid to further research from the point of view of obtaining the most optimal surface fragmentation.

Acknowledgement

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External loading of the motor grader during the operation of the cutting operation and moving the processed surroundings

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Abstract: The main feature of modern earthmoving machines is the execution of a wide range of different operations. At the same time, the loading mode changes and it is characterized by coordinates, values of the applied forces acting on the machine and the regularities of their change in time. In order for the machine to be able to adapt to the listed variables, it must be equipped with the appropriate systems. Existing calculation methods do not allow taking into account the entire range of these effects. In the proposed work, adaptation approaches of earthmoving and transport vehicles to variable operating conditions are analyzed.

Keywords: EARTH-MOVING MACHINES (EMM), MOTOR GRADER, ROAD-HOLDING ABILITY, DYNAMIC LOADING.

Topicality

A promising area for improving earth-moving equipment, in particular motor graders, is the adaptation of a motor grader to external loading conditions, when performing a cutting operation and moving the processed medium.

For excavating and earth-moving machines, characteristics of the road-holding ability are influenced, apart from the abovementioned parameters, by certain additional destabilizing factors. Firstly, a number of machines is equipped with active implements, which, during the excavation of soil move relative to the base machine leading to occurrence of additional inertia forces in the horizontal plane. Secondly, the main vector of the external resistance forces acting on the blade- and bucket-type implement can be considerably displaced in relation to the longitudinal axis of the base machine, which has randomly changed its position in the process of soil digging. This causes not only occurrence of additional torques in the horizontal plane but also additional lateral loads on the implement [1, 2].

Since for performing a technological operation by a motor grader, the main blade is installed with a grip angle different from 90° and with a skew angle in the vertical plane up to $25-30^\circ$, the additional lateral forces will act on the motor grader during operation, as well as the moments in the horizontal plane that contribute to leaving the planned trajectory of movement.

Review

In accordance with the suggested methodology, at the initial stage, it was proposed to use the indicator of roadholding stability of a motor grader as an adaptation criterion. A review of scientific and technical information showed that, as a criterion for directional stability, the researchers use the coefficients, the levels of the ratio of the total force factor, which contributes to keeping the car on the planned trajectory of movement, to the total force factor, which contributes to the displacement of the car from this trajectory [3]

$$k_y = \frac{P_{y0}}{P_{oecm}} \quad (1)$$

where P_{y0} is the total force factor that keeps the car on the planned trajectory of movement; P_{oecm} is the total power destabilizing factor, which contributes to the deviation of the machine from the planned trajectory of movement.

This approach does not fully correspond to the technological operations that a motor grader performs. To substantiate the criterion of road-holding stability and the structure of the dynamic model of the car movement, the exploratory experimental studies were carried out at the educational and scientific base of Kharkiv National Automobile and Highway University (ESB KhNAHU), in which the trajectory of the motor grader was recorded in the process of performing various technological operations. The experiments were carried out in summer on the soil of the II category. As a base

machine, the DZK-251 motor grader of the Kryukov Railway Car Building Works was used.

The experimental studies have shown that the trajectory of the motor grader movement was formed in different ways: the linear trajectory of the motor grader movement is formed in cases where the working resistance on the blade is relatively small. In this situation, deviations of the real trajectory of the motor grader from the planned one are not registered. In situations where the coefficient of adhesion of the propelling units to the supporting surface is insignificant, the movement of the motor grader was recorded when performing technological operations along a curved trajectory; when cutting the soil, a piecewise linear trajectory of the motor grader was also observed. At this, at the initial stage, the machine moves along the straight line, then, as the external resistance increases, it slows down, turns around the blade blocking point and then continues its straight movement.

Goal

The goal of the publication is to analyze the possibility of adapting the motor grader to the conditions of external loading, whose implementation will help increase the efficiency of machines.

Solution to the problem

In situations when the road-holding stability is lost, it should be noted that the lateral displacement of the machine occurs gradually at the distance of movement (grip). Since it is recommended to carry out most of the technological operations performed by a motor grader with overlapping passes, as a first approximation, we can take the overlap factor k_n or the corresponding lateral displacement of the blade (machine) edge ε_l as a criterion of road-holding stability.

In this case, the criterion $y_p(x)$ of directional stability for grips of length l needs the following condition:

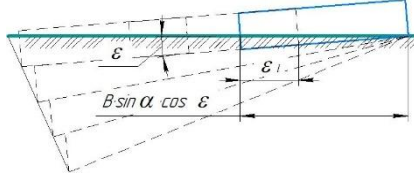
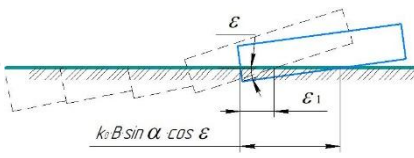
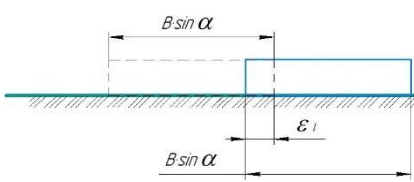
$$y_p(x) \leq y_n(x) \pm \varepsilon_l \quad (2)$$

where y_p is the lateral displacement of the machine while driving along the real trajectory of movement; y_n is the lateral displacement of the machine while driving along the planned trajectory of movement.

The values of ε_l can be determined based on the information given in the reference literature [4, 5], Table 1.

The coefficient k_0 depends on the depth of soil cutting and the value of the skew angle of the blade in the vertical plane, which are determined by the type of technological operation performed. According to previous estimates, the value of this coefficient ranges from 0.2 to 0.65.

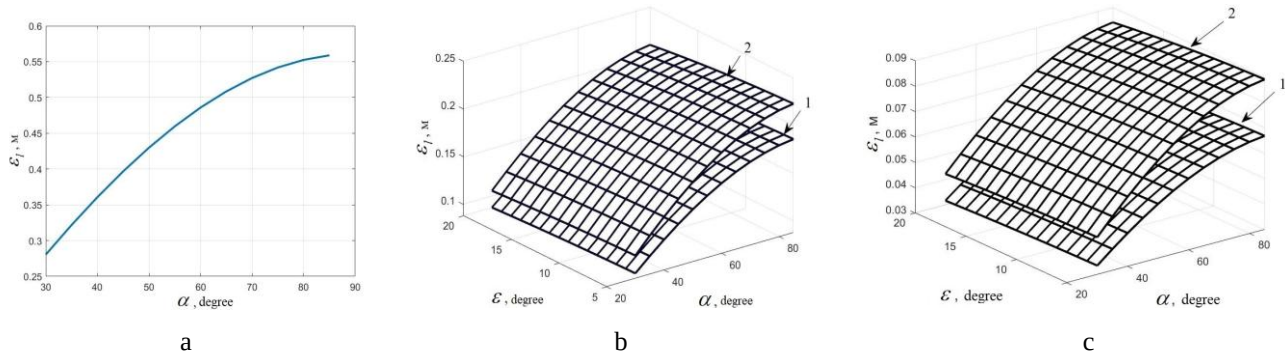
Table 1. Recommended values of admissible displacement of the motor grader blade edge during technological operations

Type of technological operation	Calculation scheme	Value of k_n	Value of ε_l
Cutting, beam development pattern		Loosened soil 1.15–1.3	$(k_n - 1) \cdot B \cdot k_v \cdot \sin \alpha \cdot \cos \varepsilon$ (3)
		Unbroken soil 1.25–1.6	
Cutting, layer-by-layer development pattern		Loosened soil 1.45–1.7	$(k_n - 1) \cdot k_0 \cdot B \cdot k_v \times \sin \alpha \cdot \cos \varepsilon$ (4)
		Unbroken soil up to 2	
Soil displacement		1.1–1.15	$B \cdot k_v \cdot \sin \alpha \cdot (k_n - 1)$ (5)

The coefficient of variation k_v is determined by the normative requirements for the quality of the work performed and the technical and economic indicators that characterize the motor grader operation. These include productivity and unit cost. Previous calculations have shown that the value of this coefficient varies within the range from 0.05 to 0.25 (Fig. 1 a).

The calculation results for the admissible displacement values of ε_l for $k_v = 0.1$ are given in Figure 1 b-c. The value of ε_l varies

within a wide range from 0.033 m to 0.186 m. The range of admissible values of ε_l depends not only on the type of technological operation performed, but also on the physical and mechanical characteristics of the developed soil. Increasing the dragging angle from 40 to 60 results in ε_l increase from 34% to 36%. Increasing the skew angle in the vertical plane from 5 to 20 reduces the values ε_l by 5%–8%.



1 – loosened soil ($k_n = 1.6$); 2 – unbroken soil ($k_n = 1.8$)

Fig.1 Graph of the dependence of the admissible lateral displacement of on the angle of grip α during the operation: a – displacement of the soil ε ; b – cutting the soil using the beam pattern; c – cutting the soil using the layer-by-layer pattern

Taking into account the assessment of the criterion of road-holding stability, it is necessary to calculate the deviation of the real trajectory of the motor grader blade edge relative to the planned trajectory at a given distance, which corresponds to the length of the face or the grip.

The second stage of the methodology, assuming the technological adaptation of the machine, in our case, was provided by the installation of the main blade of the motor grader with the angle of grip and the angle of skew in the vertical plane in accordance with the normative recommendations. Our studies have shown that due to the variation in the properties of the surroundings being developed and the specifics of the technological operation performed, it is possible to change the recommended geometric characteristics of the installation of the main dump. Their refined values can be determined by solving the problem of optimizing the process of developing the surroundings. Here, the performance

criterion for a given specific technological operation is used as an objective function.

At the third stage of the motor grader adaptation methodology, recommendations should be developed to keep the machine on the planned trajectory within the assigned value of the adaptation criterion. There are two ways to achieve this:

- by the effect of theoretical research based on the development of a mathematical model of the motor grader movement process and subsequent analysis of the formed trajectory;
- by the effect of the analysis of experimental data.

The proposed study takes into account the results of a multifactorial experiment carried out by the authors in the conditions of the KhNAHU test site on the DZk-250 motor grader. With unchanged geometric characteristics of the blade installation

during the experiment, the most significant pre-determined factors were varied: the angle of the cross slope of the supporting surface, the coefficient of adhesion of the motor grader wheels to the supporting surface, the angle of rotation of the front wheels in the horizontal plane and the angle of their skew in the vertical plane. The analysis of the results obtained showed that the cross slope angle and the coefficient of adhesion are destabilizing factors, while the variation of the front wheel alignment angles allows the motor grader to be kept on the planned trajectory.

Thus, the choice of rational values of these angles allows to adapt the motor grader to varying operating conditions and to provide its trajectory within the specified adaptation criterion.

On the basis of the experimental study, regression equations were obtained connecting all four of the variable parameters [6].

The obtained regression equations allow in graphic and numerical form to establish the effect of simultaneous changes in several factors on the indicators of road-holding stability, in particular, on the deviation of the motor grader from the planned trajectory.

The graphs of the dependence of the lateral displacement H of the motor grader on the angle of rotation of the front wheels in the horizontal plane γ and the angle of skew in the vertical plane ρ for different cross slopes of the supporting surface are shown in Figure 2.

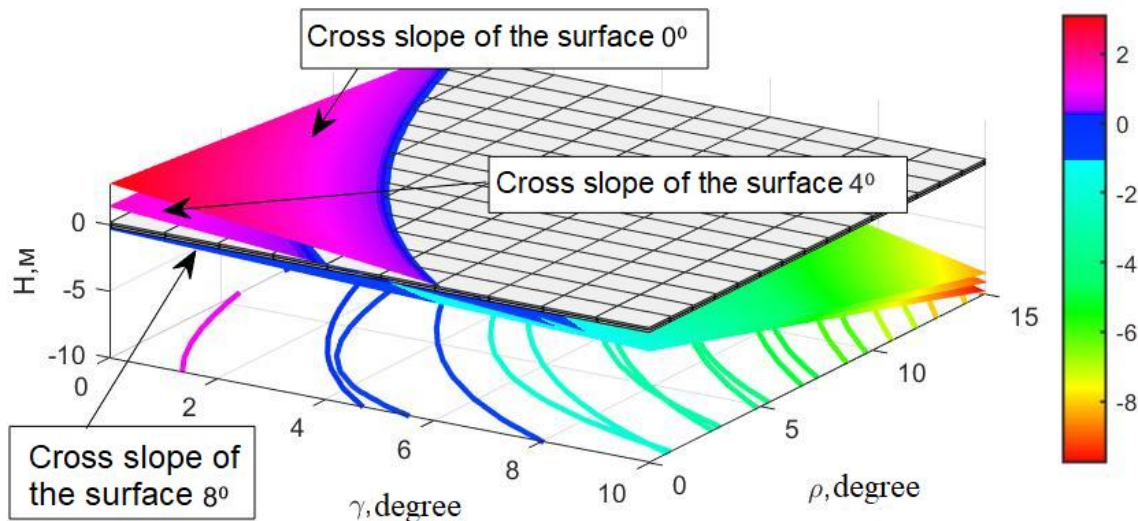


Fig. 2. Graph of the dependence of the lateral displacement of the motor grader on the angles of rotation in the horizontal and skew in the vertical plane of the front wheels for different values of the cross slope of the supporting surface

Similar graphs, but for different adhesion coefficients, are shown in Figure 3. All constructed surfaces are nonlinear. The greatest deviations of the motor grader from the planned trajectory were recorded at $\gamma = 10^\circ$ and $\rho = 10^\circ$ and are $-8.4 \dots -9.7$ m on the grip length of 20 m. In situations when $\gamma = 0^\circ$ and $\rho = 0^\circ$ the deviations are $1.4 \dots 3.2$ m.

The analysis of the regression equations shows that for the given values of the cross slope and the coefficient of adhesion it is possible to determine the relationship between the angles γ and ρ according to which the criterion of road-holding stability is satisfied. Graphically, the range of these values is located in the zone of intersection of the constructed surfaces by two parallel planes, which are located at distance $\pm \varepsilon_i$ relative to the zero offset. In the graphs shown in Figure 4, the range of admissible values of angles γ and ρ is located between the two curves.

The results of such calculations for variable values of the coefficient of adhesion are shown in Figure 5.

Thus, the adaptation of a motor grader according to the criterion of road-holding stability for different angles of the cross slope of the supporting surface and adhesion coefficients is reduced to the choice of wheel alignment angles simultaneously in the horizontal and vertical planes from among the recommended.

Conclusion

The conducted research has proved that the proposed method of adaptation of EMM to variable operating conditions makes it possible to synthesize an adaptation system that meets the selected criteria.

For motor graders of classical design, the adaptation system is reduced to choosing the angle of rotation of the front wheels in the horizontal plane and the corresponding angle of skew in the vertical plane in accordance with the given graphical dependencies.

