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Editors: Prof. dr ***Jovanka Lukić****; Prof. dr* ***Čedomir Duboka***

MVM *Editorial Board*
University of Kragujevac
Faculty of Engineering
Sestre Janjić 6, 34000 Kragujevac, Serbia
Tel.: +381/34/335990; Fax: + 381/34/333192

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CONTRIBUTION TO THE RESEARCH OF SIDESLIP ANGLE INFLUENCE ON VEHICLE STEERABILITY

*Stefan Milićević[1]**

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RESEARCH ARTICLE

ABSTRACT: Knowing the limits of transverse handling and vehicle stability is very important from the aspect of designing a system aimed at improving handling and safety. One of the phenomena that have a great impact on vehicle stability and handling is the sideslip angle. Unfortunately, direct measurement of the sideslip angle requires very complex and expensive equipment that is not suitable for installation on ordinary passenger vehicles; therefore, this quantity must be estimated on the basis of measurements of other parameters. As a result of limited information, this parameter is mainly estimated or linearized relative to lateral force when used for calculations though such calculations can be less accurate. In this paper it is concluded that a clear relationship can not be formed between the lateral force and the sideslip angle and that for precise determination of the sideslip angle several parameters need to be known such as tire construction, tire pressure, rim diameter, wheel camber as well as micro and macro road structure.

KEY WORDS: Sideslip angle, steerability, lateral force

[1]*Stefan Milićević, MSc Student, Faculty of Mechanical Engineering, University of Belgrade, 17.oktobra 30, Kneževac, stefanm9670@gmail.com *(Corresponding author)*

PRILOG ISTRAŽIVANJU UTICAJA UGLA POVOĐENJA TOČKOVA NA UPRAVLJIVOST VOZILA

REZIME: Poznavanje granica poprečnog upravljanja i stabilnosti vozila veoma je važno sa aspekta projektovanja sistema usmerenog na poboljšanje upravljanja i bezbednosti. Jedan od fenomena koji ima veliki uticaj na stabilnost i upravljivost vozila je povođenje točkova. Nažalost, direktno merenje ugla povođenja točkova zahteva vrlo složenu i skupu opremu koja nije pogodna za ugradnju na obična putnička vozila; zbog toga se ova veličina mora proceniti na osnovu merenja drugih parametara. Kao rezultat ograničenih informacija, kao i činjenice da se bočni koeficijent prianjanja i ugao povođenja brzo menjaju u zavisnosti od vrste i kvaliteta puta ili prilikom preduzimanja određenih manevara, ovaj parametar se uglavnom procenjuje ili se vrši njegova linearizacija u odnosu na bočnu silu kada se koristi za proračune, mada takvi proračuni mogu biti manje tačni. U ovom radu se zaključuje da se ne može stvoriti jasan odnos između bočne sile i ugla povođenja točkova i da je za precizno određivanje ugla povođenja potrebno znati nekoliko parametara kao što su konstrukcija pneumatika, pritisak u pneumaticima, prečnik oboda, ugao nagiba točka kao i mikro i makro reljef puta......

KLJUČNE REČI: ugao povođenja točkova, upravljivost, bočna sila

CONTRIBUTION TO THE RESEARCH OF THE SIDESLIP ANGLE INFLUENCE ON VEHICLE STEERABILITY

Stefan Milićević

INTRODUCTION

Knowing the limits of transverse handling and vehicle stability is very important from the aspect of designing a system aimed at improving handling and safety. Such systems tend to prevent unwanted vehicle behavior by using active control systems and assisting the driver in controlling the motor vehicle. Examples of such systems are the Anti-lock braking system (*ABS*), traction control system (*TCS*), and Electronic Stability Program (*ESP*) [2].

One of the phenomena that have a great impact on vehicle stability and handling is the sideslip angle. When a high-intensity lateral force acts on the vehicle during movement, due to their elasticity, tire deformation occurs, and, as a result, the direction of vehicle movement changes. This problem is especially present when turning, when, due to centrifugal or some other force (e.g. wind force), oversteer or understeer occur. In many cases, the driver is unable to correct the vehicle's trajectory and accidents can occur. Therefore, knowledge of the vehicle's lateral performance is very important because it directly affects the occurrence of oversteer and understeer, and the main factor is the phenomenon of the sideslip angle.

Knowledge of the vehicle's sideslip angle, which relates its lateral velocity to its longitudinal velocity, is largely unavailable for current safety systems; systems such as ESC have access to measurements of sideslip rate, not sideslip angle [2]. Unfortunately, direct measurement of the sideslip angle requires very complex and expensive equipment that is not suitable for installation on ordinary passenger vehicles; therefore, this quantity must be estimated on the basis of measurements of other parameters such as lateral and longitudinal acceleration, velocity, yaw rate, and steer angle. The difficulty in slip angle estimation is due to nonlinear characteristics of tires and influence of relative slant of the road surface. Methods that design observers to estimate sideslip often depend on accurate tire parametrization, which is problematic since tire parameters vary based on the road surface [3-5].

As a result of limited information, as well as the fact that the lateral coefficient of adhesion and sideslip angle change rapidly depending on the type and quality of the road soil or when undertaking certain emergency maneuvers, this parameter is mainly estimated or linearized relative to lateral force (Figure 1.c) when used for calculations though such calculations can be less accurate.

However, if a clear relationship was to be formed between the lateral force and the sideslip angle, at least for the adopted road parameters and the shape and construction of the tires, it would be possible to determine the sideslip angle at every moment. In the case where it is possible to determine the sideslip angle, it is also possible to design a system where the handling control, e.g. via steer-by-wire, would be near perfect..

1 BASIC CONSIDERATIONS ON SIDESLIP ANGLE AND VEHICLE STEERABILITY TESTING

The motion of a vehicle is governed by the forces generated between the tire and the road. In this part of the paper, an important concept related to the characterization of forces between tires and road is described. It is explained how lateral tire force is generated as a function of tire deformation.

Due to the elasticity of the tire, a lateral deformation is formed under the action of a force (F_y) that acts in the direction normal to the tire rolling plane (Figure 1).

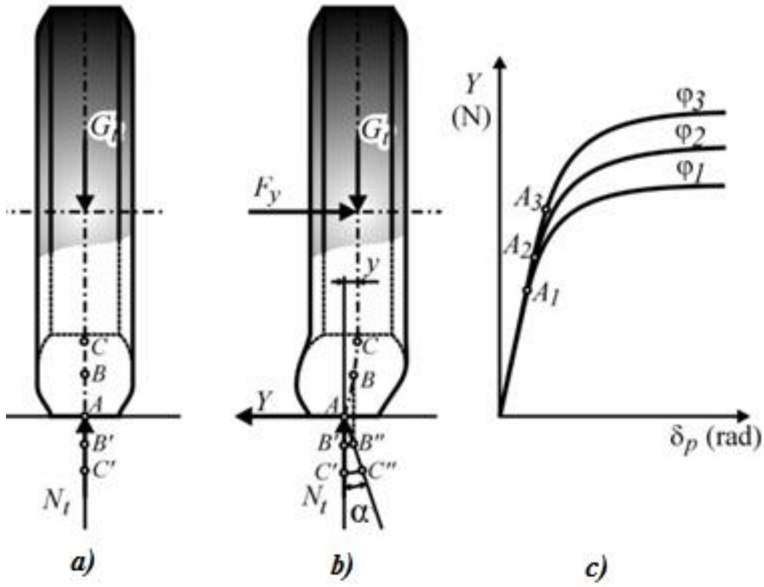

Figure 1. Front view of a laterally deflected tire

The force causes a horizontal reaction of the road (*Y*) which is parallel to it and a linear displacement (*y*) of the force (G_t) relative to the contact surface and the normal reaction (N_t). If points A, B, and C are observed on the circumference of the tire symmetrical ridge, it is obvious that they will come into contact with the road at points A', B' and C' found in the rolling plane when rolling without lateral force (Figure 1.a). , ie. the tire trajectory is a line located in rolling plane. If, however, there is a lateral force (F_y) and a linear displacement (*y*), points A, B and C no longer lie in the same plane, so when rolling the wheel will come into contact with the ground at points A", B" and C" (Figure 2.b), ie. the tire trajectory is a line which is at an angle α relative to the rolling plane. The phenomenon of a change in the angle of the wheel trajectory relative to the rolling plane is called the sideslip angle.

Lateral force appears as a consequence of external influence, e.g. strong crosswind, or as a consequence of turning, ie. consequence of centrifugal force.

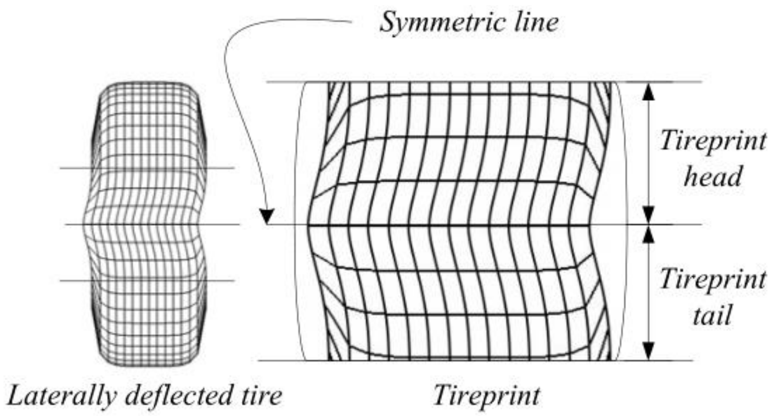

Figure 2. Bottom view of a laterally deflected tire, [7]

In the literature [6,7,8] the relation is considered to be as follows:

$$Y = K_p \cdot \alpha \,, \tag{1}$$

where: K_p - cornering stiffness of the tire.
The coefficient Kp is defined [7]:

$$K_p = \lim_{\alpha \to 0} \frac{\partial(-Y)}{\partial \alpha} = \left| \lim_{\alpha \to 0} \frac{\partial Y}{\partial \alpha} \right| , \tag{2}$$

A sample of measured lateral force Fy as a function of slip angle α for a constant vertical load is plotted in Figure 3. [7]. The lateral force Fy is linear for small slip angles, however the rate of increasing Fy decreases for higher α. The lateral force remains constant or drops slightly when α reaches a critical value at which the tire slides on the road. Therefore, we may assume the lateral force Fy is proportional to the slip angle α for low values of α as described with the above equations [7].