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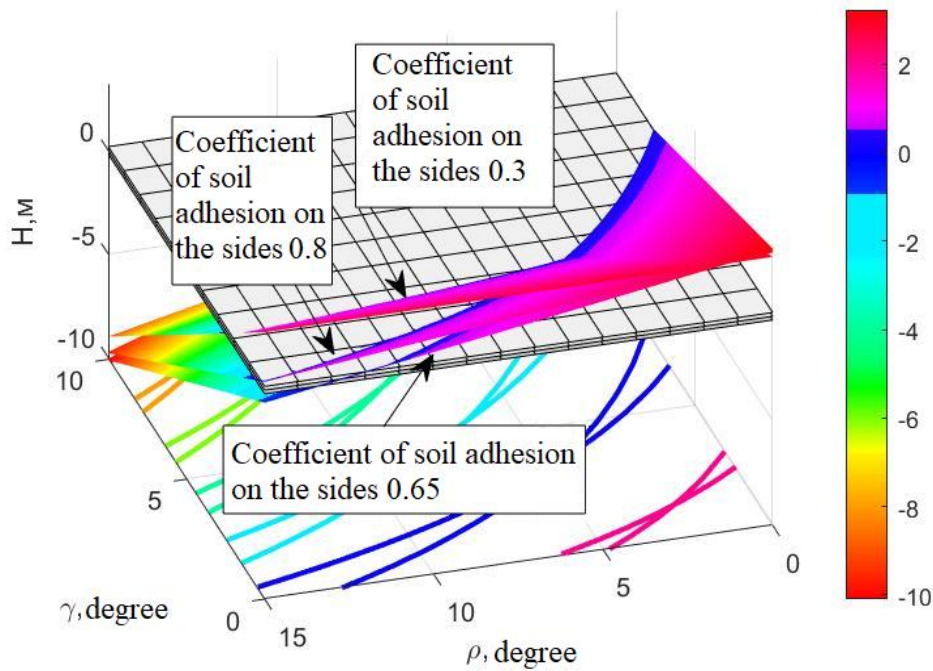


Fig. 3. Graph of the dependence of the lateral displacement of the motor grader on the angles of rotation in the horizontal and skew in the vertical plane of the front wheels for different coefficients of adhesion

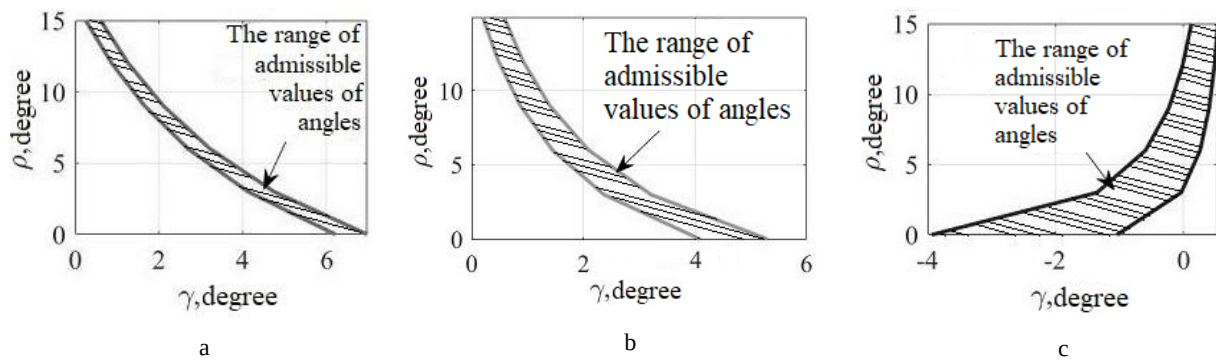


Fig. 4. Graphical dependencies that allow you to determine the ratio of the angles that provide the admissible lateral displacement of the motor grader within $\varepsilon_l = \pm 0.18 m$: a – the cross slope of the supporting surface is 0° ; b – the cross slope of the supporting surface is 4° ; c – the cross slope of the supporting surface is 8°

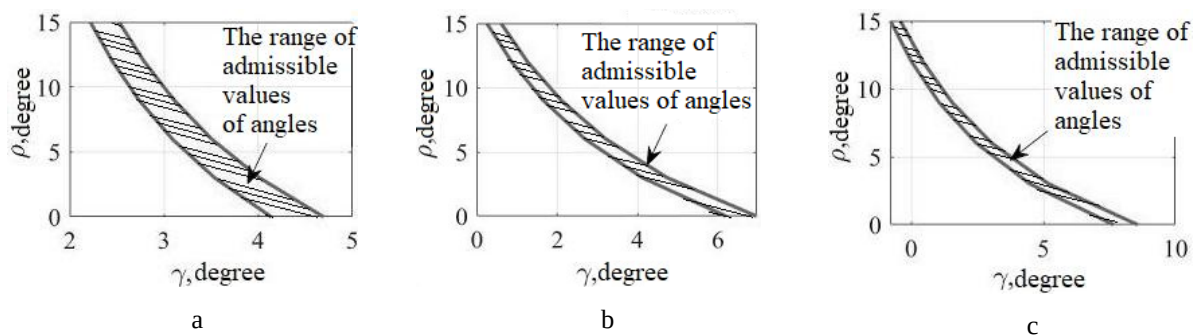


Fig. 5. Graphical dependencies that make it possible to determine the ratio of the angles that provide the admissible lateral displacement of the motor grader within $\varepsilon_l = \pm 0.18 m$: a – the coefficient of adhesion is 0.3; b – the coefficient of adhesion is 0.65; c – the coefficient of adhesion is 0.8

Risky behaviour of electric scooter users in Novi Sad

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Abstract: *The usage of electric scooters (e-scooters) has experienced a real expansion in the territory of the Republic of Serbia in recent years. These vehicles represent an easy and simple way of transportation in city conditions, especially on shorter distances. The lack of legislative frameworks for this type of vehicle is the main problem in Serbia. That is why e-scooters are used according to the wishes and needs of users, which very often leads to unsafe situations. Research that includes the risky behaviors of e-scooters users is presented within this paper. The research of e-scooter users was conducted in the area of Novi Sad. The speeds of these vehicles at the selected locations were also measured during research.*

Keywords: E-SCOOTERS, SPEED, SAFETY

1. Introduction

Organizing the transportation of passengers is one of the biggest challenges during solving traffic problems in overpopulated cities. Strategies to reduce the use of passenger cars favor the use of public transport vehicles, as well as cleaner or non-motorised modes of transport. E-scooter is mode of transport that can be classified as green vehicles, because they do not represent direct pollutants. Their impact on environmental pollution is indirect because electricity is used to charge them. The production of electricity can greatly affect the concentration of harmful gases. Despite the use of electricity, it is estimated that electric scooters contribute 59 percent less CO₂ compared to the average car in America [1]. That is why many people consider electric scooters as mode of transport that will significantly affect mobility in urban areas. The electric scooter is recognized as one of the most popular modes of city transportation for short distances. Numerous advantages, such as accessibility, convenience, relatively low price, ease of use, etc. make them acceptable to a larger part of the population. Some research shows that electric scooters are suitable for most daily commutes in cities [2].

Their attractiveness has a significant impact on the increasingly frequent use of e-scooters in the area of Novi Sad. There are no legal provisions that regulate the riding of this mode of transport in Serbia, so there is a justified reason for determining the behavior of e-scooters users in traffic. Within this paper, the characteristics of the e-scooters riding in the area of Novi Sad were recorded. The research included measuring speed and identifying risky behaviors.

2. Legislative framework

Most countries legally allow the use of e-scooters in public areas, with legal provisions differing significantly between individual countries. E-scooters are usually equated with e-bicycles. In Sweden the category depends on the power of the e-scooter. It is considered a bicycle with a 250 watts motor and can be considered a moped class I or II if it exceeds this limit and meets the technical standards. Finnish legislation recognizes e-scooters as bicycles, if it ride faster than 15 km/h, otherwise it is categorised as a pedestrian. In Belgium, Austria, France, Germany, and Spain, e-scooters are designated as a special dedicated category [3]. There are differences between countries in terms of other legal provisions regarding e-scooters, such as age restrictions for users, maximum speed limit, part of the road they must use, etc. However, despite the fact that the use of e-scooters is regulated by law, in many countries the legal provisions are not respected. The level of enforcement of laws varies between countries. In Italy and Hungary, for example, there is no enforcement, while in Spain, Austria and Germany there is regular enforcement. The police occasionally organize special actions in Denmark to punish e-scooter riders who break the law [3].

In some countries this mode of transport is not legally defined, among which is Serbia. However, this does not mean that e-scooters are not used in countries where they are not covered by law. According to existing estimates from February 2023, more than

200,000 e-scooters are used in Serbia [4]. Since the use of e-scooters is constantly increasing, it is necessary to define this mode of transport by legal provisions. There is currently a proposal to amend the Law on Road Traffic Safety in Serbia, which includes the use of e-scooters. It is expected that these amendments to the Law will be adopted by the end of the year. It has been suggested that e-scooters represent a special category of vehicles within the legal provisions. The provisions of the law plan to regulate the speed limit of e-scooters, wearing a helmet, transporting other persons, age restrictions of users, allowed areas for riding, etc [5].

3. Safety of e-scooters

E-scooters are an excellent solution for transportation in city conditions, because they are small, quiet and fast. However, these their characteristics can lead to dangerous situations. The lack of noise does not warn other road users about the presence of e-scooters. Riding on pedestrian surfaces is a particular problem due to the speed they can develop. The small dimensions of this mode of transport allow them to slip between other vehicles on the road, which can also be extremely risky. The size of the wheels on e-scooters is not suitable for bumps, so destabilization often occurs during riding. Research in Berlin show that the cause of traffic accidents in 57% of cases was destabilization, i.e. loss of balance [6]. In general, it can be concluded that due to the characteristics of the vehicles themselves, riders of e-scooters are vulnerable road users.

The increasing use of this mode of transport leads to increasing number of traffic accidents involving e-scooters. In most countries, there are still no precise statistical data on the number of traffic accidents and their consequences. However, the available data show that their number is not negligible. According to the data Parliamentary Advisory Council for Transport Safety (PACTS), in the UK, in the first ten months of 2021 there have been 9 deaths and over 300 injured identified in traffic accidents with e-scooters [7]. These data are considered incomplete, especially that injuries related to the use of e-scooters were much more frequent in previous years and their growth was recorded from year to year. In the 2017 one death and 7700 injured were recorded, in the 2018 there have been 5 death and 14500 injured, in the 2019 there have been 21 death and 27700 injured [8]. Research in Finland related to e-scooter injuries show a higher rate of e-scooter injuries compared to other transport modes analyzed in earlier studies. 18 injuries per 100,000 rides were recorded or 7.3 per 100,000 km ridden [9].

The most common injuries in accidents with e-scooters are head injuries, followed by upper and lower extremities injuries [10-13]. In May 2020, in Frankfurt, of the total number of injured, 38% of head and face injuries were recorded. According the data, in Hamburg, from June 2019 to June 2020 were registered 54% of the injured e-scooter riders with trauma to the head or face [14]. Other researchers also found head injuries and musculoskeletal fractures to be the most common [11, 15]

Head injuries and fractures of the lower and upper extremities in accidents with e-scooters are also have also been recorded by other researchers [11,15].

A literature review show that the majority of crash events involving E-scooters also involved powered vehicle, even 79% [10]. In addition, over 80% of deaths are the result of collisions involving a heavier motor vehicle [16]. The number of traffic accidents involving e-scooters is probably significantly higher than existing statistics show. The severity of injuries to e-scooter riders, as well as pedestrians and cyclists who come into collision with these vehicles, indicate the need to find appropriate solutions regarding the regulation of this mode of transport on the street network.

4. Research methodology

The research was conducted in the area of Novi Sad, at four selected locations. E-scooters users ride along bicycle paths were recorded. Reference points were determined on each of the bicycle paths. By visiting each individual location, the mutual distance between reference points was measured. By analyzing video recordings, the time of e-scooters passing over the selected reference points was recorded. The average speed of the e-scooters was calculated based on the recorded passage times and the mutual distance of the selected reference points. From the videos, the minimum and maximum speed on the observed section, conflict situations, risky behaviours, as well as other characteristics were also determined.

4.1. Survey results

Out of the total number, the majority of e-scooter users are men (69%), while 31% are women. The following diagrams show gender and age of e-scooter users.

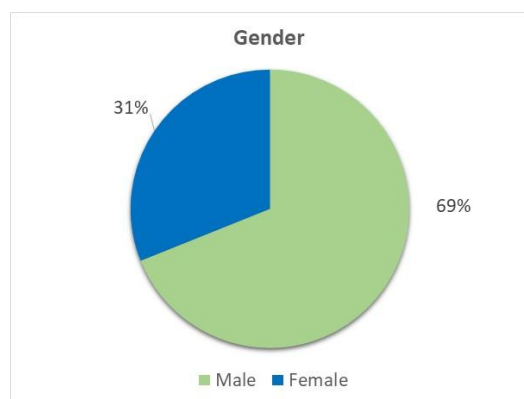


Fig. 1 Gender of e-scooter users

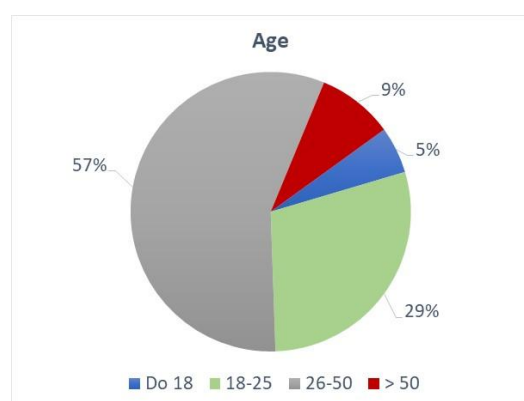


Fig. 2 Age of e-scooter users

By analyzing the speed of e-scooters, it was determined that men move at slightly higher speeds compared to women. Figure 3 shows the minimum, maximum and average speed, observed by rider's gender.