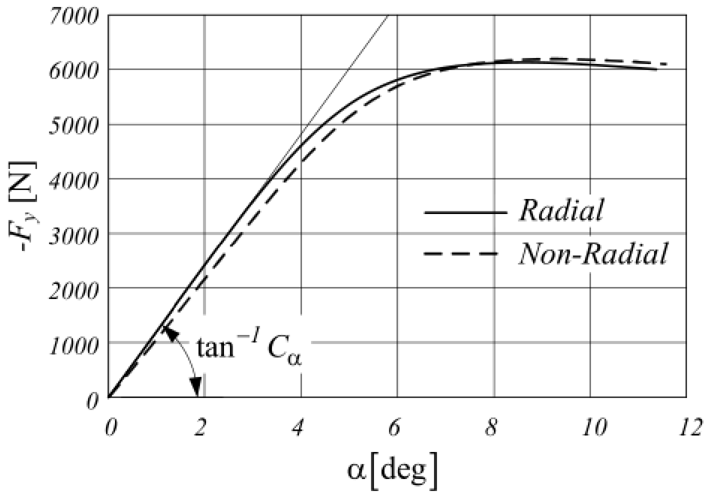

Figure 3. Lateral force F_y as a function of slip angle α for a constant vertical load, [7]

However, to determine the true value of the sideslip angle, the researcher needs the lateral forces (or the coefficient of friction) based on the slip angle and the parameters:

vertical force (or wheel load) in the centre of tire contact

- tire pressure
- wheel camber
- tire type.

The influence of the sideslip angle is most obvious in the behavior of the vehicle during turning. Due to the elasticity of the tires, there is a deformation of the part of the tire in contact with the road and the difference between the velocity vector of the vehicle and the rolling plane of the wheels. A similar thing happens on the rear wheels of vehicles with the sideslip angle of the opposite sign (Figure 4).

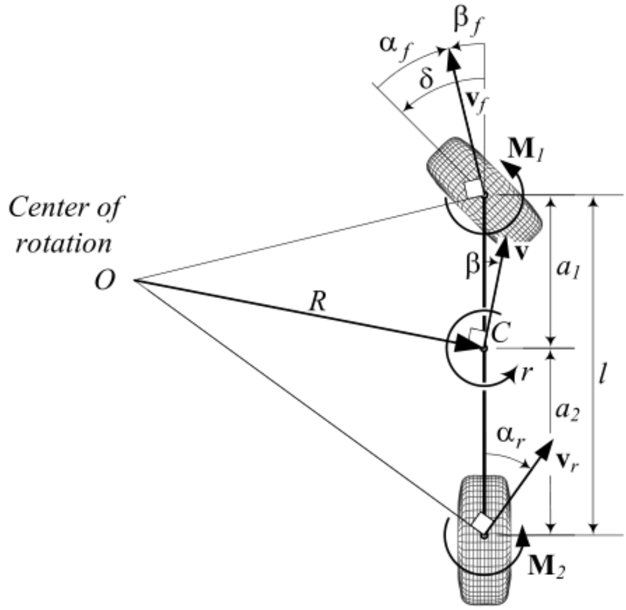

Figure 4. Cornering of a bicycle model, [7]

If its adopted:

$$K = W_f / K_f - W_r / K_r \,, \qquad (3)$$

where:

- W_f - load on the front axle
- W_r - load on the rear axle
- K_f - cornering stiffness of the front tires
- K_r - cornering stiffness of the rear tires

and to be called "understeer gradient" then depending on the size of the steering angles on the front and rear wheels there are three cases [11]:

Neutral Steer - $\alpha_f = \alpha_r, \; K = 0$

On a constant-radius turn, no change in steer angle will be required as the speed is varied. Specificallly, the steer angle required to make the turn will be equivalent to the Ackerman

Angle, 57.3 L/R. Physically, the neutral steer case corresponds to a balance on the vehicle such that the force on the lateral acceleration at the center of gravity causes an identical increase in slip angle at both the front and rear wheels.

Understeer - $\alpha_f > \alpha_r, K > 0$

On a constant-radius turn, the steer angle will have to increase with speed in proportion to K times the lateral acceleration. Thus it increases linearly with the lateral acceleration and with the square of the speed. In the understeer case, the lateral acceleration at the center of gravity causes the front wheels to slip sideways to a greater extent than at the rear wheels. Thus to develop the lateral force at the front wheels necessary to maintain the radius of turn, the front wheels must be steered to a greater angle.

Oversteer - $\alpha_f < \alpha_r, K < 0$

On a constant-radius turn, the steer angle will have to decrease as the speed (and lateral acceleration) is increased. In this case, the lateral acceleration at the center of gravity causes the slip angle on the rear wheels to increase more than at the front. The outward drift at the rear of the vehicle turns the front wheels inward, thus diminishing the radius of turn. The increase in lateral acceleration that follows causes the rear to drift out even further and the process continues unless the steer angle is reduced to maintain the radius of turn.

2 EXPERIMENTAL SETUP

Dynamic testing of the vehicle was performed with the modern measuring equipment on the motor vehicle BMW M3 E36. A sensor used is designed for direct, slip-free measurement of longitudinal and transverse vehicle dynamics which feature high-quality optical elements, the newest optoelectronical components and state-of-the-art high-performance signal processing based on DSP and FPGA's. Speed and distance information is updated at 250 Hz to track every highly dynamic maneuver.

Sensor has several mounting options as shown in Figure 5.

This sensor equipment uses electronics which provide option for connection of a gyro to attain yaw rate for measurement of sideslip angle relative to the vehicle's center of gravity.

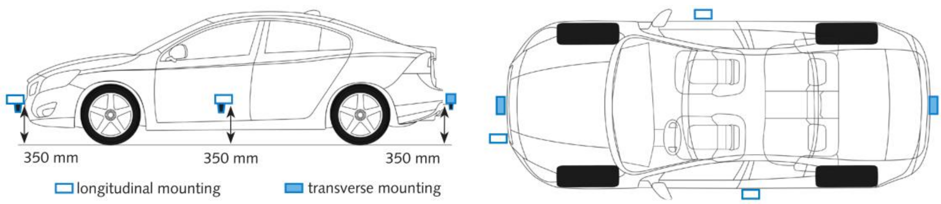

Figure 5. Possible mounting options

In this case, the sensor was mounted on the vehicles door as shown in Figure 6.

Programmable, standardized signal outputs and interfaces allow direct connection to PC and virtually all data acquisition systems, making all measured values directly available.

The testing of the vehicle steerability can be performed in three modes [13]:

- with constant radius (R = const.) while speed changes
- with constant speed (V = const.) while radius changes - preffered method in this research
- with constant steering-wheel angle while speed increases

However, this test was also performed in the so-called "eight" mode, where the vehicle alternately turns left and right, moving along the path in the form of number eight, where the interdependence of driving angle and lateral acceleration was recorded.

Figure 6. Preferred way of mounting during testing

3 RESULTS AND ANALYSIS

3.1 Steerability test

The driver gradually turns the steering wheel while maintaining a constant speed. If the vehicle has NEUTRAL steerability, the dependence of yaw angle (including sideslip angle) and the turning radius will be LINEAR. In any other case, it will be curvilinear.

In Figure 7. the changes of vehicle speed and curve radius in relation to time are shown.

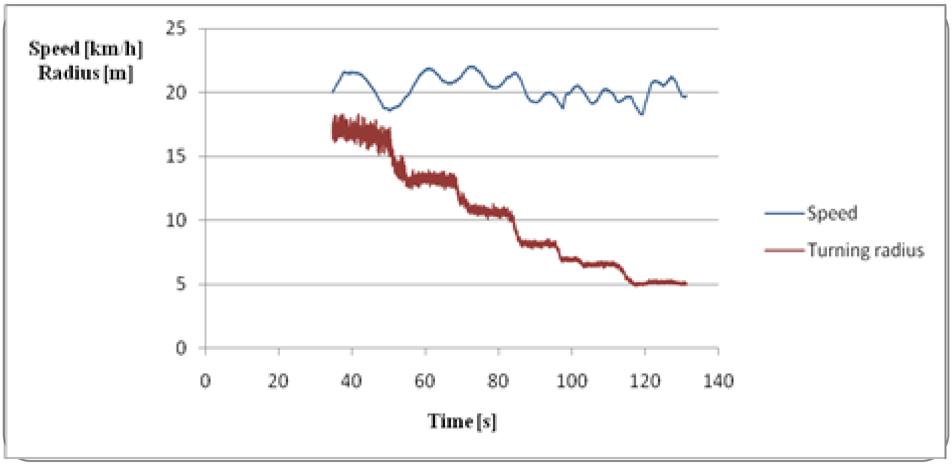

Figure 7. Change of speed and radius in relation to time

Speed was maintained at a value of approximately 20 km/h during the testing. On the other hand, the turning radius was gradually decreased which means that the sideslip angle should be increased.

The obtained results (Figure 8.) depict a linear change of the yaw angle relative to the turning radius, which means that the tested vehicle has neutral steerability.

The dispersion of the measured data (blue dots, Figure 8.) justifies the second test, the "8" test, which goal is to examine the dependence of sideslip angle relative to lateral acceleration (or force).

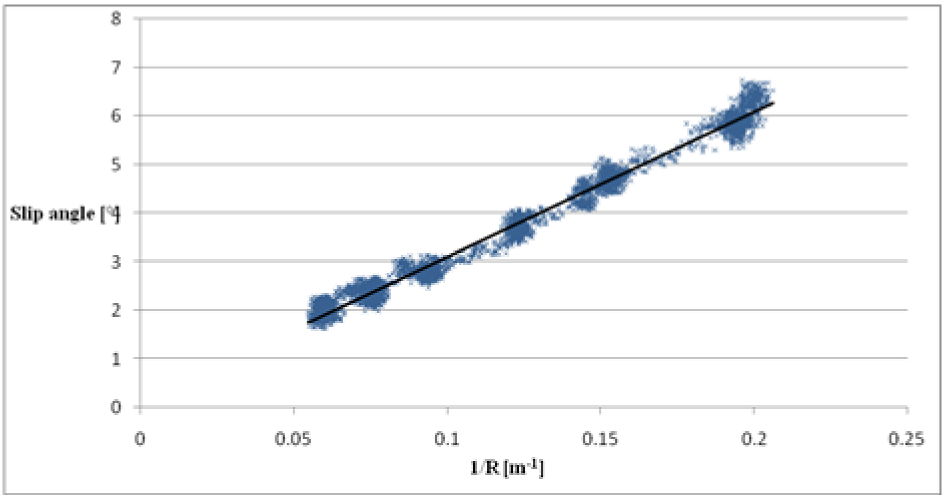

Figure 8. Relation between yaw angle and turning radius

3.2 The "8" test

Two recorded cycles were used to analyze the measured sideslip angle during the "8" test. One cycle is shown in Figure 9. The cycles are separated due to the large lateral acceleration difference.