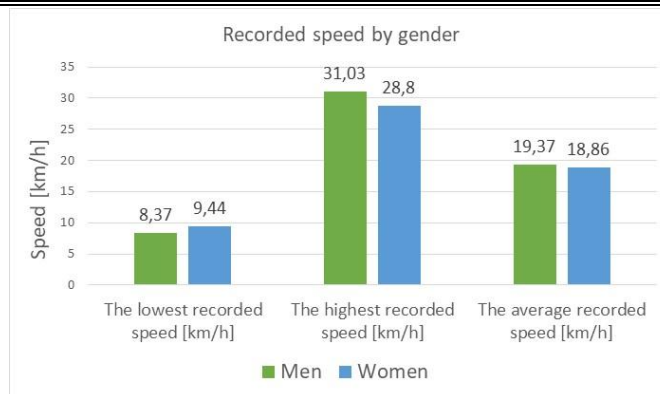


Fig. 3 Recorded speed by gender

Some research results show that pedestrians and cyclists feel safer when e-scooter users ride at a maximum speed of only 15 km/h [17]. Research in Novi Sad shows that the average speed of e-scooters is significantly higher than 15 km/h, while some riders ride at twice the speed. The highest average speeds are achieved by men aged up to 18 and from 26 to 50. For women, the distribution is somewhat different. The highest average speeds are achieved by users of e-scooters between the ages of 18 and 25, and then between the ages of 26 and 50. For both women and men, e-scooter users over the age of 50 move the slowest.

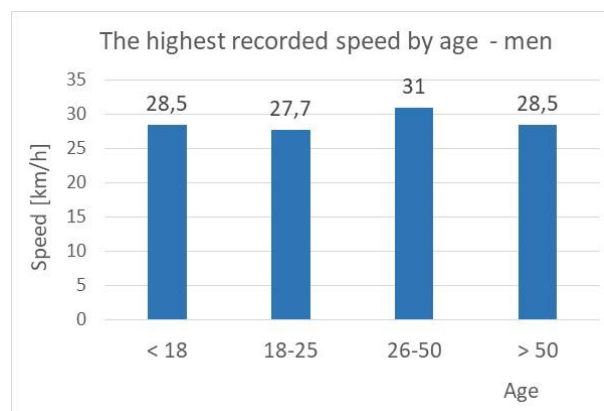


Fig. 4 The highest recorded speed by age - men

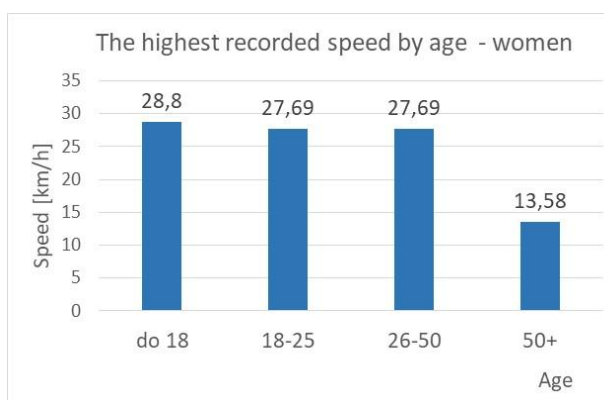


Fig. 5 The highest recorded speed by age - women

The determined speed has no influence on the possession of protective equipment of e-scooter users. Most users do not have any protective equipment. It was recorded that only 4.7% of e-scooter users had a helmet. The percentage of e-scooter users who wear a helmet is very low even in countries where wearing a helmet is a legal obligation. According to research in Austria, only 3% of the total number of e-scooter riders use a helmet [10]. According to data from the literature, only one out of 190 injured e-scooter users in Austin (US) was wearing a helmet [8]. Research in Brisbane (Australia) showed that almost half of e-scooter users commit

violations, such as using traffic infrastructure not intended for these vehicles, not wearing a helmet or carrying another person [18]. During the research on the area of Novi Sad, it was noted bad practice of transporting 2 people on an e-scooter at the same time. The second person was a child, without any protective equipment, in all recorded cases.

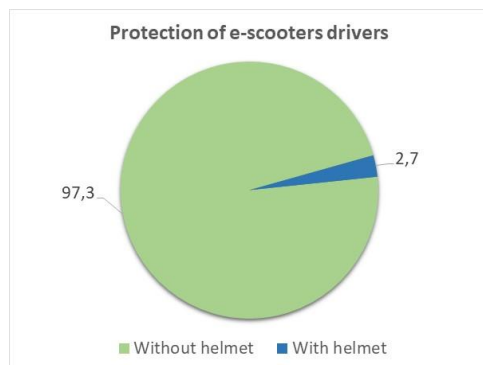


Fig. 6 The percentage of riders with helmet

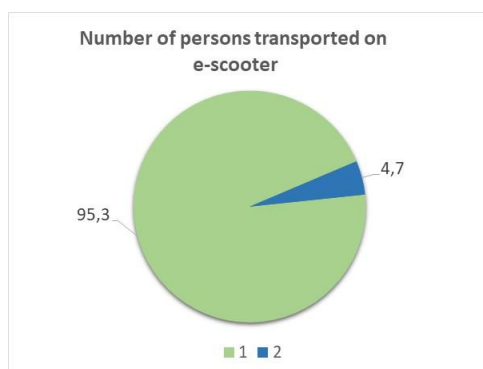


Fig. 7 The percentage of riders with other person on e-scooter

5. Conclusion

E-scooters present a new, very popular mode of transport. The use of e-scooters in urban mobility systems has a number of advantages, such as simplicity, accessibility, absence of noise, absence of harmful gas emissions, they do not require the use of fossil fuels, no special permit is required to manage this mode of transport, etc. On the other hand, the problem is the use of electricity to charge them, the lack of transport infrastructure for e-scooters, the impossibility of riding in bad weather conditions and the fact that e-scooter riders are vulnerable road users. They also endanger cyclists and pedestrians. Although there is a conflict of opinion about the environmental friendliness of e-scooters, the use of these vehicles is certainly more environmentally friendly compared to the use of passenger cars.

Research in Novi Sad has shown that it is necessary to legally regulate the use of e-scooters as soon as possible. Drivers do not use protective equipment, transport other persons at the same time, but also ride at high speeds, which must be legally limited. When legal provisions are adopted, it is necessary to control their implementation, because the experiences of other countries show that many e-scooter riders do not follow the legal provisions even though they exist.

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The impact of tehnological changes on the future of work in transportation

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Abstract: Transport plays an important role in the economic and social development of each country. It also has a major impact on growth and employment. Today, transport faces great uncertainties and problems that will continue to have a strong and unpredictable impact on transport services and transport jobs in the future. Transport jobs are about to change in the coming period – on the one hand due to the development of technology, but also due to other factors, such as the rapid evolution in the organization of work and the nature of labour relations. It is the responsibility of all stakeholders in transport to prepare for these changes – to manage it, minimize its costs and maximize its benefits. The paper presents sets of measures that stakeholders in transport could apply to prepare for upcoming changes.

Keywords: TECHNOLOGICAL CHANGES, WORK IN TRANSPORT

1. Introduction

Transport plays an important role in the economic and social development of each country. It also has a major impact on growth and employment.

However, transport work is ready for dramatic changes in the years to come – on the one hand due to the development of technology, but also due to other factors, such as the rapid evolution in the organization of work and the nature of labor relations. It is the responsibility of all stakeholders in transport to prepare for this change – to manage it, minimize its costs and maximize its benefits.

2. The importance of transport

In 2020, about 195 million people out of a total of 447 million were employed in the European Union. About 10.8 million workers were employed in occupations in the field of transport, which is 6% less than in 2019, when 11.6 million were employed. The number of employees in these occupations is about 5.5% of all employees and about 2.5% of the total population [1].

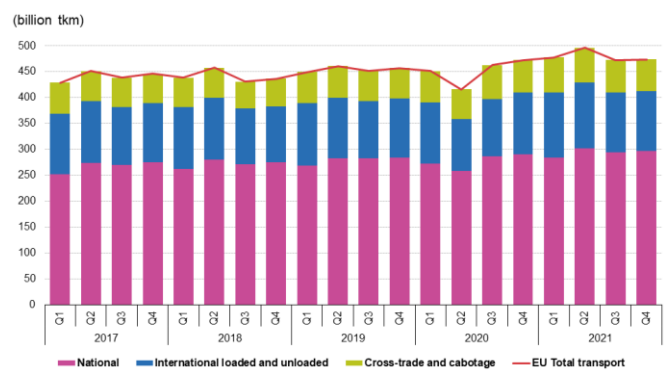
The structure of workers in transport occupations consists of: drivers of heavy goods vehicles and buses (35% or 3.78 million), workers with simple occupations in transport and storage (22%, 2.38 million), drivers of cars, delivery vehicles and motorcycles (19%, 2.05 million), couriers, deliverymen, etc. (12%, 1.30 million), waste removal workers (5%, 0.54 million), engineers, etc. (3%, 0.32 million) and tourist escorts and guides, stewards and conductors (3%, 0.32 million).

Compared to 2019, the biggest drop in employment in 2020 was recorded by tourist escorts and guides, stewards, and conductors (16%) and workers with simple occupations in transport and storage (11%).

The majority of transport workers are men, about 85%, while women make up only 15% of employees. More than a third were older than 50 (37%) or 35 to 49 (36%). 29% of employees are under the age of 35.

Southeast Europe has the highest rate of workers in transport activities in relation to the number of inhabitants; in some regions, there are up to 65 workers per 1,000 inhabitants.

The volume of road freight transport is constantly increasing (Fig. 1). In 2021, the volume of road freight transport (in tkm) increased by 6.5% compared to 2020.



Source: Eurostat (online data code: road_go_tq_tot)

Fig. 1 Quarterly road freight transport by type of operation, EU, 2017-2021

The total number of light, medium and heavy duty vehicles in the EU, EFTA, Russia, Turkey and the United Kingdom increased by about 10% in the period 2016-2020 (Table 1) [2]. The largest increase in the number of these vehicles is in Poland, Lithuania, Slovenia and Romania.

Table 1: Freight vehicles in use, EU, EFTA, Europe, 2016-2020

Year	2016	2017	2018	2019	2020
Light freight vehicles, up to 3.5 tonnes					
EU	26,294,146	27,126,697	27,824,973	28,285,850	28,715,247
EFTA (Iceland, Norway, Switzerland)	873,465	895,253	915,650	936,434	959,127
Russia	3,989,430	4,062,864	4,108,271	4,165,269	4,189,037
Turkey	3,906,416	4,121,243	4,243,107	4,290,292	4,432,127
United Kingdom	4,178,733	4,299,828	4,407,561	4,527,724	5,141,909
Total	39,242,190	40,505,885	41,499,562	42,205,569	43,437,447
Medium and heavy freight vehicles, over 3.5 tonnes					
EU	5,794,166	5,931,832	6,052,048	6,128,743	6,230,100
EFTA (Iceland, Norway, Switzerland)	152,359	154,008	155,306	153,657	157,857
Russia	3,703,635	3,733,711	3,759,152	3,780,977	3,773,297
Turkey	876,152	898,817	908,821	909,951	929,979
United Kingdom	595,542	602,799	605,393	607,998	727,913
Total	11,121,854	11,321,167	11,480,720	11,581,326	11,819,146
Total - freight vehicles					
EU	32,088,312	33,058,529	33,877,021	34,414,593	34,945,347
EFTA (Iceland, Norway, Switzerland)	1,025,824	1,049,261	1,070,956	1,090,091	1,116,984
Russia	7,693,065	7,796,575	7,867,423	7,946,246	7,962,334
Turkey	4,782,568	5,020,060	5,151,928	5,200,243	5,362,106
United Kingdom	4,774,275	4,902,627	5,012,954	5,135,722	5,869,822
Total	50,364,044	51,827,052	52,980,282	53,786,895	55,256,593

In the European Union, the degree of motorization of freight vehicles is 78 vehicles per 1,000 inhabitants. The average age of the fleet of light duty vehicles is 11.9 years, while the average age of the fleet of medium and heavy duty vehicles is 13.9 years.

The transport industry accounts for about 5% of the gross domestic product (GDP). Transport services, broadly defined, make the main and essential contribution to other economic branches, and transport is also a large buyer of the products and services of other economic branches.

The value of the road freight market is growing steadily, except in 2020. It is estimated that the value of the market will continue to grow in the coming years (Fig. 2).

Transport also has an indirect impact on other industries. For the performance of its activities, transport buys products and services from other industries (vehicles, fuel, information systems services, professional services, etc.). Personal consumption by transport employees and investments by transport companies in new facilities and equipment are of particular importance for the economy.

Other economic branches use transport for their own production or service provision. Without reliable and high-quality transport, other economic branches would suffer significant losses in production, creation of new values, efficiency and reputation. The provision of high quality, reliable transport services is therefore essential to ensure continued productivity, profitability and employment in all sectors of the economy.

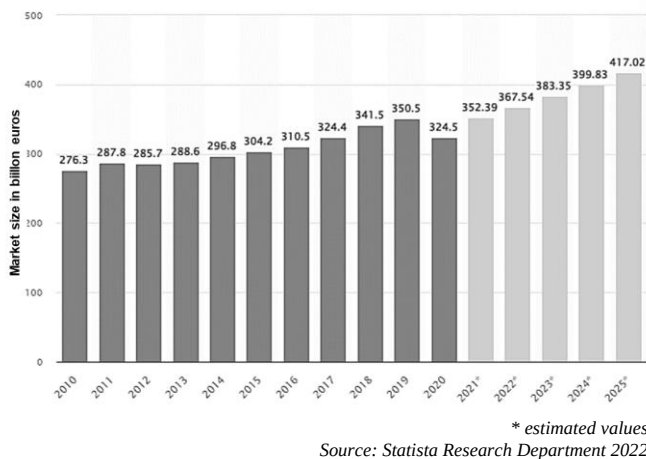


Fig. 2 Size of the road freight market in Europe from 2010 to 2025

3. Work in transport

The largest group of road transport employees are drivers. Driver jobs are particularly sensitive to upcoming technological changes, given the emergence of semi-automated and automated driving and navigation systems.

The average age of transport workers is high. The level of formal training and qualifications is relatively low, although a job in transport is a demanding occupation. Employees, for the most part, acquired knowledge and skills through on-the-job training, rather than through formal qualifications and higher education.

The development and changes in the organization of work in transport services will be a key factor in the change of work in transport. The number of transport workers employed in ancillary services functions is steadily increasing, as carriers now hire external associates (suppliers and subcontractors).

Most employees are engaged in traditional "standard" employment: full-time, paid full-time work with standard rights such as vacation and sick leave. One part of the employees are part-time (in occasional, irregular jobs), while a significant part are self-employed (bus companies). Owners-managers-car carriers perform the same tasks as standard/traditional paid employees, but usually with lower remuneration, but without the same protections and the same rights (which include taxes and contributions) [3]. This is characteristic of letterbox transport companies, where company register in countries with lower labour and operational costs and

weak enforcement when they are actually operating in other countries.