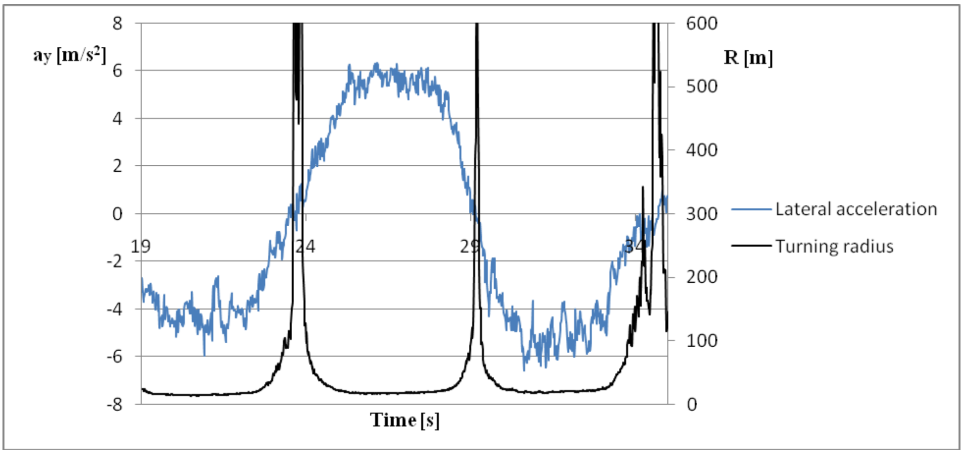

Figure 9. First of the two cycles

Sideslip angle to lateral acceleration dependence is shown in Figures 10 and 11.

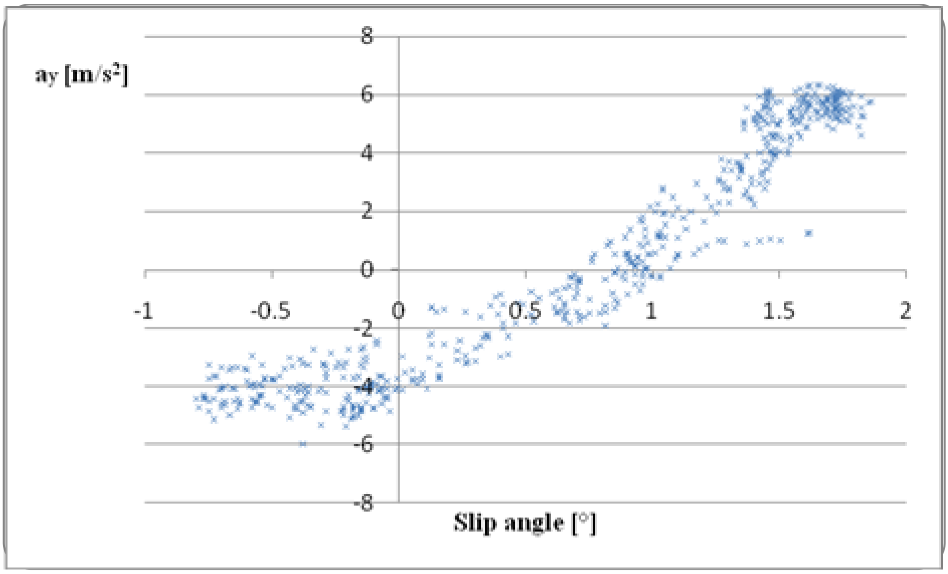

Figure 11. Sideslip angle to lateral acceleration dependence in first cycle

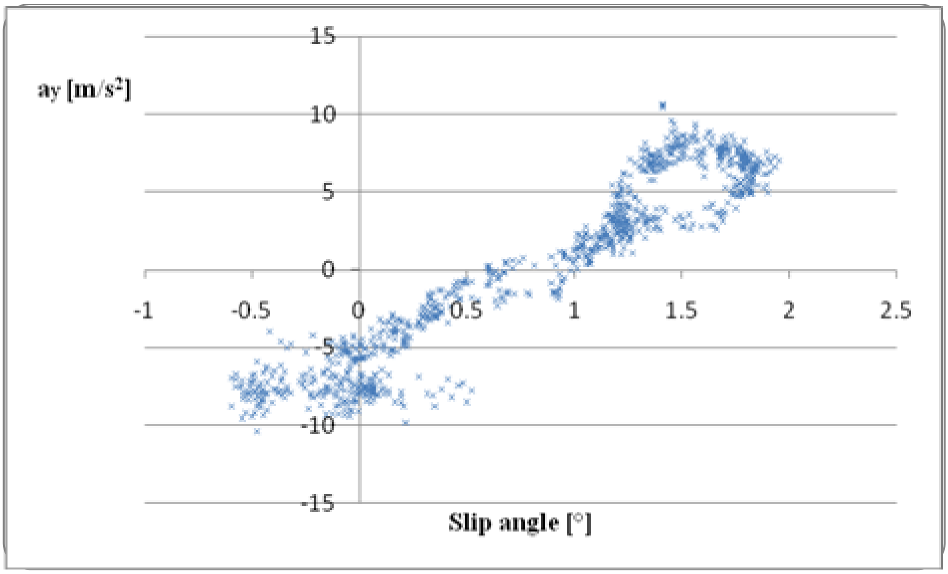

Figure 12. Sideslip angle to lateral acceleration dependence in second cycle

The relationship between these two parameters throughout the entire testing is shown in Figure 13.

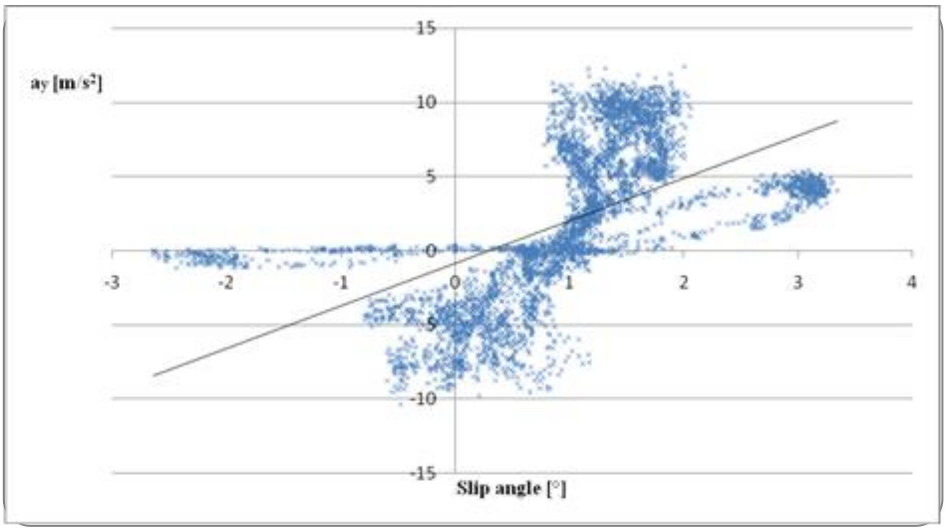

Figure 13. Sideslip angle to lateral acceleration dependence throughout entire testing

Due to not knowing the actual dependence of these two parameters, the linear dependence (straight line, Figure 13) is often adopted in literature. However, in the same figure, it can be seen that the adoption of linear dependence in certain calculations can lead to an error of great margin. Therefore, it is necessary to know other parameters of importance related to the construction of tires, the wheel camber, and the micro and macro structure of the road.

4 CONCLUSION

The aim of this paper was to investigate the influence of sideslip angle on the vehicle steerability and the relative dependence of the sideslip angle and lateral force, which in the literature is most often presented as a linear dependence until the point of lateral sliding, and then as a uniform increase of sideslip angle without further increase of lateral force.

It is shown that modern measuring equipment can be used for fast, simple, and efficient testing of motor vehicle steerability including relatively accurate sideslip angle estimation, however, it is necessary to keep in mind that the obtained results deviate to a certain extent from the real ones due to the great stochasticity of the sideslip angle, ie dependence on numerous other parameters.

It was concluded that a clear relationship can not be formed between the lateral force and the sideslip angle between and that for precise determination of the sideslip angle several parameters need to be known such as tire construction, tire pressure, rim diameter, wheel camber as well as micro and macro road structure.

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TESTING THE CHARACTERISTICS OF THE DRIVER - MOTORCYCLE - ROAD SYSTEM ON THE TECHNICAL INSPECTION LINE

*Ivan Mačužić[1] , Branislav Aleksandrović[2] , Marko Đapan[3]**

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RESEARCH ARTICLE

ABSTRACT: The characteristics of the motorcycle in relation to the driver's behavior significantly affect traffic safety. Motorcycle accidents are usually more severe. The specifics of the construction and the very complexity of the kinematics and dynamics of the motorcycle to a considerable extent complicate the comparative implementation of theoretical and experimental research. The research of the stated characteristics was realized on the line of technical inspection. These obtained results could be used in order to educate motorcyclists in order to increase the overall traffic safety

KEY WORDS: motorcycle, experimental measurements, technical inspection, traffic safety

[1] *Ivan Mačuzić, PhD, associate prof., University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, ivanm@kg.ac.rs*
[2] *Branislav Aleksandrović, PhD, Professor, Academy of Professional Studies Sumadija Department in Kragujevac, Serbia b.aleksandrovic@vts.edu.rs*
[3] *Marko Djapan, PhD, assistant prof., University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, djapan@kg.ac.rs (*Corresponding author)*

ISPITIVANJE KARAKTERISTIKA SISTEMA VOZAČ – MOTOCIKL – PUT NA LINIJI TEHNIČKOG PREGLEDA

REZIME: Karakteristike motocikla u relaciji sa ponašanjem vozača bitno utiču na bezbednost saobraćaja. Saobraćajne nezgode sa motociklima su najčešće sa težim posledicama. Specifičnosti konstrukcije i sama kompleksnost kinematike i dinamika motocikla u znatnom stepenu usložnjavaju uporedno sprovođenje teorijskih i eksperimentalnih istraživanja. Istraživanje navedenih karakteristika je realizovano na liniji tehničkog pregleda. Dobijeni rezultati se mogu koristiti u cilju edukacije vozača motocikla radi povećanje ukupne bezbednosti saobraćaja.