The transport industry is an important employer. The overall demand for transport services has increased compared to other industries. And in traditional occupations (drivers), employment growth is relatively high. The unique demographic characteristics of the transport industry – with a relatively older, predominantly male and less formally educated workforce – represent both a challenge and an opportunity for upcoming changes. Transport faces problems in terms of job quality and stability, mainly associated with the expansion of non-standard employment (part time jobs, occasional jobs, self-employed and hiring external service providers).

4. Causes of change

Transport continues to develop and grow and is becoming more and more important for the work and development of other economic branches. It faces enormous uncertainties and problems that will have a strong and unpredictable impact on transport services and transport businesses in the future.

The first cause of change is the accelerated pace of innovation in technology: drive systems, driving and navigation systems, support systems, information and data management technology. In addition to innovation, transport is influenced by environmental challenges, fiscal issues, governance, globalization and demographic ageing.

Another cause of changes in transport is a change in the nature of labor relations. New forms of work engagement and giving compensation for the work performed (self-employment and contracts with service suppliers) and vertical disintegration of relationships in the supply chain (with several jobs taking place in independent subsidiary companies instead of all jobs being performed in one company, i.e. all jobs being integrated into the company itself).

4.1. Technology

Technological innovation and automation will have a significant impact on transport activities. The possibility of vehicles moving without a driver attracts public attention, but also causes great concern. There are other much less visible, but equally important ways in which new technology will affect jobs in transport.

It is a historical fact that previous waves of technological change did not produce mass unemployment as a permanent outcome. In some cases, new technology, by encouraging more business investment, has led to greater job creation and lower unemployment rates.

Currently, the technological changes are different from previous ones, and therefore their impacts on the labor market may be more significant. Innovations in computing and automation are capable of undertaking entirely new sets of tasks that have not been susceptible to industrial production in the past[4]. Automation was only possible for repetitive routine functions.

The current wave of automation enables the automation of non-routine tasks - including those that require reasoning, flexibility and decision-making ability, in conditions of uncontrolled or unpredictable environments and incentives. New applications include machine learning (ML), data mining, machine vision, computer statistics, artificial intelligence (AI) and mobile robotics. In any case, computers rely on large databases of previous experience to make the best decisions in unpredictable circumstances. This allows them to assume non-routine functions [5].

Frey and Osborne [6] carried out detailed audits of various occupations to simulate their susceptibility to computerization. They analyzed the content of specific tasks in different jobs and then assessed the extent to which they could be automated based on the new capabilities of computers to perform non-routine functions.

They came to the conclusion that nearly half of all jobs in the U.S. economy were susceptible to automation within a few years, based on technology that already exists. Transport was seen as one of the hardest hit industries.

Driverless vehicle control technologies have been discussed in media and political discussions. Many driver activities face a high degree of automation. In technological solutions, the control of the vehicle driving environment has been improved, and automated driving is already appearing on highways and industrial roads. For now, drivers who have to show greater flexibility and judgment in their work are less sensitive to job automation.

Disposable jobs, sales of transport services and administrative tasks are also suitable for automation.

A more complex understanding of the impact of new technologies on transport employment is needed. There are many prerequisites and obstacles that must be overcome before these technologies reach a wide spread in real life. There are significant changes in both the quantity and the nature of transport jobs, and not only because of technology. Stakeholders should be prepared to make the most of these changes.

4.2. Organization of work and labor relations

Major changes in the organisation of work, which include the nature of the relationship between workers and their employers, and the relationships within and between companies in the entire transport supply chain – are also restructuring transport jobs. These changes pose challenges to the quality and stability of work that can be dramatic, and are certainly more immediate than the challenges arising from new waves of technological innovation [7].

The growth of the so-called "gig economy" poses fundamental challenges to the traditional employment model and traditional methods of regulating work and ensuring minimum labour standards. For the most part, it is not clear whether the existing labor regulations apply to freelancers (and in some cases it is explicitly clear that they do not apply). Avoiding traditional regulations and job responsibilities is part of the reason for the growth of freelancers practices, which is characteristic of hiring drivers in the past period.

The transport sector has been an important place for the development of digitally based "gig" business models. The development of other platform-based transport companies (courier and delivery services, as well as intercity parcel and freight delivery) has raised concerns that the transport sector could be disrupted more broadly by the mediation of digital platforms.

Some historical perspective is needed to better understand the jobs on the digital platform and to distinguish between the technical innovations they use and the changes in the organization of work that their business models introduce. In fact, the main organizational features of working on a digital platform are not new at all. Practices such as work-on-demand, remuneration per unit of performance, requiring workers to supply their own tools and workplaces, and the use of intermediaries in work have been common for hundreds of years. The only key difference is that previous versions of these practices could not use digital methods to organize, monitor and compensate for work. The growth of unsafe work in "gig" business models is not exclusively the result of technology development. Instead, the growing job insecurity, which includes those linked to digital platforms, clearly reflects the evolution of social relationships and the balance of power, as much as technology itself.

The transition to non-standard forms of work is likely to continue in the coming years, without major changes in business strategy, macroeconomic conditions and regulatory stance. The development of new platform-based transport business models is still at an early stage. These models bring more transparent and greater competition, while reducing the quality of services, wages and working conditions.

4.3. Preparing for changes

Historical experience suggests that epochal shifts in technology and other dimensions of work can be managed without destroying economic and social values. All actors - including employers, workers and their trade unions, customers and senders, government administration, investors, and training institutions and educational institutions - play a role in preparing the sector to make the most of the upcoming changes [7].

Change is inevitable, and therefore preparation for change management will be more successful if it is jointly created by stakeholders through analysis, consideration and decision-making, rather than being guided solely by individual actions and preferences of narrow interests within the sector.

It is necessary to identify sets of proactive measures through which stakeholders in transport could prepare to minimize costs and maximize the benefits of upcoming changes.

New jobs will emerge in connection with the emergence of new transport technologies. The obvious answer is to help existing workers fill new jobs by providing notification, support and access to training and customization programs. Financial support from employers and the state will be required. Training and adjustment programmes should take into account the age of transport workers and adapt the supply to meet the needs of older workers with less formal qualifications [8].

New technologically intensive jobs will require a wide range of new skills. The specific requirements and qualifications for these skills must be formalized and regulated. Stakeholders in the sector should work closely with existing bodies to specify job requirements. A quality internship is crucial.

The high average age of transport workers is an advantage in transition times. Reduction or restructuring may be partially managed by facilitating the departure of workers who are not interested or unable to retrain or adapt. Providing benefits and incentives for early retirement, with the support of the state, facilitates the transition and bypasses layoffs from work.

Adaptation is more successful when all parties have accurate information about how it is implemented and managed. Stakeholders in transport must commit to the exchange of information, consultations and negotiations on technological changes. Workers and their unions need to be informed about plans for new technologies. The time, scope and effects of new investments should be discussed. Opportunities should be provided for early information from workers about how change will be managed. Collective bargaining should include the terms of technology and its application [7].

4. Conclusion

Transport is facing changes that bring challenges and uncertainty. Accelerating technological change is one of the drivers of this change. But other factors are shaping and reshaping the entire sector and the lives of the people who work in it – including the trend towards non-standard or precarious forms of employment, which has significantly affected the stability and quality of work. The influential factors in the production and sale of transport services are environmental, demographic and fiscal in nature.

At the heart of all these changes and uncertainties, there are also sources of stability and continuity that can inspire confidence in stakeholders as they prepare for the upcoming changes. There is no question about the economic and social significance of transport. The only question is how to manage this sector, in the conditions that bring about change. Transport jobs will change significantly, but they will not disappear.

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An experimental study of lane change distance in obstacle avoidance maneuver

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Abstract: *The obstacle avoidance maneuver was the subject of many researches. Most of the models for calculation of distance necessary to perform the avoidance maneuver were based on theoretical researches, that took into account a large number of simplifications. In order to analyse the influence of different drivers and vehicles on a maneuver, an experimental research study of lane change was carried out at the test track which enables repeatability in the same conditions. Based on those researches it was established the empirical model for calculation of evasive maneuver distance. This model can be used for traffic accidents reconstruction, but also in the development concept of modern "intelligent" vehicles.*

Keywords: LANE CHANGE, MANEUVER, OBSTACLE, DISTANCE, MODEL

1. Introduction

Participating in traffic, the driver has a permanent need to undertake maneuvers in order to change the speed or direction of movement of the vehicle he is driving. At the same time, these changes can be a function of voluntary and planned actions, and they can also be initiated by dangerous situations. Changing the direction of movement, during which the vehicle deviates laterally, is most often undertaken in normal driving modes, in order to establish the desired direction or mode of movement over the lane changing or overtaking. However, in certain traffic situations, the driver is forced to act on the steering mechanism suddenly, trying to avoid an accident. After noticing a stopped vehicle or an immovable obstacle on the road, the driver will act depending on the conditions dictated by the overall traffic situation. If an obstacle on the roadway is spotted in time, the driver will, if conditions exist for this in the given traffic situation, start to bypass it, without suddenly changing the direction of movement. If the obstacle was noticed late, or if the danger in the form of an obstacle on the roadway appeared suddenly, the driver is forced to take one of the sudden actions in order to avoid the accident. At the same time, he has three alternatives in front of him. The first is to try to avoid the accident by braking until the vehicle comes to a complete stop at the obstacle, the second is to try to avoid the collision with the obstacle by controlling the lateral position of the vehicle, and the third, the most complex, is to try to avoid the collision with the obstacle by simultaneously controlling the speed and the lateral position of the vehicle.

In an experimental study in which the possibility of avoiding a collision with a sudden obstacle on the road was analyzed, Rice and Dell'Amico [1] found that 70.5% of drivers tried to avoid the collision only by using the brake, while 23.5% undertook an evasive maneuver in order to try to avoid the collision.

In researching real traffic accidents, Fleury [2] determined that in situations of sudden encounter with an obstacle, drivers tried to avoid the collision by forced braking. In cases where an evasive maneuver was undertaken, the drivers dodged the vehicle mostly in the direction in which the obstacle was also moving.

Limpert and Gamero [3], within the framework of a multidisciplinary analysis of traffic accidents, found that in a sample of 100 accidents, 56% of the drivers tried to avoid the collision by braking, while 7.5% took an evasive maneuver. Simultaneous braking and evading was undertaken by 15% of drivers. This research determined that with the increase in the speed of the vehicle involved in the accident, the number of drivers who tried to avoid the accident by undertaking evasive maneuvers also increased. Based on the conducted research, Limpert and Gamero defined a critical speed, at which a collision with an obstacle cannot be avoided by braking, but only by an eventual evasive maneuver.

Hatterick and Bathurst [4], by the research on a sample of 265 traffic accidents in which the possibility of avoiding a collision with a sudden obstacle on the road was analyzed, showed that 52.7% of drivers tried to avoid the collision by braking. Only by swerving to

the side, 2.3% of drivers tried to avoid the collision, while 43.4% of drivers attempted to brake and swerve at the same time in order to avoid the collision.

Mathematical models that describe the evasive maneuver are basically based on the assumption that it is carried out at a constant speed of movement, as well as that each steering maneuver is instantaneously manifested through an arcing movement of the vehicle. These models do not take into account the reaction time necessary to undertake steering maneuvers, as well as the mechanical response time of the steering mechanism to turning the steering wheels and tires. In addition to the above simplifications, there are also differences in the approach to mathematical modeling of the vehicle evading process. Some of the models are based on the assumption that during this maneuver the vehicle moves along a regular circular arc path. Others are based on the sinusoidal function of the lateral acceleration of the vehicle during the evasion process. There are other mathematical models of the vehicle trajectory during the evasion process: cubic parabola, 5th order polynomial, 7th order polynomial, combination of circular arc and polynomial, clothoid, etc. [5]. In any case, the differences in the length of the escape route, depending on the model used, are not small and amount up to 40%. Bearing in mind such large differences, it is concluded that even the answers regarding the required length of the escape route cannot be completely reliable.

All these models are mostly based on a theoretical basis and certain simplifications, so they do not include one of the most important categories for the realization of this maneuver, which is the behavior of the driver. In the previously mentioned research, it was shown that the driver's behavior also differs in the situation when a decision has to be made as to which evasive action will be taken. Therefore, it is quite realistic to expect that the parameters that characterize the movement of the vehicle during the evasive maneuver differ to a certain extent, from case to case and from driver to driver. Precisely for this reason, the idea of this work is that the basis of the model for calculating the length of the road necessary for the realization of the evasive maneuver is the results of experimental research. For this research to be meaningful, it must be designed in such a way as to enable the experiment to be repeated, under as similar conditions as possible. In this way, a valid sample for analysis would be provided, which would be more heterogeneous in nature, in terms of the vehicles participating in the experiment and the drivers who drive them.

2. Types of vehicle maneuvers during obstacle avoidance

Unlike the evasion in order to change the traffic lane, which is performed in the mode of normal, comfortable lateral acceleration for the driver and the passengers in the vehicle at a distance sufficient to perform the planned maneuver, the evasion in order to avoid running into a sudden obstacle is unplanned and forced by the current traffic situation. The maneuver is performed at the available distance, which is usually not enough to avoid a collision by braking. For this reason, the lateral acceleration that occurs during

this maneuver exceeds the limits of comfortable acceleration and can often result in the destabilization of the vehicle.

One of the frequent fundamental differences in the approach to the analysis of evasive lane change maneuver is the unique treatment of the concept of the length of the road necessary to move the vehicle sideways for the width of the obstacle and the length of the road necessary for the obstacle impact avoidance by swerving. These problems were pointed out by Bonett [6]. The concept of lateral evasion for the width of the obstacle implies the transition of the vehicle from one path to another, parallel to the initial one (Fig. 1.)

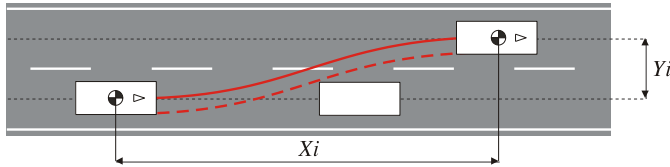


Fig. 1 Maneuver necessary for avoiding the impact with an obstacle by the offset for the width of the obstacle

When avoiding a collision with an obstacle by sudden turning, this maneuver ends when the vehicle pass near the obstacle without contact with it. This means that at the end of this action, the vehicle is in an inclined position compared to the position it had at the beginning of the maneuver (Fig 2.).