KLJUČNE REČI: motocikl, eksperimentalna merenja, tehnički pregled, bezbednost saobraćaja

TESTING THE CHARACTERISTICS OF THE DRIVER – MOTORCYCLE - ROAD SYSTEM ON THE TECHNICAL INSPECTION LINE

Ivan Mačužić, Branislav Aleksandrović, Marko Đapan

1. INTRODUCTION

In road traffic, vehicles of different construction concepts and different characteristics can be found. According to the number of tracks and wheels, it is common for vehicles to be classified into vehicles with one track and two wheels and vehicles with two tracks, ie with four or more wheels. Bicycle and motorcycle are two representative categories of vehicles with one track and two wheels, which meet in traffic and whose dynamic characteristics in interaction with the driver's behavior significantly affect traffic safety [1]. It can be said that the movement of bicycles and motorcycles has a lot in common, but also that it differs significantly from the movement of two-wheeled vehicles [2] [3]. Unlike two-track vehicles, which have the stability of keeping the direction of movement without the help of the driver, single-track vehicles do not have the stability of the direction of movement or the stability of the position in relation to the road [4]. For these reasons, the role of drivers of single-track vehicles is very complicated and difficult [5]. The driver gets tired while driving and is very often the cause of traffic accidents with severe injuries or deaths [6].

In dynamic analyzes of two-wheelers, both theoretical and experimental, a special problem is the inclusion of the influence of the driver [7]. This is due to the fact that in motorcycles the driver's behavior affects the stability and safety of movement more than in other vehicles [8] [9]. The motorcycle can easily be found in a position of unstable balance, because it is stabilized by the dynamic forces that are a consequence of the driving mode [10] [11]. It is known that the bicycle, as a two-wheeler, keeps the rider in direct balance. The equipment used in technical inspections can be part of the experimental measuring system and the results obtained in this way are valuable in testing the characteristics of the rider-motorcycle-road system [12] [13] [14] [15].

2. EXPERIMENTAL MEASUREMENT SYSYTEM

The experimental measurement system [3] used in the tests with the YAMAHA YZF R6 motorcycle is shown in Figure 1.

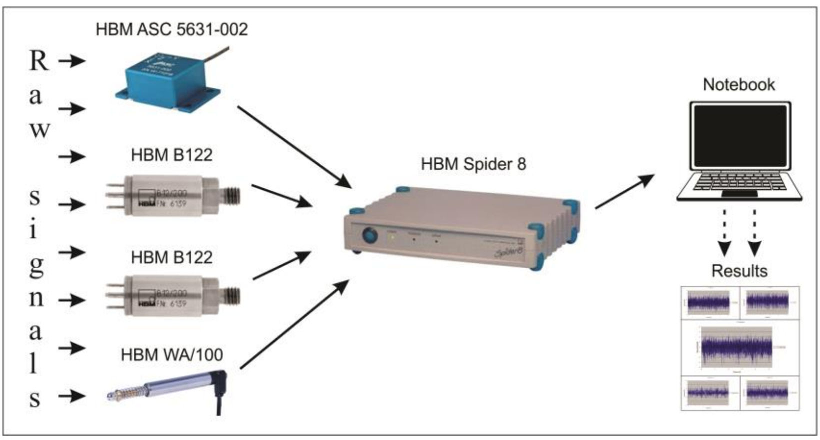

Figure 1: *Experimental testing equipment*

The raw signal (A, B, C and D) act on the transducers, which send the processed signal to the HBM SPIDER 8 amplifier, after which the amplified signal is sent to the PC for further processing. Figure 2 shows the three-axis accelerometer HBM ASC 5631-002 SN W-71003, which is mounted in the center of gravity of the motorcycle and measures three components of acceleration: longitudinal, transverse-lateral and vertical.

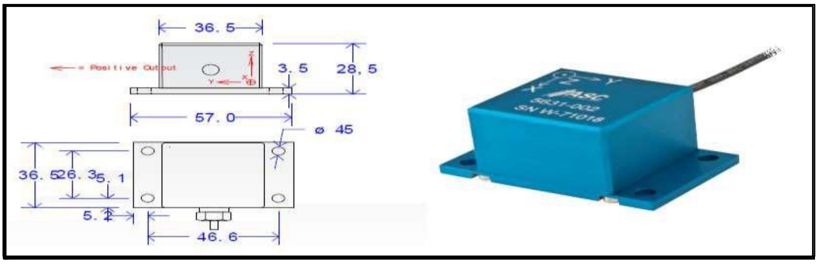

Figure 2: *Triaxial acceleration sensor Hottinger Baldwin Messtechnik-HBM*

Figure 3 shows the HBM WA/100 translational displacement transducer mounted on the handlebars of the motorcycle and shows the displacement of the motorcycle when cornering.

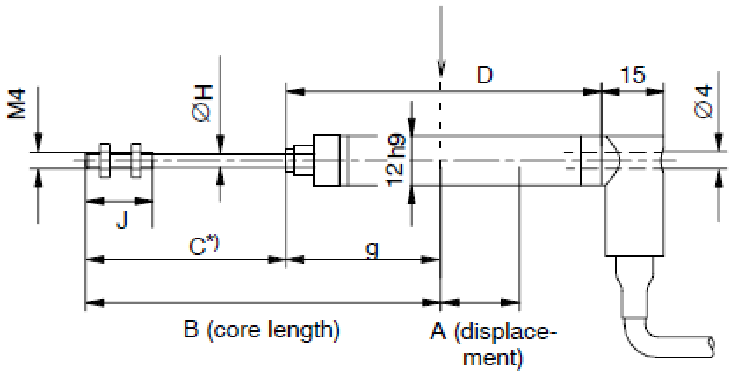

Figure 3: *Translational displacement transducer HBM WA / 100*

Figure 4 shows the uniaxial HBM B12 accelerator transducer located in the centers of the front and rear wheels and which followed the movement in the vertical direction.

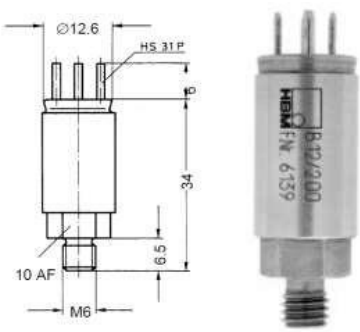

Figure 4: *Single-axis acceleration transducer HBM B12*

The HBM Spider 8 amplifier was used in the experiment. HBM Spider 8 is a simple, universal amplifier that can have from 4 to 8 usable channels (inputs) and has a connection to a PC on which, with the software support, measured signals are processed. The amplifier is shown in Picture 5.

Figure 5: *HBM SPIDER amplifier*

HBM Spider 8 is a multi-channel electronic measuring unit PC for parallel, dynamic measurements and data processing. It is an integrated and more cost-effective alternative to systems consisting of external units. The entire measuring system must be pre-connected with cables and configured. With the HBM Spider 8 measuring system, everything needed to perform the measurement is housed in a compact housing. Unlike older systems, there are no redundant switches, potentiometers and no plug-in card with code and address is required to configure the system, so the Spider 8 simply connects to a computer and printer, via a printer port and is ready to use immediately

Each channel in Spider 8 provides pulses for passive converters, amplifiers, filters and has its own A/D converter. All A/D converters operate in sync and can provide up to 9,600 measurements from each channel with a resolution of 16 bits. The base unit has four 4.8 kHz frequency amplifiers (ie 600 Hz for the type Spider 8-30), stable and noise-tolerant, which allow the general application of the Spider 8. It allows the measurement of force, lenght, pressure and other mechanical quantities by means of voltage measuring systems and inductive transducers. Spider 8 can be expanded to 8 channels in one device or to a total of 64 channels from 8 devices. Plug-in modules are available in two versions for expansion in the device: one as an additional CF channel amplifier and the other as a DC version, with electrically insulated inputs for temperature measurements with thermocouples or for measuring direct voltage, direct current and resistance.

3. SETTING MEASUREMENT EQUIPMENT ON MOTORCYCLE

To investigate the influence of the dynamic characteristics of the driver - motorcycle - road system [3] on traffic safety, an experimental measurement system was designed and implemented on a YAMAHA R6 motorcycle Figure 6.

The basic parameters of a motorcycle are:

- Working volume: H = 599 cm3,
- Maximum power Pemax / np = 89.7kW, at 13000 rpm,
- Net weight: ms = 183 kg.

Figure 6: *Test motorcycle YAMAHA YZF R6*

Measuring system HBM Spider 8, connected to a PC on the front passenger seat in a special housing attached to the frame of the motorcycle Figure 7.

Figure 7: *The measuring system HBM Spider 8*

The three-axis accelerometer HBM ASC 5631-002, is set at the position of the approximate center of gravity of the rider-motorcycle system (Figure 8). The first uniaxial accelerometer HBM B 12, is attached to the carrier approximately in the center of the front wheel of the motorcycle, as shown in Figure 9.

The experimental system shown could be expanded, if necessary, by introducing an appropriate number of uniaxial HBM B12 accelerometers. These accelerometers that can be placed on the motorcycle frame at the front and rear elastic wheel suspension systems connection, the center of mass of the system, the driver's and front passenger's seat, driver's belt and helmet, etc. In this way, it could ne measured the levels of oscillations to which the components of the system are exposed, as well as indicators of the dynamic redistribution of the load on the wheels during starting and braking.

Figure 8: *Three-axis accelerometer*

Picture 9: *Single axle*

HBM ASC 5631-002	*accelerator HBM B12 on the front wheel*

Figure 10 shows the measurement process of the YAMAHA YZF R6 motorcycle on the technical inspection line - measuring rollers.

Figure 10: *Motorcycle YAMAHA YZF R6 on the line of technical inspection - measuring rollers*

4. MEASUREMENT RESULTS

With the Yamaha YZF R6 motorcycle, a number of measurements in different test conditions were performed on the technical inspection line. The presented measurement results refer to the identification of the motorcycle acceleration tested on the measuring rollers placed on the line of technical inspection. In different modes of operation of the motorcycle engine, starting from the mode when the engine is not running and the rollers are turning, to the mode when the engine is running at the maximum number of revolutions (which were allowed by the test conditions). The accelerations on the wheels and in the center of gravity of the motorcycle were measured with uniaxial and triaxial accelerometers. All modes were repeated several times to prove the validity of the measurement.