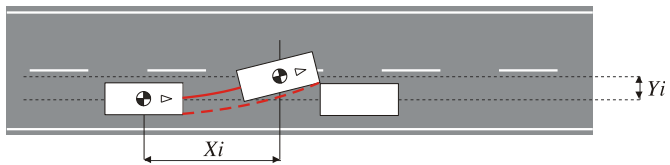


Fig. 2 Maneuver necessary for avoiding the impact with an obstacle by swerving for the width of the obstacle

Due to the identical treatment of the width of the lateral evasion in both maneuvers, there are significant differences in the length of the road required for their implementation. From the aspect of the vehicle as a technical system, the evasive maneuver begins at the moment when the change in its direction of movement begins, that is, when the center of gravity of the vehicle begins to deviate from the straight path it was traveling on until that moment. At the same time, there is an appearance of centrifugal force, which causes an increase in the intensity of lateral acceleration. Unlike the start of the evasive maneuver, which is unambiguously determined, one of the most important aspects of researching the length of the road necessary for the realization of the vehicle evasive maneuver is the correct definition of the criteria for when it can be considered completed. In this sense, the following can be highlighted:

- Avoiding collision with an obstacle by swerving begins at the moment the vehicle begins to change its direction of movement, and ends at the moment when the vehicle, with its most protruding part, passes the obstacle without making contact with it. In this maneuver, the lane change width corresponds to the width of the obstacle;
- Lane change for the off set for the obstacle width begins at the moment when the vehicle starts to change its direction of movement, and ends when it, after avoiding the obstacle, takes a position parallel to the initial one. If the lateral off set is performed in order to avoid running into an obstacle, the width of the evasion field must be larger than the width of the obstacle.

3. Experimental research of the vehicle obstacle avoidance maneuver

3.1. Survey results

The basis of experimental research is the procedure and test polyg defined in accordance with the ISO 3888-2 standard. This standard was prepared by Technical Committee ISO/TC 22, Road vehicles, Subcommittee SC 9, Vehicle dynamics and stability. ISO

3888, entitled Passenger cars – Test track for a severe lane-change maneuver — Part 2: Obstacle avoidance [7].

art of the ISO 3888-2 standard defines the dimensions of the test track for the closed loop test of the sharp lane change maneuver and is applicable for passenger cars and light commercial vehicles whose maximum permissible weight does not exceed 3.5 t.

The length of the track section is unchanged and is a total of 61 m, while the width of the lanes depends on the width of the vehicle used for the test.

Taking in account that the object of research in this work is the evasive maneuver when avoiding a collision with an obstacle, for the purposes of experimental research, the polygon was modified, in such a way that the test track was shortened, for sections 4 and 5, so that the total length of the polygon is 36.5 m, while the width of the sections remained dependent on the width of the vehicle. The polygon was formed using traffic cones, in accordance with the lengths of individual sections. A schematic representation of the modified polygon on which the experimental research was carried out is given in Figure 3, while the dimensions of the track with the section lengths are given in Table 1.

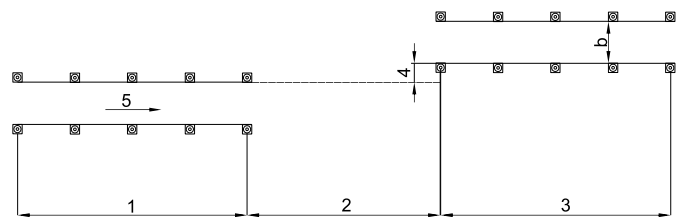


Fig. 3 Modified test polygon for avoiding collisions with an obstacle

Table 1: Dimensions of the modified test track for obstacle avoidance

Section	Section length (m)	Lateral off-set (m)	Section width b (m)
1	12	–	1,1 x vehicle width + 0,25
2	13,5	–	–
3	11	1	vehicle width + 1

The test maneuver to avoid running into an obstacle by swerving involves lateral moving of the vehicle from the entrance gate to the next gate, parallel to it, at the maximum possible speed, without knocking down the set cones. As a lane change distance in obstacle evasive maneuver depends on the lateral off set width, in accordance with the needs of the research, the experiment was performed for the lateral off set width of 1.0 m, 1.5 m, 2.0 m and 2.5 m.

The polygon created in this way enables the repetitability of a large number of experimental test drives, under similar conditions, which is very important for further statistical processing of the collected research results. In addition, the described concept provides an opportunity to investigate the influence of the obstacle width on the maximum input speed, and therefore on the value of the coefficient C_x , which figures in the almost every expression for the calculation of the lane change distance.

The vehicles participating in the experimental research included the categories of small (up to 3.5 m length), medium (3.5–4.0 m length) and larger cars (4.0–4.5 m length). The vehicles were driven by drivers of different ages and driving experience.

3.2. Measuring devices and software

For research purposes, the GPS measuring device Performance Box Sport was used, which can record speed, current path and position, lateral and longitudinal acceleration and many other data relevant to the analysis of the vehicle's lateral evasion maneuver. All recorded data is archived in the memory card located inside the device. Recording begins after establishing communication with the satellites. The measurement is performed at a frequency of 10 Hz.

The device does not have its own display, so the analysis of records is performed using the accompanying computer program PerformanceTools Software or by exporting the data to MS Excel.

The application of the mentioned measuring device made it possible to determine the trajectories of the vehicles during maneuver on the created polygon, on the basis of which, for each of the specified widths, it was possible to accurately define the length of the road necessary for its realization. Figure 4 shows the trajectories of one of the vehicles participating in the research when dodging for a certain width.

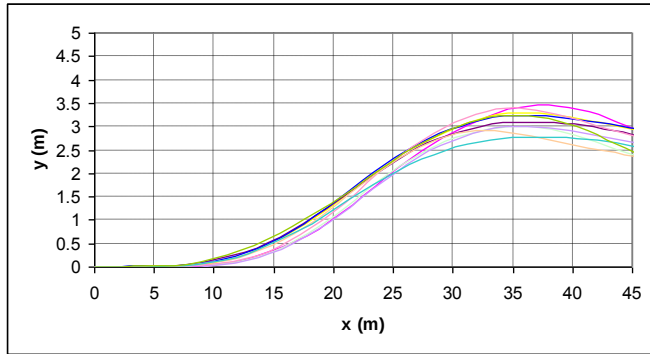


Fig. 4 Vehicle trajectories in an obstacle avoidance maneuver for offset width of 2.5 m

4. Empirical model for determining the lane change distance

Using the GPS data logger, it is possible to measure all the quantities relevant to the realization of the obstacle lane change maneuver, i.e. speed, distance, lateral acceleration and the width of the evasive field.

Considering that, the lane change distance in obstacle evasive maneuver in most theoretical mathematical models is expressed by an equation of identical form, using the coefficient C_x , which can be calculated, as a only unknown quantity.

$$C_x = \sqrt{\frac{X_e^2 \cdot \mu_s \cdot g}{V^2 \cdot Y_e}} \quad (1)$$

The differences between avoiding an obstacle by swerving and lateral swerving by the width of the obstacle was previously explained. It means that it cannot be spoken about the same lateral off-set distances (Y_e).

The vehicle lateral off-set necessary to avoid the contact with obstacle is Y_1 , while the offset necessary to complete the lateral transfer of the vehicle from the lane one to lane two, parallel to lane one is Y_2 .

Therefore, on the length of road X_{e1} , it is possible to avoid contact with the obstacle, while in order to bring the vehicle to the position parallel to the initial one, it is necessary for it to cross the road X_{e2} . Analogously, the value of the coefficient C_x will not be the same either, considering that lateral swerving by parallel transmission of the direction of movement represents a full maneuver, while avoiding a collision with an obstacle is only part of it. Therefore, when evasive maneuver swerving, it will be marked with C_{x1} , and in the case of a full lateral lane change, it will be marked with C_{x2} .

Statistical processing of the value of the coefficient C_{x1} , calculated on the basis of a total of 140 realized maneuvers to avoid bumping into an obstacle by swerving, with different vehicles and drivers, at different speeds and obstacle widths from 0.8 m - 3.0 m, was performed in the Statistica software.

Figure 5 shows a histogram and a box diagram of the frequency values of the coefficient C_{x1} obtained by the research.

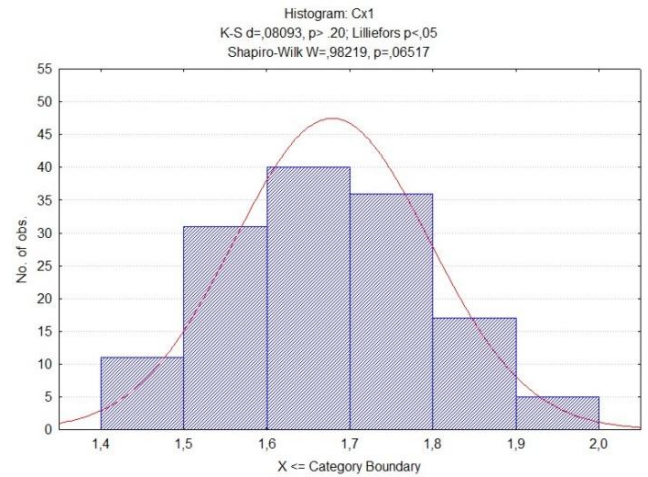


Fig. 5 Histogram of the distribution of the value of the coefficient C_{x1} on the examined sample

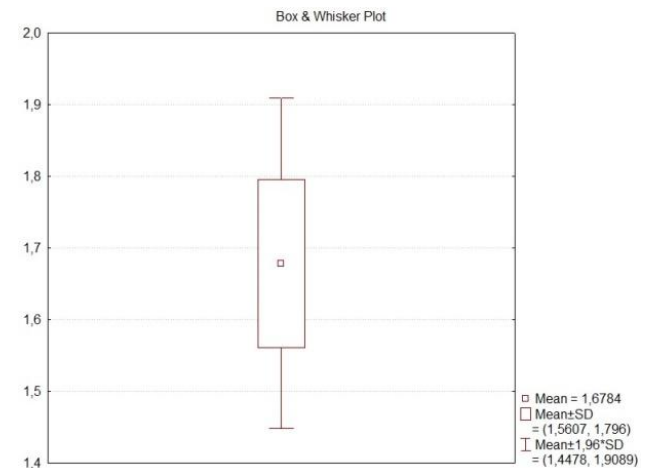


Fig. 6 Box-diagram of the distribution of the value of the coefficient C_{x1} on the examined sample

The statistical analysis of the examined sample determined that the distribution of the value of the coefficient C_{x1} is in accordance with the normal distribution, which was confirmed by the Kolmogorov-Smirnov test, the Shapiro-Wilk test and the analysis of Skewness-Kurtosis values. The mean value of the coefficient on the tested sample is 1.678357, and the standard deviation is 0.117624. Given that the research carried out within this work was carried out for the needs of traffic accident experts, it is necessary to look at the limit values of the length of the road on which it is possible to avoid running into an obstacle by swerving. In this sense, the value of the coefficient C_{x1} , defined on the basis of the determined parameters of the normal distribution, that is, the sum of the mean value and the double value of the standard deviation, would cover over 95% of the examined sample. The value of the coefficient C_{x1} determined in this way would be:

$$C_{x1} = 1.913605 \quad (2)$$

In accordance with the performed analysis, the empirical model for calculating the length of the road needed to avoid running into an obstacle by swerving would have the form:

$$X_{e1} = 1.91 \cdot V \sqrt{\frac{Y_{e1}}{\mu_s \cdot g}} \quad (3)$$

where the speed of the vehicle is expressed in (m/s).

The statistical processing of the calculated values of the coefficient C_{x2} , based on a total of 140 lateral evasion maneuvers,

performed by different vehicles and drivers, for different widths and speeds, was performed in the Statistica software package.

Figure 6 shows a histogram and a box diagram of the frequency values of the coefficient C_{x2} obtained by research.

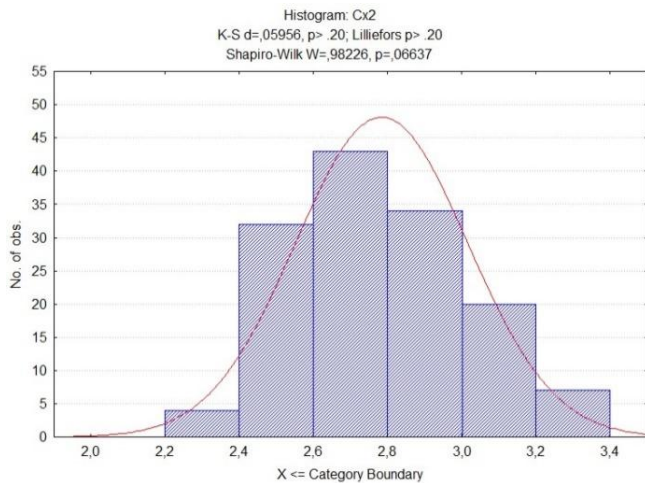


Fig. 7 Histogram of the distribution of the value of the coefficient C_{x2} on the examined sample

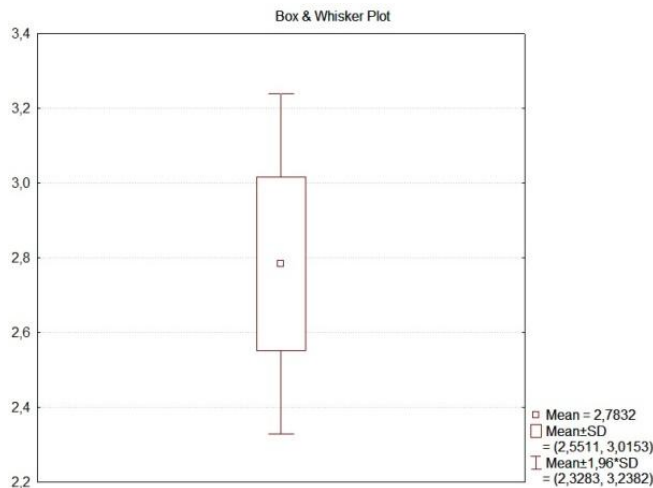


Fig. 8 Box-diagram of the distribution of the value of the coefficient C_{x2} on the examined sample

Based on the conducted analysis, it is concluded that the distribution of the value of the coefficient C_{x2} is in accordance with the normal distribution. The mean value of the coefficient on the tested sample is 2.783214, and the standard deviation is 0.232110.

From the aspect of traffic accident expertise, the analysis of the possibility of avoiding a collision with an obstacle by swerving (lane change) is certainly more significant than the analysis of a complete lateral swerving maneuver. This means that in order to establish a model for the overall realization of this maneuver, it is not necessary to look at the limit values of the length of the evasion path, and that the value of the coefficient C_{x2} can be expressed through the average determined value of the examined sample, which is:

$$C_{x2} = 2,783214 \quad (4)$$

In accordance with the performed analysis, the empirical model for calculating the length of the road necessary for a complete lateral maneuver would have the form:

$$X_{e2} = 2,78 \cdot V \sqrt{\frac{Y_{e2}}{\mu_s \cdot g}} \quad (5)$$

where the speed of the vehicle is expressed in (m/s).