It is important to note that the research was done on a YAMAHA YZF R6 motorcycle, manufactured in 2005, and cannot generally apply to all motorcycles. The test was performed on the technical inspection line of "Tandem" d.o.o. in Kragujevac.

The analysis of the recorded accelerations led to the conclusion of how much amplitude of dynamic forces we can expect at the front and rear point in different modes of operation of the motorcycle engine. These variations in the amplitude of the dynamic force directly have the consequence of changing the braking force, and thus the stability of the motorcycle in braking conditions. No braking force was measured during the test, but the rollers were used to drive the motorcycle and test in stationary conditions. The research was performed to determine the phenomenon of lateral acceleration in motorcycles.

The modes were used during the experiment are presented in the Table 1.

Table 1: *The experimental modes*

Exper imental mode	Roller speed	Revolution per min (rpm)	Numbe r of measurements
I	*5 km/h*	*/*	*3*
II	*5 km/h*	*800 o/min*	*4*

III	*0 km/h*	*2000 o/min*	*3*
IV	*5 km/h*	*2000 o/min*	*3*
V	*5 km/h*	*4000 o/min*	*3*
VI	*5 km/h*	*6000 o/min*	*3*

During the processing of the results, a standard deviation was found for all measured quantities and further analyzes were performed with it.

Measurements were performed on the motorcycle in three positions:

- Rear wheel center (vertical component)
- Motorcycle center of gravity (three components: longitudinal, lateral, vertical)
- Front wheel center (vertical component).

The measurements are systematized as measurements I, II, III, IV, V, VI. The accelerations in the wheels were measured with single-axis accelerometer, while the three-axis accelerometer measured the accelerations at the measuring point placed in the center of gravity of the driver-motorcycle system. The measurements and obtained results provide the possibility of comparison within the same group of measurements, as well as deviations and specificity in comparison with road tests. The results of the performed measurements is given in table 2.

Table 2: *The results of the measurements*

Experimental modes		Center of gravity (X)	Center of gravity (Y)	Center of gravity (Z)	Rear wheel	Front wheel
I	Stdev*	0.087363	0.287621	0.242389	0.284783	0.175867
	Average	-0.00604	-0.01392	0.011588	0.011533	0.018555
	RMS**	0.087572	0.287957	0.242666	0.285017	0.176843
II	Stdev	0.524582	2.188214	1.037928	0.44751	0.266237
	Average	0.001875	-0.01715	0.007026	-0.00599	0.019273
	RMS	0.524586	2.188281	1.037952	0.44755	0.266933
III	Stdev	0.818491	4.332546	1.306306	0.376482	0.839195
	Average	0.135181	0.391819	0.140271	0.003846	0.012531
	RMS	0.829579	4.350227	1.313816	0.376502	0.839289
IV	Stdev	0.966637	5.793635	1.77192	0.496649	0.841698
	Average	0.273508	0.146934	-0.1004	-0.00596	0.003348
	RMS	1.004586	5.795498	1.774762	0.496685	0.841704
V	Stdev	2.745689	2.851367	2.798665	1.492879	1.30541
	Average	0.103086	0.084769	-0.34257	-0.01229	0.026109
	RMS	2.747623	2.852627	2.819553	1.49293	1.305671
VI	Stdev	2.354594	2.715101	2.864484	1.738071	2.073573
	Average	-0.25947	-0.26244	-0.29972	-0.00352	-0.00721
	RMS	2.368847	2.727756	2.880122	1.738074	2.073586
* Stdev – Standard deviation ** RMS – Root Mean Square						

For the whole record in the time interval, the mean values of the standard deviation were found, which are shown in Table 3.

Table 3: *Standard deviations of the obtained results*

Experimental modes,	Center of	Center of	Center of	Rear	Front

experimental number and average		gravity (X)	gravity (Y)	gravity (Z)	wheel	wheel
I	No. 1	0.087363	0.287621	0.242389	0.284783	0.175867
	No. 2	0.081666	0.289754	0.232399	0.309762	0.171898
	No. 3	0.086047	0.296877	0.245645	0.334654	0.182863
	Average	0.085025	0.291417	0.240144	0.309733	0.176876
II	No. 1	0.524582	2.188214	1.037928	0.447510	0.266237
	No. 2	0.425928	1.327984	1.073978	0.409906	0.243223
	No. 3	0.326165	1.093907	0.790957	0.368447	0.241885
	No. 4	0.314499	0.824464	0.836635	0.350278	0.247671
	Average	0.397794	1.358642	0.934874	0.394035	0.249754
III	No. 1	0.818491	4.332546	1.306306	0.376482	0.839195
	No. 2	0.884504	4.403498	1.406201	0.380782	0.834731
	No. 3	0.733019	3.982337	1.532768	0.377452	0.850148
	Average	0.812005	4.239460	1.415092	1.522654	0.841358
IV	No. 1	0.966637	5.793635	1.771920	0.496649	0.841698
	No. 2	1.085818	6.888796	1.599797	0.553871	0.790123
	No. 3	1.044752	5.902189	1.598560	0.516292	0.830319
	Average	1.032402	6.194873	1.656759	0.522271	0.820713
V	No. 1	2.745689	2.851367	2.798665	1.492879	1.305410
	No. 2	2.811196	3.195967	3.235410	1.520104	1.311694
	No. 3	2.825407	3.232931	2.935280	1.396834	1.381601
	Average	2.794097	3.093422	2.989785	1.469939	1.332902
VI	No. 1	2.354594	2.715101	2.864484	1.738071	2.073573
	No. 2	2.412932	3.116204	3.147391	2.160495	2.283178
	No. 3	2.217954	3.092894	3.114779	1.811462	2.610930
	Average	2.328493	2.974733	3.042218	1.903343	2.322560

Based on the obtained results, a significant component of lateral acceleration in the center of gravity of the motorcycle can be noticed, although the measurements were realized in quasi - static conditions, on the line of technical inspection. We can interpret the above as a specificity of the construction of a single-track vehicle, as well as the behaviour of the driver, who managed to keep the motorcycle in balance and maintain approximately vertical position of the motorcycle. Figure 8 shows the impeller blade design for the following basic parameters: Y = 360 J/kg, Q = 0.3 m^3/s, n = 1000 rpm, D_1=0.27m, D_2=0.36m, b_1 = 0.095m, b_2 = 0.055m.

5. CONCLUSION

Experimental tests of acceleration measurements at stationary modes were performed on the line of technical inspection. By analyzing the measured values, we come to the conclusion of how much dynamic force we can expect at the front and rear wheel, as well as at the center of gravity of the driver-motorcycle system at different modes of operation of the motorcycle engine. Variations of dynamic forces in the center of the front and rear wheels result in a change in braking force, and thus directly affect the stability of the motorcycle in braking conditions. The forces in the center of gravity, in addition to affecting the stability of the motorcycle, also affect the oscillatory comfort, comfort of the rider and co-driver. If the driver-motorcycle system is exposed to prolonged vibrations, various negative effects occur, which can affect driving safety, as well as the health of the rider ("white toe syndrome"). Motorcycle and moped riders are most exposed to these vibrations, who use this vehicle to perform their primary activity (postmen, traffic police, couriers, fast food suppliers, etc.).

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SIMULATION OF ROAD TRAFFIC NOISE POLLUTION IN KRAGUJEVAC USING QGIS SOFTWARE

Angelina Pavlović[1]*, Goran Bošković*[2]*, Nebojša Jovičić*[3]***

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RESEARCH ARTICLE

ABSTRACT: Noise is characterized as an environmental problem that represents an exceptional danger to human health. With increased urbanization and motorization, road traffic has been identified as the dominant source of noise in urban areas. The traffic noise originates from vehicle exhaust and braking systems, devices for giving sound signals, engine operation, or as a result of contact between the wheels and the road. In urban areas, the intensity of traffic noise depends on the speed of the vehicle, the flow of traffic, and the surface on which the vehicles are moving.

This study aims to monitor traffic noise using the device Brüel & Kjær 2250 on the territory of the city of Kragujevac at specific locations along the roads and during peak hours. Based on the numerical modeling of traffic noise in the Quantum GIS software (abbr. QGIS), it is possible to identify impacts of noise pollution as well as deviations of real noise values from the permissible noise limits. Serbian law regulates that the highest noise level along city roads can be 65 dB (A). The final results obtained by this research can be used to assess the current state of environmental noise pollution, which can be taken into account in the future process of transport planning in the city of Kragujevac.

KEY WORDS: road traffic noise, noise pollution, monitoring, QGIS

[1]*Angelina Pavlović, PhD student and Junior researcher, University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, angelina.pavlovic@uni.kg.ac.rs (*Corresponding author)*

[2]*Goran Bošković, PhD, assist. prof., University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, goran.boskovic@kg.ac.rs*

[3]*Nebojša Jovičić, PhD, full prof., University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, njovicic@kg.ac.rs*

SIMULACIJA ZAGAĐENJA BUKOM SAOBRAĆAJA U KRAGUJEVACU POMOĆU PROGRAMSKOG PAKETA QGIS

REZIME: Buka je okarakterisana kao ekološki problem koji predstavlja izuzetnu opasnost po zdravlje ljudi. Sa povećanom urbanizacijom i motorizacijom, drumski saobraćaj je prepoznat kao dominantan izvor buke u urbanim sredinama. Saobraćajna buka potiče od izduvnih i kočionih sistema vozila, uređaja za davanje zvučnih signala, rada motora ili kao rezultat kontakta između točkova i puta. U urbanim sredinama intenzitet saobraćajne buke zavisi od brzine vozila, protoka saobraćaja i površine po kojoj se vozila kreću.

Ova studija ima za cilj praćenje saobraćajne buke pomoću uređaja Bruel & Kjær 2250 na teritoriji grada Kragujevca na određenim lokacijama duž saobraćajnica i tokom časova vršnih opterećenja. Na osnovu numeričkog modeliranja saobraćajne buke u softveru Quantum GIS (skraćeno QGIS), moguće je identifikovati uticaje zagađenja bukom, kao i odstupanja stvarnih vrednosti buke od dozvoljenih granica buke. Srpski zakon definiše da najviši nivo buke na gradskim putevima može biti 65 dB (A). Konačni rezultati dobijeni ovim istraživanjem mogu se koristiti za procenu trenutnog stanja zagađenja životne sredine bukom, što se može uzeti u obzir u budućem procesu planiranja transporta u gradu Kragujevcu.

KLJUČNE REČI: buka drumskog saobraćaju, zagađenje bukom, monitoring, KGIS

SIMULATION OF ROAD TRAFFIC NOISE POLLUTION IN KRAGUJEVAC USING QGIS SOFTWARE

Angelina Pavlović, Goran Bošković, Nebojša Jovičić

INTRODUCTION

In recent years, there has been a significant increase in the world population. According to the latest available report of the United Nations (abbr. UN), the world population reached 7.7 billion in 2019 [1]. Population growth has led people to move from rural to urban centers, which has affected the development of urbanization. Today, 55.3% of the total world population lives in cities. Globally, over 80 percent of economic activity is concentrated in cities [2]. The expansion of cities and the increase in the number of inhabitants in them also caused an increase in the use of motorized transport, i.e., an increase in individual travel to achieve mobility of the population.

The urbanization and motorization phenomenon has significantly contributed to the excessive burden on the environment. This phenomenon leads to the emergence of numerous environmental problems that affect the all living beings' quality of life. Precisely, the quality of life of the world's population is disturbed because of dominant environmental problems. Aside from the air quality, as the most dominant environmental problem stands out the increased noise level in the environment.

Noise can be defined as any unwanted sound of different types and intensity occurring in the living and working environment. If the comparison of noise with other environmental pollutants is carried out, it can be concluded that it as a pollutant is particular because of its effect that can have temporary or permanent consequences for human health. Constant exposure to this environmental pollutant has implications on people's physical and mental health and can cause acute and chronic acoustic trauma. The pyramid of noise effects is shown in Figure 1.

Noise can originate from a variety of outdoor and indoor sources. Traffic represents a significant source of noise in urban centers. Noise generated by traffic causes at least 10,000 cases of premature death, hypertension occurs in 910,000 inhabitants and closes by 43,000 hospital admissions per year in countries belonging to the European Union [4]. For this research, only the noise caused by road traffic is analyzed. Road traffic is the most dominant source of noise in cities. More than 40% of the European population is exposed to road traffic noise at levels exceeding the permissible noise limits [5]. The problem of traffic noise is made even more complicated by traffic conditions in the city, i.e., the fact that the number of vehicles on the streets is higher than the number for which the roads are designed.

Due to the above problems that noise creates, it is necessary to find the most optimal way to manage traffic noise. Road traffic noise management is becoming one of the most complex processes under the responsibility of urban planners and public health professionals. For that reason, one of the main aims of this paper is to estimate the population's exposure to a high noise level caused by road traffic among urban buildings in the city of Kragujevac at three specific locations (abbr. SL) is considered. That estimation can facilitate the prediction of traffic noise in the city of Kragujevac. Assessment of noise levels in this paper was performed using two methods: actual measurements of traffic noise using devices Brüel & Kjær 2250 and openNoise Mobile App and simulation of noise pollution using QGIS software and its special plugin opeNoise.

Simulation of road traffic noise pollution can display that its intensity varies in different locations of the city. The level of road traffic noise pollution depends on the noise source's location, the receiver, and the existing obstacles [6]. Noise mapping in this paper serves to understand how traffic noise pollution varies in space and how it can be reduced. The primary purpose of mapping noise traffic in QGIS software is to identify locations exposed to noise levels above the permitted limit values. According to mapping noise, it is possible to define activities that should be undertaken to reduce noise levels to protect public health (barriers, building design, sound insulation, land-use planning, personal protective equipment, etc.).

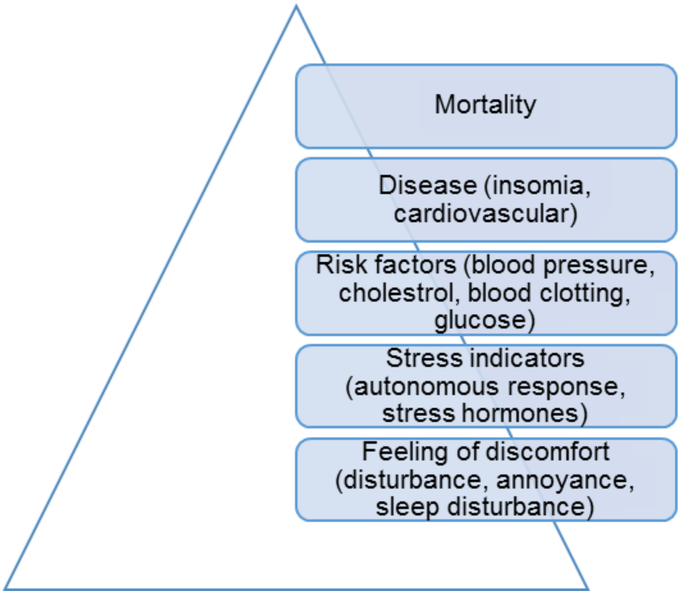


Figure 1 The pyramid of noise-induced health effects [3]

1. NOISE REGULATIONS

As already mentioned, noise is characterized as one of the primary environmental problems and pollutants in the environment. For that reason, it is necessary to manage noise following appropriate standards and legislation. It is generally known that the European Union is a world leader in defining legal directives, which refer to the protection of the population from the harmful effects of noise. In the 1980s, noise management activities as pollutants began in Europe. Noise management activities are performed following legal regulations and standards. One of the first documents, which is considered valid in the field of noise management, is the "Green Paper - Future Noise Policy," published by the European Commission in 1996. The "Green Paper" states that any future anti-noise strategy must be based on the fact that no person should be exposed to noise levels that can endanger its health and quality of life [7]. By publishing this document, opportunities have been created to improve actions related to noise exposure assessment, noise mapping, and harmonization of noise indicators in the environment.

Based on the document "Green Book - Future noise policy," the European Commission formed a working group in 1998. The main reason for the formation of the working group was to define noise indicators that would be used in the European Union to describe all noise sources, and for its assessment, mapping, planning, and control. As a result of three years of work on the development of noise indicators, in 2002, The Environmental Noise Directive (abbr. END) 2002/49/EC was created. Directive 2002/49/EC of the European Parliament and the Council regulates activities relating to [8]:

- noise assessment through the development of strategic noise maps using harmonized noise indicators and methods,
- development of action plans for maintaining noise levels in environment that are within the permissible level,
- establishing a noise level database and
- ensuring that information on environmental noise and its effects are made available to the public.

Today, the list of European Union regulations in the field of noise protection includes 13 acts of different legal force, among which the most important is Directive 2002/49/EC. Two international projects, "Harmonise" and "Imagine," have emerged from the mentioned Directive. The purpose of these projects was to develop a harmonized noise impact assessment methodology in all EU Member States. The methods defined by these projects are not officially proposed for noise assessment. It is currently recommended that "Common Noise Assessment Methods in Europe (abbr. CNOSSOS-EU)" developed in 2012 by the European Commission be used for noise assessment. The focus of this methodology is on the evaluation of road, rail, and air traffic noise, as well as industrial noise [9].

To form documents at the local, regional and national levels that relate to the current state of environmental noise pollution and whose purpose is to create - remediation of public health, it is essential to know accurate data on annual values of noise indicators. The noise indicator is an acoustic quantity that describes the noise in the environment [10]. When assessing noise levels, it is crucial to consider the variations of noise levels for 24 hours. According to those variations, three fundamental indicators appear:

•daily noise level measured from 6 am - 6 pm (LA_{day}),
•evening noise level measured from 6 pm – 10 pm (LA_{evening}), and
•night noise level measured from 10 pm – 6 am (LA_{night}).

Based on the above indicators, it is possible to evaluate LA_{den} indicator, which represents a standard European indicator. LA_{den} serves to define the average noise level throughout the day, evening, and night, to which a citizen is exposed during the year. This indicator is determined by mathematical relation 1 [11]:

$$LA_{den} = 10\log\frac{1}{24}\left(12\times10\times\frac{LA_{day}}{10} + 4\times10\times\frac{LA_{evening}+5}{10} + 8\times10\times\frac{LA_{night}+10}{10}\right) \quad (1)$$

The defined indicator is characterized, such as annually sound pressure level expressed in dB(A). These values are derived from the sound pressure level in dB, applying the so-called A-weighting.

2. NOISE REGULATIONS IN THE REPUBLIC OF SERBIA

The Republic of Serbia, as a candidate for membership in the European Union, needs to harmonize its legislation and bylaws with EU legislation. During Serbia's integration into the EU, the area of noise is not at the top of the priority of actions. Still, the government manages to harmonize the appropriate legal regulations with Directive 2002/49/EC. The essential legislation in the field of noise management in Serbia is laws, regulations, and rulebooks. Besides, determination of the value of fundamental noise indicators performs following the standards SRPS ISO 1996-1 and SRPS ISO 1996-2 [12]. Relevant documents from the analyzed area are shown in Table 1.

Table 1 *Noise legislation in the Republic of Serbia*

Name	**Place and year of publication**
Law on Noise Protection	Official Gazette of RS, No 36/2009 and 88/2010
Regulation on noise indicators, limit values, noise indicators assessment methods, annoyance and harmful effects of environmental noise	Official Gazette of RS, No 75/2010
Rulebook on methodology for determining the acoustic zone	Official Gazette of RS, No 72/2010
Rulebook on the methods of noise measurement, content and scope of the noise measurement reports	Official Gazette of RS, No 72/2010
Rulebook on the methodology for the action plan development	Official Gazette of RS, No 72/2010
Rulebook on the conditions to be fulfilled by a professional organization for noise measurement, and documentation to be submited with application for acquirinf the authorisation for noise masurement	Official Gazette of RS, No 72/2010
Rulebook on the content and method of development of noise maps and the manner of their presentation to the public	Official Gazette of RS, No 80/2010
Rulebook on noise emitted by the equipment used in the open space	Official Gazette of the RS, No 01/2013
SRPS ISO 1996-1: 2016 Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures	Institute for Standardization of Serbia, 2010
SRPS ISO 1996-2: 2010 Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of sound pressure levels	Institute for Standardization of Serbia, 2010

It is important to emphasize that Directive 2002/49/EC has only been partially transposed by the Law on Environmental Noise Protection and its accompanying bylaws. At the same time, its full implementation is planned by the end of 2021 [13].