5. Conclusion

The established empirical models of the vehicle's lateral evasion maneuver are based on the results of experimental research and certainly describe this maneuver more reliably than theoretical mathematical models. Considering the different nature of the maneuver, i.e. the reason for undertaking it, lateral evasion in order to avoid running into an obstacle, and especially evasion in order to overtake or realign, were analyzed separately.

When defining the model for avoiding collision with an obstacle by side swerving, the limit capabilities of the vehicle and the driver who were driving it were treated. The basis of the model consists only of maneuvers that have been successfully implemented, without collapsing the boundaries of the polygon defined by the cones. Research conceived in this way made it possible to establish a clear difference between avoiding collision with an obstacle by swerving and lane changing by parallel transmission of the direction of movement. Namely, one of the most frequent mistakes in traffic accident expertise is the identical treatment of these two maneuvers, by analyzing the same width of the evasion field, regardless of whether it is necessary to determine the possibility of avoiding a collision with an obstacle by dodging or side evasion for the width of the obstacle. The values of the coefficients that figure in the defined models were determined based on the statistical analysis of the calculated values, and in accordance with the results of the conducted research.

In road accident investigations, it is often necessary to answer the question of whether the driver had the opportunity to avoid hitting an obstacle by swerving on the available road. In this sense, every driver should not be expected to use the maximum subjective abilities and possibilities of the vehicle, as a technical system that it controls, to realize this action on the minimum road. For this reason, for the purposes of establishing an empirical model for calculating the length of the minimum lane change distance, the parameters of the normal distribution of the calculated values of the coefficient C_{x1} , i.e. the sum of the mean value and double the value of the standard deviation ($C_{x1}=1.91$), were used. The coefficient defined in this way covers over 95% of the values calculated based on the results of experimental research. The results of the research showed that it is absolutely wrong to treat the length of the road necessary for the realization of a full lateral evasion maneuver as double the length of the evasion path. Even the mean value of the coefficient C_{x1} on the examined sample (1.678) is significantly higher than half the value of the coefficient commonly used in the practice of traffic-technical expertise (2.51/2), and is the result of a theoretical trajectory model described by a sinusoidal function.

The expertise of traffic accidents, there are much rarer situations in which it is necessary to analyze the length of the road of lateral avoidance by parallel transmission of the direction of movement. For example, the vehicle, after a successfully realized maneuver to avoid running into an obstacle by dodging and taking a direction parallel to the initial one, collides with a vehicle moving from the opposite direction. Given that this maneuver ends after the vehicle has avoided contact with the obstacle, from the aspect of time-space analysis it is not necessary to consider the limit possibilities for its realization. For this reason, the coefficient C_{x2} was determined based on the results of experimental research, as the mean value of the calculated coefficients for the full maneuver.

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The Possibility of Using Event Data Recorder in the Traffic Accidents Analysis in Republic of Croatia

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Abstract: Event Data Recorder is a specialized device that is installed in the airbag module of vehicle and is used to monitor vehicle movements in traffic accidents. Access to the data from the Event Data Recorder device is possible only through authorized and certified equipment, which enables the technical and legal credibility of the collected data. Directive EU 2019/2144 of the European Parliament and Council defined that all new type-approvals vehicles after 6 July 2022 must be equipped with an Event Data Recorder device. Accordingly, recently in the Republic of Croatia, data from Event Data Recorder devices have been used more and more often for the purpose of analyzing traffic accidents. Accordingly, this paper will present the possibilities of analyzing traffic accidents using the Event Data Recorder device and the methods by which it is possible to access said data.

KEYWORDS: EVENT DATA RECORDER, TRAFFIC ACCIDENTS, VEHICLES, CRASH DATA

1. Introduction

Vehicle safety factors can be divided into active and passive elements. Active safety elements have the task of reducing the probability of a traffic accident, while passive safety elements are activated in the event of a collision and their main task is to reduce the possibility of injuries to drivers and passengers and fatalities to road users. Since the systems are most responsible for the safety of vehicle occupants, the European Union has enacted several laws that specify which protective systems must be installed in vehicles. With the Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles with regard to their general safety and the protection of occupants and vulnerable road users, it will become mandatory to specify which devices must be installed in all new vehicles. One of the devices that will become mandatory for all vehicles with new type-approval is the Event Data Recorder (EDR), which must be installed in all vehicles with new type-approval from July 2022. The Event Data Recorder is a device whose purpose is to collect data from the vehicle before, during and immediately after a collision.

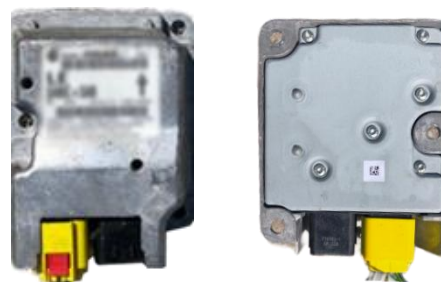
This paper presents the capabilities and operation of the Event Data Recorder and the legal requirements that enable its use. Since some vehicle manufacturers have been installing Event Data Recorders in their vehicles for many years, this paper analyzes the potential of using data from Event Data Recorders in traffic accidents in the Republic of Croatia.

2. Working principle of Event Data Recorder

The Event Data Recorder is a device which main purpose is to collect data of the movement of vehicles in collisions, which is why it is often referred to in the literature as a "black box" for vehicles. In America, the device has been mandatory for all new vehicles since 2014 and is now regularly used as a data extract in the analysis of traffic accidents. In European Union countries, it is mandatory for all newly type-approved vehicles starting in July 2022.

The basic task of the device is to continuously collect data on the movement of the vehicle while driving. When the device registers an event/collision, it records in its memory all the information about the vehicle's movement that occurred in the period from five seconds before the collision to the end of the event.

The Event Data Recorder is in the airbag module, but the airbag does not have to be activated for the device to be activated.



Picture 1. Air Bag Control Module.

The method of activation of the Event Data Recorder is specified in the regulation [1], and accordingly, the device must record all events in which the following parameters are registered:

- a change in the longitudinal speed of the vehicle by more than 8 km/h in an interval not exceeding 150 ms,
- a change in the lateral speed of the vehicle by more than 8 km/h in an interval not exceeding 150 ms,
- triggering of the irreversible passenger or driver restraint system, and
- triggering of the secondary safety system for the protection of vulnerable road users.

In all cases where the irreversible passenger or driver restraint system is activated, in the event of a frontal collision when the vehicle does not have an irreversible passenger or driver restraint system, or when the secondary safety system is activated to protect vulnerable road users, the device locks the data to a prevent possible overwriting of the data by a subsequent event [1].

The data that the device must record is defined in the set of rules [1]. In addition to the elements that must be recorded, the recording interval time, data sampling rate, minimum range, accuracy, and resolution are also defined. The data elements that the instrument must record are: longitudinal delta V, maximum longitudinal delta V, time, vehicle speed according to the display in the vehicle, fuel supply to the engine (percentage of maximum), service brake (on/off), ignition cycle - collision, ignition cycle - download, seat belt status, airbag light, Front airbag deployment time in the case of a single-stage airbag or time to first stage activation in the case of a multi-stage driver airbag, multiple event collision (number of events), time from first to second event, and lateral acceleration (after collision) [1]. Excluded from the scope are data about the vehicle and data about the location/coordinates of the vehicle, information about the driver, and the date and time of the event. If there is not enough space in the EDR buffer, the previously recorded data is overwritten so that the EDR device can record new data. The first recorded event is deleted first [1].

3. Legal regulations in the application of Event Data Recorder

The basic legal documents in European union on which the operation and application of devices for collecting data from vehicles are based are [4]:

- EU Regulation 2019/2144,
- EU Regulation 2022/545, and
- UN Regulation 160.

Regulation (EU) 2019/2144 establishes the requirements for the recognition of the same technical regulations and the design of vehicles with regard to their general characteristics and the safety and protection of persons in the vehicle. Therefore, according to Article 6 of the said Regulation, motor vehicles must be equipped with advanced systems, which refers, among other things, to devices for recording event data [2].

EU Regulation 2019/2144 specifies that devices that record data about the event cannot be turned off and that the data the devices can record relates to the period before, during and immediately after the collision, which includes data about vehicle speed, braking, the position, and inclination of the vehicle on the road, the state and speed of activation of all safety systems and the state of brake application. In addition, the manner in which the data can be recorded and stored must be such that it operates in a closed loop.

The data collected by the Event Data Recorder must be protected from tampering and misuse and may only be used for the purpose of accident investigation and analysis. Delegated Regulation (EU) 2022/545 supplementing Regulation (EU) 2019/2144 of the European Parliament and of the Council with detailed provisions on the specific test procedures and technical requirements for the type-approval of motor vehicles regarding their Event Data Recorders and for the type-approval of these systems as separate technical units and amending Annex II to that Regulation [3].

To comply with the right to data protection, EU Regulation 2019/2144 stipulates that the event recorder must not be able to record and store certain data that can be used to identify the vehicle itself, its. The main problem with the use of data from the EDR relates to the privacy and sensitivity of data that can be associated with a natural person.

UN The purpose of Regulation 160 is to establish uniform requirements for the type-approval of motor vehicles of categories M1 and N1 regarding their devices for recording event data. The regulation relates to minimum requirements for the collection, storage, and protection of motor vehicle crash data in the event of an accident. It does not specify methods and tools for reading the data from the system, as this is required at the national level. The purpose of this regulation is to ensure that the EDR records data useful for crash investigation and analysis of the operation of safety devices (e.g., advanced restraint systems) in a user-friendly manner. This data will contribute to a better understanding of the circumstances in which accidents and injuries occur and facilitate the development of safer vehicles [1].

4. Methods for collecting data from Event Data Recorders

For collecting data from the Event Data Recorder, it is necessary to have a special and certified device. For most vehicle manufacturers, the approved data collection device is the Bosch Crash Data Retrieval (CDR) (Picture 2), while some vehicle manufacturers such as Kia, Hyundai, and Tesla have their own EDR data collection devices.



Picture 2. Bosch CDR 900 Device [4]

Data acquisition requires a laptop, connecting cables, and possibly special adapters, if required by the manufacturer, in addition to a special device. There are two basic methods of data collection [5]:

- Diagnostic Link Connector Method (DLC), and
- Direct To Module Method. (DTM).

The Direct To-Link method is simpler because this method does not require the EDR to be physically removed from the vehicle; instead, detection is accomplished by connecting the CDR device to the vehicle's OBD II port (Picture 3). A prerequisite for using this method is that the impact has not caused significant damage that could physically break the connection between the airbag control module and the OBD II connector, and that it can be ensured that the voltage in the vehicle is sufficient to acquire the data. The advantage of the direct-to-link method is that it reduces the possibility of data manipulation, and the working principle is simple and does not take much time to download the data.



Picture 3. Collecting data with the "Direct to Link" method

The Direct to module method is used in cases where the vehicle is so badly damaged after a collision that the electronic system no longer functions, and no communication is possible between the airbag control module and the OBD II connector. In this case, the "direct to link" method is not used, but it is necessary to remove the module from the vehicle and connect it directly to the module. The EDR device is usually placed in the passenger compartment between the driver and passenger to avoid damage. This method requires several special cables and adapters to be connected directly to a specific module (Picture 4).



Picture 4. Collecting data from the Event Data Recorder using the "Direct to module" method

5. Collection of data from the Event Data Recorder

To test the possibility of using Event Data Recorder data for traffic accident analysis, a crash test was conducted involving a vehicle with a built-in EDR device.



Picture 5. Vehicles used in testing.

The first collision involved a passenger car Toyota that slammed into the side of a Fiat Scudo pickup truck that was not moving.



Picture 6. The position of the vehicle at the time of the accident

Picture 5 shows the vehicles that participated in the test, while Picture 6 shows the position of the vehicle at the time of the collision.

Data collection using the DLC method was successful as all sensors remained connected to the airbag control module. The Event Data Recorder recorded two events with 15 milliseconds between them, suggesting that this was a single traffic accident in which the vehicle impacted multiple times (Picture 7).

System Status at Time of Retrieval	
ECU Part Number	89170-02B90
EDR Generation	12EDR
Complete File Recorded	Yes
Freeze Signal	ON
Freeze Signal Factor	Front Airbag Deployment
Diagnostic Trouble Codes Exist	No
Ignition Cycle Download (times)	27629
Multi-event, number of events (times)	2 or greater
Time from event 1 to 2 (s)	-0.015
Time from Previous Pre-Crash TRG (msec)	16381 or greater
Latest Pre-Crash Page	1
Contains Unlinked Pre-Crash Data	No

Picture 7. Data on registered events in EDR

The impact was registered due to the activation of the front airbag, and the device had a previously stored event in its memory in addition to the two mentioned events of the observed impact (Picture 8).

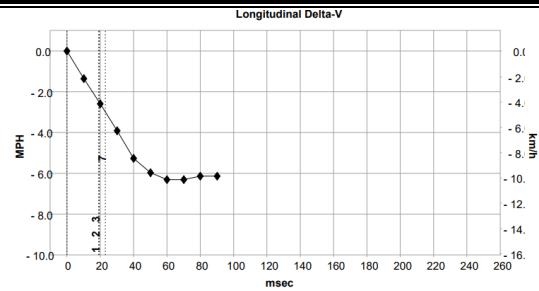
Event Record Summary at Retrieval

Events Recorded	TRG Count	Crash Type	Time (msec)
Most Recent Event	3	Front/Rear Crash	0
1st Prior Event	2	Side Crash	15
2nd Prior Event	1	Front/Rear Crash	-16381 or greater

Picture 8. All events registered in the EDR.

The report also showed that in the 19th millisecond of the collision, four airbags were activated and a longitudinal change in speed was achieved in the maximum amount of 9.9 km/h in 90 milliseconds (Picture 9).

Therefore, in the test conducted based on the results shown in Picture 10, it was found that the driver was travelling at a speed of 37 km/h five seconds before the collision and accelerated to 62 km/h two seconds before the collision, then applied the brake and decelerated to 33 km/h until the collision itself. The table also shows that the driver swiveled the steering wheel significantly from one direction to the other, which is very often an indicator of hazard avoidance by the



Picture 9. Longitudinal Delta-V in an accident.

The Event Data Recording device monitors the vehicle's movement data up to five seconds before the actual event and presents it in a table in such a way that the driver's activities during this period are displayed along with the time history.