Following the mentioned legal documents, noise limit values have been defined in the Republic of Serbia. The permissible noise limits represents the highest allowed value of noise indicators (LA_{day}, $LA_{evening}$, and LA_{night}). Depending on some criteriums (the noise source, an outdoor or indoor space, space's use, etc.), the permissible noise limits differ.

As the aim of this paper is to simulate traffic noise pollution at specific locations in the Kragujevac city, table 2 shows only the limit values of noise indicators in the outdoor space.

Table 2 *Limit values of outdoor noise indicators [10]*

Zone	**Use of space**	**Level of noise dB (A)**

		LA_{day} / $L_{evening}$	**LA_{night}**
1.	Leisure and recreation areas, hospital zones, cultural and historical spots, large parks	50	40
2.	Tourist areas, small settlements and villages, camps and school zones	50	45
3.	Purely residential districts	55	45
4.	Combined business and residential districts, combined commercial and residential districts and playgrounds	60	50
5.	The city center, craftsman, commercial and administrative areas with housing, zones along highways, main roads and city traffic arteries	65	55
6.	Industrial, storage and service areas and transport terminals without residential buildings	At the border of this zone, the noise must not exceed the limit value in the zone with which it borders	

As already explained, noise indicators are physical quantities that describe noise in the environment. If the value of the indicators is higher than the values given in the previous table, then the noise harms human health, and it is considered that the population at that location is endangered by noise.

3. CASE STUDY: TRAFFIC ROAD NOISE IN KRAGUJEVAC

The city of Kragujevac belongs to the group of medium-sized cities, with 179,417 inhabitants [14]. During the past decades, the increase in traffic capacity on city roads affects that most residents in cities live in acoustically non-conformal zones. Thus, it is necessary to identify deviations of noise levels in Kragujevac comparing the real and the maximum allowed levels to simulate noise pollution from traffic.

Based on the analysis, it is concluded that the traffic-geographical position of the Kragujevac city is exceptionally favorable. This statement is explained by the city's position in the traffic corridor, which connects the southern, southwestern, and western parts of the country with the northeastern and northern areas of Serbia. State roads of I and II order and municipal roads form the road network of the city of Kragujevac. Namely, on the road network, there are city arterial highways, city roads, and collecting roads.

For this research, city roads are essential, which are intended for medium and long city’s trips. They connect collection roads with highways and residential zones with the city center and other facilities, serving most of the local traffic and introducing intercity’s roads in the city [15].

Motorized and non-motorized road traffic takes place on city roads in Kragujevac. In recent years, there has been an increase in motorized traffic load. In addition to the increase in the number of passenger vehicles daily, there is also an increase in freight traffic and public passenger transport. The street network in the city area have inappropriate profiles, making it impossible for pedestrian and bicycle traffic to run smoothly, which is characterized as non-motorized traffic.

In Kragujevac's territory, the traffic regime is not restrictive, and most of the roads operate in a two-way regime. On the city traffic network, direct intersections are regulated by light signals or by horizontal signalization.

The purpose of the movement of passengers is diverse. However, in the peak period of the day, the purposes of movement related to going to work and the school have a very dominant share of almost 95 % of the total movement.

The increase in traffic load also caused an increase in traffic noise emissions. The emission level of traffic noise on the Kragujevac territory depends on the following factors [16]:

- traffic load (number of vehicles / h),
- traffic flow structures (passenger, freight, buses, etc.),
- vehicle speeds,
- traffic flow management (braking, acceleration),
- characteristics of streets (road surface layer, ascent, curvature),
- techniques' conditions of vehicles (engine insulation, tires, exhaust systems),
- driving style and engine load.

Noise determination in Kragujevac performed at six measuring points considered to be the busiest in the city. The measurement is performed by organizations that meet the requirements for environmental noise measurements. In Kragujevac, the organization that meets those conditions is the Institute of Public Health. During the measurement, the day and night noise level is monitored, as well as the number of heavy and light vehicles. The results of noise measurements on an annual basis are forwarded to the Environmental Protection Agency of the Republic of Serbia. At the same time, the local self-government publishes them in the Environmental Bulletin. All recent measurements of noise levels in Kragujevac showed exceedances during the observed period. Measured values of noise levels could harm the health of citizens [15].

4. SPECIFIC LOCATIONS IN KRAGUJEVAC

The subject research is based on measuring the parameters of road traffic noise at three specific locations on the territory of the city of Kragujevac. Measurements were performed at three locations in the city where it was estimated that the impact of noise caused by traffic, as well as other communal activities, was the greatest. The listed locations are:

- SL1 - a four-way intersection of streets: Nikola Pašić and Dr Zoran Điniđić,
- SL2 - a four-way intersection of streets: Radoje Domanović, Kralja Milana, Milentija Popović and Potporučnika Govedarice,
- SL3 - a four-way intersection of streets Bulevar Kraljice Marije and Daničićeva.

Figure 2 shows the analyzed locations in the broader area of the city.

Figure 2 *Analyzed locations in the broader area of the city*

The locations selected for the subject research are characterized by very intensive road traffic. Near the analyzed locations, there are residential buildings with high housing density, business facilities, scientific and educational institutions, health, and other public institutions, such as the administrative building of the local self-government unit in Kragujevac.

Figure 3 presents four approaches to intersections that include possible directions of traffic flows through the intersection, marked with arrows and numbers (1, 2, 3, and 4).

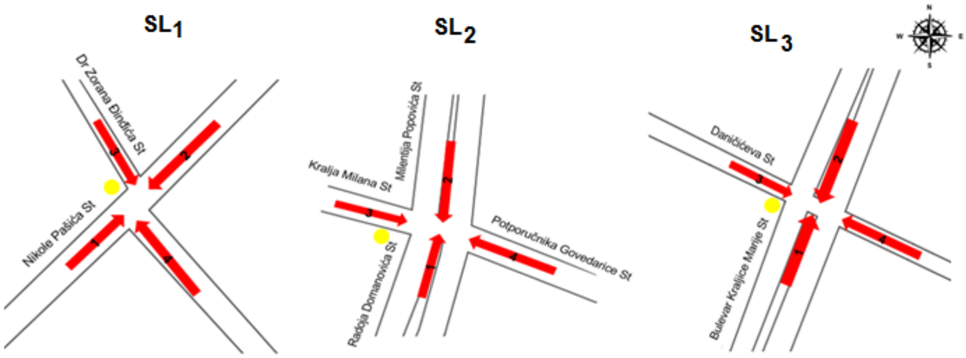


Figure 3 *Traffic directions at the analyzed locations*

The basic characteristics of the analyzed roads are shown in Table 3.

It is already said that the emission level of traffic noise depends on factors such as traffic load. Consequently therefore, when modeling noise levels in urban areas is performed, besides the characteristics listed in the table, one of the essential characteristics of road traffic is the load on the road or the traffic flow. The flow of traffic can be most easily defined as the number of vehicles that pass through the center of the analyzed intersection in a unit of time. This characteristic of road traffic can be determined by traffic-counting. Traffic-counting is extremely important when planning traffic in cities and creating spatial and urban plans. Thanks to the counting of traffic, which can be manual and automatic, data on the intensity and structure of traffic flows are obtained. Besides, traffic counting is important for planning the future size of roads and intersections.

For this research, manual traffic counting was conducted at specific locations. Vehicle frequency measurement was performed according to the specified flows, i.e., traffic direction for each intersection (1,2,3 and 4). The counting was static, i.e., the counting of vehicles passed through a particular section of the road in a specific time interval was performed. A simple counting pattern was used for counting, on which a mark was placed after the vehicle passed, depending on the direction of movement and the type of vehicle.

The vehicle counting pattern is shown in Figure 4.

Table 3 *Characteristics of analyzed roads*

	SL_1	**SL_2**	**SL_3**
Geographical characteristics	The terrain on approaches 1,4,2 is flat, while approach 3 is under a slope,	The terrain of approaches 1 and 3 is flat, while approaches 2 and 4	The terrain of approach 1 is flat, while approaches 2, 3, and 4 are falling

	i.e., an ascent depending on the movement's direction.	are falling or rising, depending on the direction of movement.	or rising depending on the direction of movement.
Characteristics of the space/ objects in the analysed area	Residential buildings, catering facilities, business facilities, public buildings, etc.	Residential buildings, catering facilities, business facilities, educational institutions, etc.	Residential buildings, catering facilities, business facilities, etc.
Characteristics of the road	Two-way traffic takes place on the approaches to all traffic routes. Approaches 1,2, and 4 have three lanes, while approach 3 has two lanes per road. The main surface of the road is asphalt. Vertical traffic lights regulate traffic at the intersection.	Two-way traffic takes place on the approaches to all roads. The number of lanes is four for directions 1, 2, and 4, while direction 3 has three lanes. The main surface of the road is asphalt. Vertical traffic lights regulate traffic at the intersection.	Two-way traffic takes place on the approaches to all roads. The number of lanes is four for roads 1 and 2, while directions 3 and 4 have three lanes. The main surface of the road is asphalt. Vertical traffic lights regulate traffic at the intersection.

Traffic-counting is conducted at specific locations along the roads and during peak hours. Peak hours hour with the most significant volume of traffic during working hours of the day. In the Republic of Serbia, the peak hour is 8 - 10 % of the total daily traffic and occurs in the morning from 7 – 8 o’clock and the afternoon from 15 – 16 o’clock. The measured traffic load during peak hours is shown in Figure 5.