Pre-Crash Data -5 to 0 seconds (Most Recent Event TRG 3)											
Time (sec)	-5	-4.5	-4	-3.5	-3	-2.5	-2	-1.5	-1	-0.5	0 (TRG)
Vehicle Speed (km/h)	23 [37]	23.6 [38]	26.7 [40]	26.2 [47]	31.1 [50]	33.6 [54]	34.6 [55]	33.6 [54]	26.8 [48]	14.9 [34]	26.8 [53]
Accelerator Pedal % Full (%)	0.0	100.0	100.0	40.5	45.5	60.0	38.0	0.0	0.0	0.0	0.0
Percentage of Engine Throttle (%)	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Engine RPM (RPM)	4,800	4,700	2,400	2,700	3,000	3,200	3,700	3,200	2,800	1,800	1,800
Motor RPM (RPM)	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Service Brake, On/Off	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF
Brake Oil Pressure (kPa)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.02	0.05
Longitudinal Acceleration, VEC Sensor (msec ²)	1.282	1.723	1.262	1.436	1.579	1.938	0.718	-1.436	-5.312	-3.230	Invalid
Yaw Rate (deg/sec)	-0.49	-1.46	1.46	-1.46	-0.49	25.86	-28.79	36.11	-40.02	20.50	21.96
Steering Wheel (degrees)	0	0	0	-3	0	42	-108	105	-147	141	93
Shift Position	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Sequential Shift Range	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Clutch Control Switch	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Drive Mode, Sport	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Drive Mode, ECO	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Drive Mode, Shift	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Drive Mode, Stop	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Drive Mode, EV	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid

Picture 10. Movement of the vehicle five seconds before the collision

6. Representation of vehicles with Event Data Recorders in the Republic of Croatia

From July 6, 2022, every newly registered car on the European Union market must be equipped with an Event Data Recorder. For this analysis, the data on the total number of passenger cars in the Republic of Croatia were studied and compared with the data on cars equipped with an Event Data Recorder.

Table 1. Share of vehicles with EDR in the total number of passenger cars in the Republic of Croatia

No.	PRODUCER	TOTAL
1.	AUDI	7.426
2.	BMW	3.871
3.	BUICK	4
4.	CADILLAC	14
5.	CHRYSLER	253
6.	DODGE	147
7.	FIAT	3.597
8.	JEEP	2.066
9.	GMC	2
10.	LANCIA	262
11.	LEXUS	686
12.	LINCOLN	3
13.	MINI	454
14.	MITSUBISHI	2.530
15.	PORSCHE	25
16.	ROLLS ROYCE	4
17.	SUBARU	622
18.	ŠKODA KODIAQ	4.630
19.	TOYOTA	50.836
20.	VOLKSWAGEN	24.336
21.	VOLVO	6.859

Thus, it was found that in 2021, there were a total of 108,627 passenger cars in the Republic of Croatia that officially had the ability to collect data via the Bosch device CDR. The list and number of vehicles equipped with EDR is shown in Table 1

From the present Table 1, the manufacturers with the highest number of vehicles that have installed an EDR device in the Republic of Croatia are Toyota, Volkswagen, and Audi. It should be

noted that Toyota vehicles have been equipped with EDR devices since 2000, depending on the market, while Volkswagen and Audi vehicles have been equipped with EDR devices to a greater extent only since 2018.

In addition to the data on the number of all vehicles that had an EDR device installed, for the purposes of this study, the data on how many vehicles in the Republic of Croatia were involved in a traffic accident and had an EDR device installed were also analyzed. The results of the analysis are presented in Chart 1, which shows that most vehicles that were involved in traffic accidents and had an EDR device installed were also Toyota (37%), Volkswagen (27%) and Audi (11%). The total number of vehicles involved in traffic accidents that had an EDR device installed was 2,518 vehicles, representing approximately 6.65% of the total number of vehicles involved in traffic accidents.

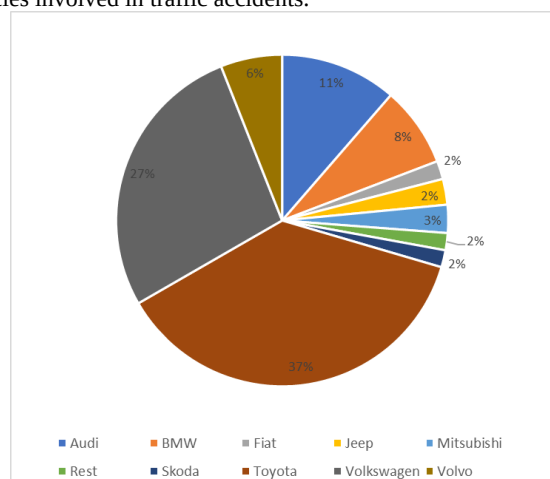


Chart 1. Representation of vehicles with EDR in Republic of Croatia

7. Conclusion

This paper presents the results of the analysis of the possibility of using an Event Data Recorder in the Republic of Croatia. The current legislation on the territory of the European Union is explained, and the possibilities of the device itself are presented. For this research, a crash test was conducted with a vehicle equipped with an Event Data Recorder, and after the accident, the collected data was analyzed and presented in this paper.

It has been found that the data recorded by the Event Data Recorder is of crucial importance for the analysis of traffic accidents, since it is now completely possible to reconstruct in a relevant way the behavior of the driver in the period of five seconds before the collision. Considering that the reports on the collected data from the Event Data Recorder are quite extensive, the expertise of trained experts is still required to interpret them clearly. Moreover, the data from the Event Data Recorder alone is not enough to fully reconstruct the traffic accident; it is necessary to correlate the data obtained from the EDR with other traces at the accident scene.

To determine the potential of using data from the Event Data Recorder in the Republic of Croatia, it was analyzed how many passenger cars are equipped with an EDR device and how many traffic accidents occurred with a vehicle with an EDR device installed. The analysis showed that currently in the Republic of Croatia about 108,627 passenger cars are officially equipped with an Event Data Recorder, which is about 7% of the total number of passenger cars.

International research has shown that there are many vehicles that have a built-in Event Data Recorder, but they are not on the official list, or their data is digitally protected, so it is assumed that the number of vehicles that have a built-in EDR is much higher. In addition, the analysis showed that 2,518 vehicles involved in traffic accidents had a built-in Event Data Recorder, which is about 6.65% of the total number of vehicles involved in traffic accidents.

Considering that the Event Data Recorder must be installed in all vehicles with new type-approval from July 2022, it is expected

that more and more vehicles on the market will be equipped with an Event Data Recorder, which will allow a more relevant traffic accident expertise.

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Comparative assessment and development perspectives of the efficiency of transport routes of the "South-west" direction

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Abstract: In the article, the "South-West" international transport corridor was studied, the economic expediency of the main and alternative transport routes (including those passing through the territory of the Republic of Armenia (RA) for cargo transportation in the direction of "Asia-Iran-Europe" was evaluated, the possibilities of RA participation in the "New Silk Road" international transport program were considered.

KEYWORDS: LOGISTICS, "SOUTH-WEST" INTERNATIONAL TRANSPORT CORRIDOR, NEW SILK ROAD, CARGO TRANSPORTATION.

1. Introduction

The development of the country's economy is impossible to imagine without international economic relations with other countries, including the development of international trade relations, which, in its turn, is impossible to imagine without the formation and constant improvement of logistics infrastructure, which is the basis for the efficient organization of transportation and ensures that the necessary shipments are carried out at the intended location, within the agreed time frame, with minimum total cost. The development of logistics infrastructure in the country is the basis not only for the development and integration of all branches of the economy, but also contributes to the integration of the country into the international transport system, international transport routes and programs.

The "South-West" transport corridor is designed to ensure the transport connection between South Asian and European countries. During 2021 the corridor provided more than 200 million tons of cargo transportation. Moreover, the latter includes all the goods exported and imported between South Asian and European countries, the transportation of which was carried out by railway transport. Oil and gas, the transportation of which is carried out by pipeline transport, precious and semi-precious stones, metals, and perishable goods are not included. The results of the research show that in 2021, 115.5 million tons of cargo was exported from South Asian countries to European countries, and 83.4 million tons of cargo was imported. Moreover, in terms of both export and import, China and India are the main trade partners of European countries among South Asian countries (In 2021, China's export volume to European countries was 83.8 million tons of cargo, import volume was 52.2 million tons of cargo, and India's export volume to European countries in 2021 was 21.4 million tons of cargo, import volume was 12.3 million tons of cargo) [6].

2. Modern transport projects promoting the development of the "South-West" direction.

The "New Silk Road" and "Persian Gulf-Black Sea" international transport projects promoted by China and Iran, respectively, are currently of great importance in terms of creating more efficient transportation routes in the "South-West" direction and strengthening trade ties.

The New Silk Road initiative as a revival of the historic Great Silk Road was launched in September 2013 by Chinese President Xi Jinping. The main goal of this initiative is to create more efficient transport routes and strengthen trade ties between China and Eurasian and African countries, in the context of developing their respective infrastructures and creating closer economic ties [7]. As a result of all this, it will be possible to have other competitive transport routes parallel to the sea route passing through the Suez Canal, by which cargo transportation will be more affordable, shorter and safer.

Being one of the modern large-scale transport projects, within the framework of the "New Silk Road" it is planned to create

7 zones; transport, energy, trade, information, science and technology, agriculture and tourism [1]. At the same time, 5 main principles of the implementation of the project were distinguished, namely; respect for the territorial integrity and sovereignty of countries, non-interference in the international relations of other countries, equality, mutual benefit, and peaceful coexistence [4].

The Silk Road Investment Fund was established in December 2014 with an initial capital of 40 billion dollars in order to develop infrastructure projects in the countries included in the "New Silk Road" transport program and to enter new markets for the sale of Chinese products, and on January 16 of 2016, the Asian Infrastructure Investment Bank (AIIB) with a capital of \$100 billion. Starting its activities with 57 founding members (37 regional and 20 non-regional), already in 2023 the number of approved members of the latter was 106 countries (92 full right, 47 regional, 45 non-regional and 14 prospective), which represents more than 79% of the world's population and 65% of global GDP and is open to attracting additional members [3]. As of the same period, investments in the amount of 39.44 billion US dollars were made in different countries of the world under 205 projects approved by the latter, during which the bank's strategic goals and thematic priorities were taken into account. Armenia is also one of the 14 prospective members of the Asian Infrastructure Investment Bank [3].

As a result of the performed works, already in 2021 China's export amounted to a record 3.36 trillion US dollars, increasing by 29.73% compared to the previous year, by which it had a 15.2% share in world exports, occupying the first position (for comparison, note that the export to the United States in 2021 was 1.75 trillion USD, with which it had a 7.9% share in world exports, occupying the second position).

The "Persian Gulf-Black Sea" international transport corridor project was put forward by Iran in 2016, in which, apart from the Islamic Republic, Armenia, Azerbaijan, Bulgaria, Georgia and Greece officially participate [5]. This transport corridor starts from the south of Iran (Bandar Abbas, Chabahar ports) and stretches to the Bulgarian ports of Burgas and Varna, from where to Greece and then to EU countries. The goal of this initiative is to connect the 4 largest sea basins: the Persian Gulf and the Sea of Oman (Iran), the Caspian Sea (Iran and Azerbaijan), the Black Sea (Georgia and Bulgaria), the Mediterranean Sea (Greece), for efficient cargo transportation between Asian and European countries, the creation of competitive alternative transport routes as well as deepening of trade and economic relations between participating countries. The "Persian Gulf - Black Sea" corridor implies the implementation of multimodal cargo transportation, one of the important transit countries of which may be Armenia, which will give the latter the opportunity to diversify supplies, freely use Iranian ports, mitigate the consequences of the Azerbaijani and Turkish blockade, integrate into regional transport routes, get a large economic benefits, strengthen geopolitical positions and become a transport hub of great importance in the region.

3. Comparative analyses of alternative routes within the "South-West" direction.

For the comparative analysis and evaluation of the economic expediency of the alternative routes operating within the "South-West" direction, it is necessary to study the main and alternative routes and perform an efficiency assessment. The main and alternative routes in the "South-West" direction are;
SW1; "China (India) - Iran - Armenia - Georgia - Bulgaria - EU countries".

This route will make it possible to carry out cargo transportation from the southern border of Armenia with Iran to the border with Georgia (Meghri-Yerevan-Ashtarak-Gyumri-Bavra), and from there to European countries through the Black Sea ports. The distance between Iran and Bulgaria on this transport route is 4349.5 km.

SW2; "China (India) - Iran - Armenia - Georgia - Bulgaria - EU countries".

This route will operate in case of recovery and restart of the railway "Yeraskh - Julfa - Ordubad - Meghri - Horadiz" (340 km). As a result, cargo can be transported through the "Bandar-Abbas - Tehran - Tabriz - Julfa - Yeraskh - Masis - Ayrum - Tbilisi - Poti" railway corridor, and from there through the Black Sea ports to Bulgaria and European countries. The distance between Iran and Bulgaria on this transport route is 4508.2 km.

SW3; "China (India) - Iran - Armenia - Georgia - Bulgaria - EU countries".

In case of this route, cargo transportation will be carried out through the "Bandar Abbas - Tehran - Merand - Ayrum - Tbilisi - Poti" railway corridor, which can operate only in the case of the construction of the Armenian-Iranian railway, which is of strategic importance for both Armenia and Iran, as well as in case of the construction of the 32 km long "Fioletovo-Vanadzor" railway in the territory of RA. The distance between Iran and Bulgaria on this transport route is 4435.5 km.

SW4; "China (India) - Iran - Azerbaijan - Georgia - Bulgaria - EU countries".

In case of this route, cargo transportation will be carried out through the railway corridor "Bandar-Abbas - Tehran - Qazvin - Resht - Astara (Iran) - Astara (Azerbaijan) - Baku - Tbilisi", from there to Bulgaria through the Black Sea ports, and then to European countries. The distance between Iran and Bulgaria on this transport route is 4504.8 km.

SW5; "China (India) - Iran - Azerbaijan - Georgia - Turkey - Bulgaria - EU countries".

In case of this route, cargo transportation will be carried out through the "Bandar-Abbas - Tehran - Qazvin - Resht - Astara (Iran) - Astara (Azerbaijan) - Baku - Tbilisi - Kars - Istanbul" railway corridor, from where to European countries. The distance between Iran and Bulgaria on this transport route is 5856.8 km.

SW6; "China (India) - Iran - Turkey - Bulgaria - EU countries".

On this route, cargo is transported via the "Bandar-Abbas-Tehran-Van-Istanbul" railway corridor or by sea from the Black Sea ports of Turkey: Samsun, Trabzon to Bulgaria, and from there to European countries. The distance between Iran and Bulgaria on this transport route is 5220.9 km.

In case of de-blocking and re-opening of the "Armenia-Azerbaijan", "Armenia-Turkey" transport corridors, alternative routes for cargo transportation in the "South-East" direction can be transport routes SW7 "China (India) - Iran - Azerbaijan - Armenia - Georgia - Bulgaria - EU countries". (Iran-Bulgaria distance: 4653.1 km), SW8 "China (India) - Iran - Armenia - Turkey - Bulgaria - EU countries" (Iran-Bulgaria distance: 5467.2 km), SW9 "China (India) - Iran - Azerbaijan - Armenia - Turkey - Bulgaria - EU countries" (Iran-Bulgaria distance: 5726.1 km), but they are less applicable for other economic reasons.

Main and alternative transport routes of the "South-West" direction are illustrated in the figure 1.

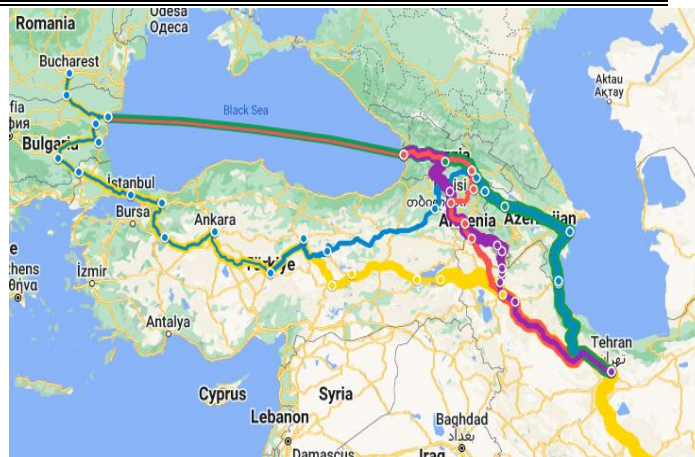


Fig. 1. Main and alternative routes for cargo transportation of the "South-West" direction

Iran is a major transport hub in the "South-West" transport corridor, through which cargo from Southeast, Central Asia, China, India, and South Korea can be transported to Europe [2]. Since the routes to Iran are mostly formed in the above transport routes, let's do the comparative analysis of the alternative routes in the "South-West" direction and the evaluation of the economic expediency from the point of view "Iran-Bulgaria", which proves that the route SW3, "Iran-Armenia-Georgia-Bulgaria" (4435.5 km) is the most efficient among the considered routes, which will operate in the case of construction of Armenian-Iranian railway. The next most efficient routes in terms of distance are the transport routes SW2 with Armenia and SW4 with Azerbaijan, which have approximately the same distance, 4508.2 km and 4504.8 km respectively. The SW5 transport corridor bypassing Armenia, which includes the Baku-Tbilisi-Kars railway built in recent years, is longer than the SW8 and SW9 transport routes passing through Armenia by 389,6 km and 130,7 km respectively. The longest of the considered routes is SW5, with a length of 5856.8 km.

AS far as the SW1 transport route also includes a motorway (the "North-South" road under construction in the Republic of Armenia), it was not considered during the comparative analysis and economic expediency assessment of the "South-West" alternative routes due to the fact that the other routes presented involve rail and sea transportation.

4. Conclusion

Thus, it can be concluded that the transport routes with the participation of RA are efficient and appropriate for carrying out cargo transportation in the "South-West" direction. And since the most efficient of the considered routes is SW3, "Iran-Armenia-Georgia-Bulgaria", it proves once again that it is economically expedient to build the "Iran-Armenia" railway, which will be a shorter route than "Iran-Azerbaijan-Georgia-Bulgaria" route, and cargo transportation along this route will be much more efficient. In addition, it is advisable that the routes that pass through neighboring countries include Armenia in them, because in this case the transport routes will be shorter and, therefore, more cost-effective. Thus, the transport route SW5 "Iran-Azerbaijan-Georgia-Turkey-Bulgaria", which includes the Baku-Tbilisi-Kars railway built in recent years and bypasses the territory of Armenia, is longer than SW9 "Iran-Azerbaijan-Armenia-Turkey-Bulgaria" transport route. Accordingly, the unblocking and restoration of economic ties and transport routes in the region will have a positive effect on both Armenia and neighboring countries, increasing the latter's chances of integration into international transport programs and ensuring high profitability.

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Development of an 1D Multicylinder Engine Model to Predict Knocking and Emissions of Large Gas Engines

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Abstract: The main subject of this paper is the development of a multicylinder engine model for the prediction of knocking combustion and emissions such as nitrogen oxide and unburned hydrocarbons based on one-dimensional simulation. The one-dimensional simulation is widely used for combustion system layout and determination of operating parameters to achieve performance targets and comply with emission limits. The paper focuses especially on the prediction of the unburned fuel mass from the combustion process and from the scavenging during the valve overlap. The calibration of the sub-models is based on measurements on a single cylinder research engine with a displacement of approximately 6 litres. The simulation results are validated with experimental measurement results on the same research engine. The paper concludes with statements about the predictive capability of the model.

Keywords: GAS FUELED ENGINES, 1D SIMULATION

1. Introduction

The trend towards high power output, higher efficiencies as well as stringent emission legislation is greatly pushing the development of large gas engines. Emission limits for large combustion engines in power generation and maritime applications are steadily reduced, especially nitric oxide emissions (NO_x) and hydrocarbon (HC) emissions [1], [2], [3]. Due to the increasing demand for modern large gas engines regarding power output and fuel efficiency it is often desired to operate the engines closer to the operating limits – including the knock limit. The prediction of knocking combustion is therefore of considerable importance since knocking causes high frequency oscillations that are superimposed to the cylinder pressure which can cause severe damage to the engine components.

This paper describes the development of 1D models for the prediction of NO_x and unburned fuel emissions as well as knocking combustion.

2. LEC Development Methodology

LDM (LEC Development Methodology) is used to develop and optimize combustion concepts for engines at the LEC GmbH [4]. LDM is based on the intensive interaction between simulation and experimental investigations on single cylinder research engines (SCE) and multicylinder engines (MCE). This methodology makes use of 3D CFD simulation and a 0D/1D engine cycle simulation. While 3D CFD simulation is employed above all to optimize the details of individual relevant processes (e.g., mixture formation and combustion in the prechamber and main combustion chamber, determination of the location of end-gas knock initiation), 0D/1D engine cycle simulation is applied to pre-optimize significant engine parameters (e.g., compression ratio, valve timing). For the application of this methodology, it must be guaranteed that the results from the single cylinder engine tests can be transferred to the multicylinder engine, see Figure 1.

3. Modelling of the combustion process and NO_x formation

As baseline simulation model, an MCE model including gas mixers and two stage turbocharging, is used. The 1D simulation platform allows the use of combustion models as well as the prescription of heat release rates. In order to avoid additional uncertainties due to modeling inaccuracies, measurement data from relevant operating points, measured on the SCE, are used to determine the actual rate of heat release history using engine cycle calculation. The combustion duration in the cylinder and the fraction of fuel burned are strongly dependent on the excess air ratio (EAR) and are therefore adjusted for each operating point as functions of the EAR that have been determined from measured EAR variations on the SCE test bed [5].

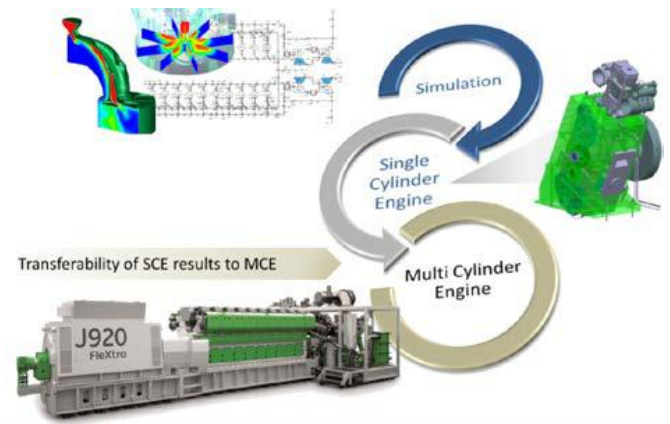


Fig. 1 LDM: LEC Development Methodology

The NO_x concentration that arises during combustion is calculated from the well-known Pattas and Häfner model [6] in the used simulation platform, which accounts for the formation of thermal nitric oxide using an extended Zeldovich mechanism. The temperature of the burned zone for simulating the post-flame reactions is calculated from the two-zone combustion sub-model.

4. Knock prediction

The two-zone modeling approach enables a simple approach to determine the maximum temperature in the unburned zone, which was shown to be a good indicator of conditions for knock events and as a criterion for the knock limit. As a first approximation the knock behavior of the engine stays unchanged as long as this temperature is constant.

Another possibility for knock prediction is the application of the LEC knock model [7]. For the simulation of the highly complex processes during knocking combustion zero-dimensional models are particularly well suited. The model for the knock timing is based on the assumption, that knocking combustion is initiated when through pre-reactions in the unburned gas a certain concentration of radicals is reached. The reaction rate is controlled by pressure, temperature and composition of the cylinder charge and by the fuel type.

The model structure for the prediction of knock characteristics contains two essential parts, the knock detection for the assessment of knock timing, knock intensity and knock hardness from measured in-cylinder data from the test bed, and a method for the prediction of the knock combustion.

In order to establish a data base suitable for the calibration of a model for predicting the knocking behavior, methods were developed to determine knock timing and knock hardness from engine test bench data. Starting point for the knock detection is the measured pressure curve. Figure 2 shows a typical measured

1. *Journal of Management Studies*, 1990, 27, 1.

The simulation results are then evaluated applying the following

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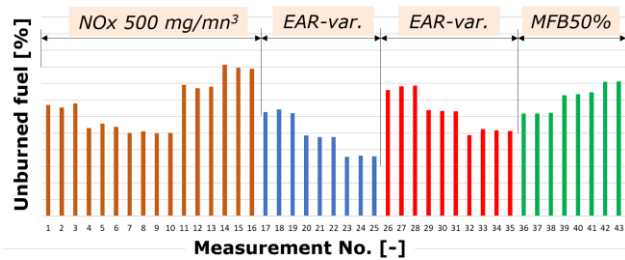


Fig. 6 Measured operating points: different parameter variations at full-load operation

Figure 7 describes measured operating points with constant EAR and variation of the scavenging gradient. It is expected that the unburned fuel mass from the combustion is nearly constant, because of the constant EAR. Based on Figure 7, the unburned fuel fraction can be determined as a linear function of the scavenging gradient.

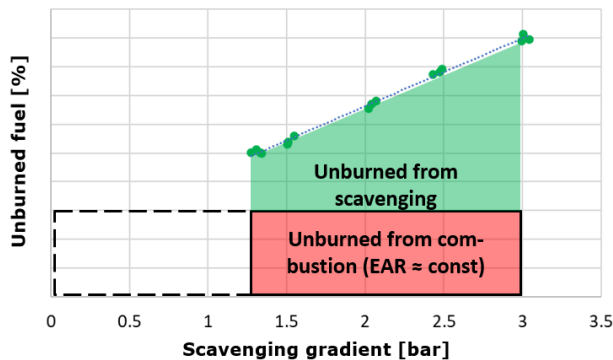


Fig. 7 Measured operating points: variation of the scavenging gradient at full-load operation

The unburned fuel mass of the combustion process is determined as a function of EAR. The coefficients of the function are calculated using the commercial software MODDE. Figure 8 shows a very good agreement of the measured unburned fuel fraction and the one predicted by the function. Figure 9 gives the calculated unburned fuel ratio split in the contribution from combustion and scavenging for each measured operating point from Figure 6. The influence of different parameters such as combustion phasing, EAR and the scavenging gradient can be determined. Especially the last two parameters show large influence.

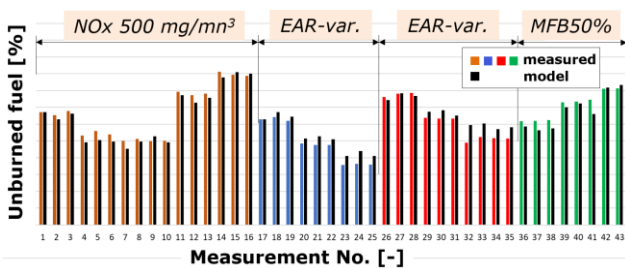


Fig. 8 Measured and predicted unburned fuel rate

For verification of the forecast quality of the model, new measurements on the SCE test bench with the same engine, but with another cam shaft were carried out. The new cam shaft was manufactured with different peak valve lifts and different valve overlap, configuration 3. The model for the prediction of the unburned fuel was calibrated on the basis of measured operating points at standard NOx levels.

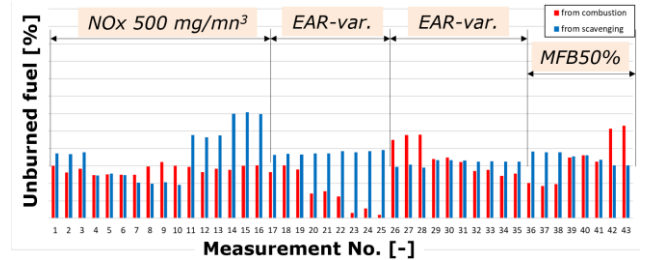


Fig. 9 Simulation results: unburned fuel rate from combustion and from scavenging

Figure 10 shows the unburned fuel fraction of 29 measured operating points. The operating points 1–3 are the base operating points at configuration 1 and NOx level 500 mg/mn³, operating points 4–23 show a variation of EAR at configuration 3, and the operating points 24–29 represent a variation of the scavenging gradient at the same configuration.

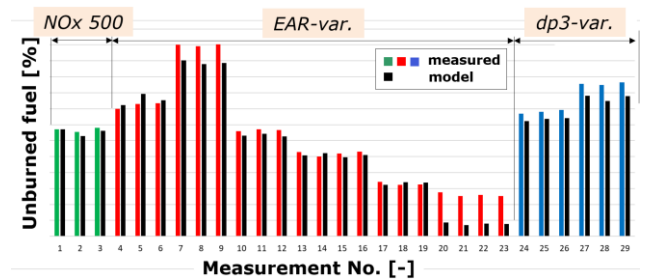


Fig. 10 Measured and predicted operating points with engine configurations 1 and 3

The agreement between measurement and prediction is very good, except operating points 20–23. Those four measurement points show very rich mixture and very high NOx levels, so that they are far off relevant operation for practical use.

6. Summary and outlook

This paper presents the development of sub-models for knocking combustion and unburned fuel rates, as well as their implementation in 1D simulation models. The sub-models were calibrated on the basis of SCE measurements on the test bench at LEC. The simulation results were also confirmed by additional measurements at the SCE.

Further investigations are planned with enhanced hardware and relevant adaption of the operating parameters.

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