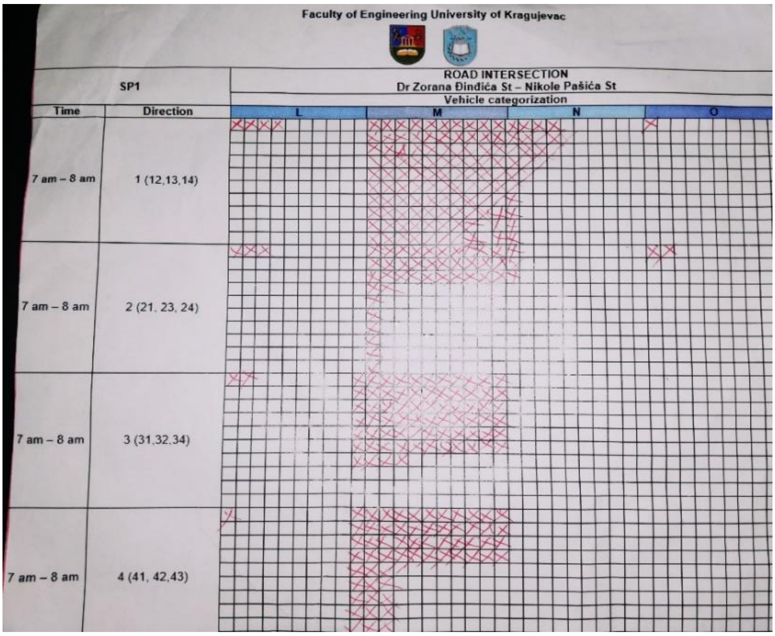


Figure 4 Representative form used for manual traffic-counting on SL1

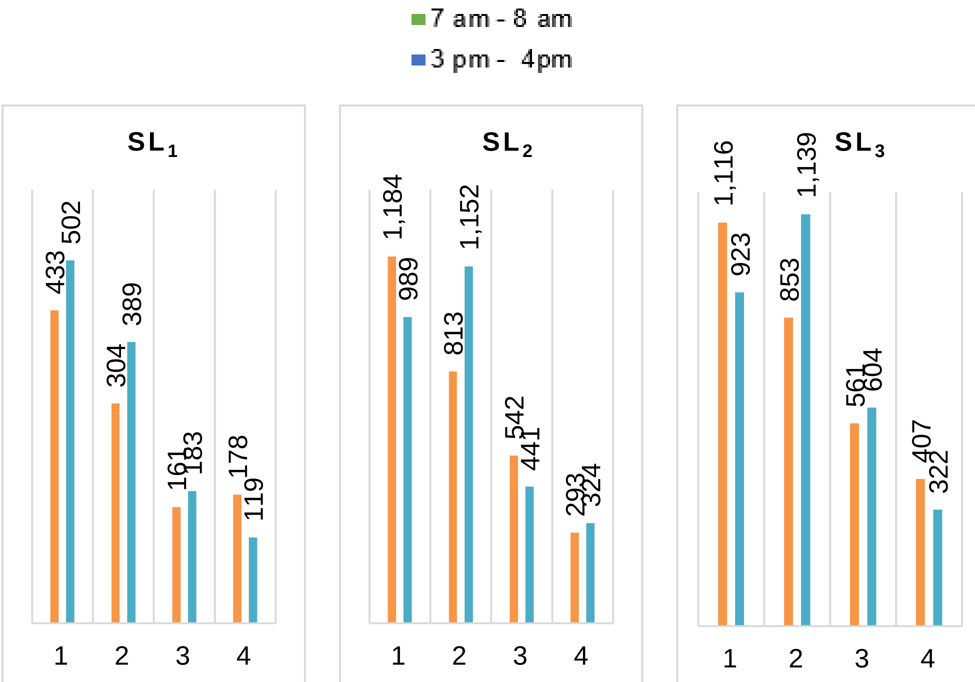


Figure 5 Counted traffic load during peak hours at specific locations

It is mentioned that the emission level of traffic noise also depends on traffic flow structures. So, the manual traffic-counting is conducted according to vehicle categorization. In the Republic of Serbia, vehicle categorization is defined by the Rulebook on

Classification of Motor Vehicles. The categories of vehicles that are used in this research are [17]:

- L – 2-wheel, 3-wheel and 4-wheel vehicles (mopeds, motorcycles, tricycles and quadricycles),
- M – passenger-carrying vehicles, abbr. PCVs (cars and buses),
- N – goods-carrying vehicles (lorries and vans), – trailers and semitrailers.

These categories are analyzed because the noise emission of different vehicle categories varies greatly. In the road vehicles, it can be distinguished the numerous sources of noise depends on the vehicle category. The primary sources of noise in the road vehicles are engine, powertrain, tires cooperating with the road surface, the flow of liquids and gases in systems and installations of the vehicle, a vibration of the vehicle and its components, etc. For that reason, the United Nation's Economic Commission for Europe (abbr. UNECE) has published regulations which are related to road vehicle noise. Regulations developed by UNECE defines limit values for pass-by noise of road vehicles. In the Republic of Serbia, limit values of allowed exterior noise emitted by different category of road vehicles in laboratory conditions are determined in Rulebook on the classification of motor vehicles and trailers and specifications for vehicles in road traffic.

Both the regulations of the European Union and the regulations of the Republic of Serbia do not define the limit values of noise emitted by O category of vehicles. It can be explained by the fact that this category of vehicles is pulled and not autonomous. However, the O category of vehicles is taken during this analysis because it has an impact on the overall traffic noise. That impact is visible through the cooperation of the wheels with the road surface and the airflow around the O vehicle.

The counted vehicle categories in the analyzed locations are given in Figure 6.

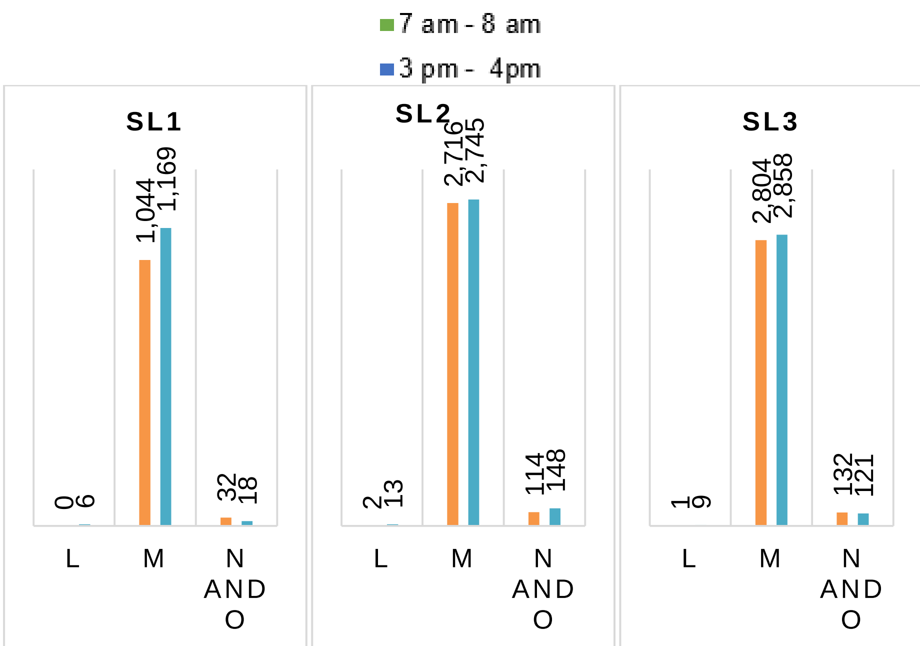


Figure 6 Counted traffic load according to vehicle categories

The traffic load on the Kragujevac's street network has a growth trend, with the share of PCVs in the structure of traffic flows more than 90%.

5. NOISE LEVEL MONITORING

To perform a simulation of noise pollution, it is first necessary to determine the sound pressure levels at the analyzed locations. The measurements were performed using appropriate types of equipment. Brüel & Kjær 2250 sound level meter and the Open Noise Mobile Application were used to measure the equivalent noise level (abbr. LAeq). LAeq is the equivalent sound level of the last range of time setted (0.5, 1 or 2 seconds), expressed in dB(A).

The measurement was performed continuously for 10 minutes along mentioned streets in the peak periods: in the morning from 7 - 8 o'clock and in the afternoon from 3 - 4 o'clock. By such measurement, LAeq values were obtained based on LAeq values with sampling rate of 1 second.

The position of the phonometer used was as in Figure 7. Namely, the noise measurement was performed at a height of 1.5 m, while the distance of the phonometer from the edge of the road was 1.5 - 2 m. Phonometer was distanced 1.2 - 2 m from the nearest building in the area. The phonometer's position was identical in all three locations, i.e., on the corner of the street, which is directed to the south-west. The measuring points at analyzed locations are marked with yellow points in Figure 3. These points were chosen arbitrarily by the authors.

Based on the next figure, it can be seen that the height of buildings is not taken into consideration during noise level monitoring as well as modeling.

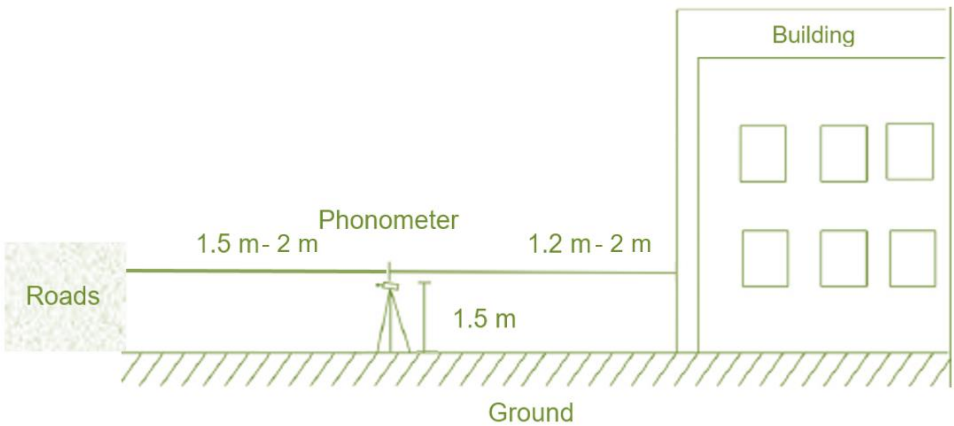


Figure 7 Position of the phonometer during monitoring

At specific location 1, the morning's noise level varies from 46.9 dB (A) to 80.1 dB (A), which is shown in Table 4. During the noise measurement that lasted 10 minutes, the equivalent noise level was 69.6 dB (A), which will be taken into account when simulating noise pollution. At the same specific location, in the afternoon, the minimum average value of environmental noise in this zone was 54.5 dB (A), while the maximum value was 84.9 dB (A). For the equivalent noise level in this period, 75.7 dB (A) was obtained.

The second specific location records higher noise levels, which is explained by the fact that the road that passes next to the place where the measurements were made is a transit road to which most freight traffic is directed. As shown in table 5, in the period from 7 am - 8 am, the minimum and maximum value of environmental noise in this zone was 46 dB (A) and 88.1 dB (A), respectively. During the analyzed period, LAeq was 84.2 dB (A). Slightly higher values were recorded in the afternoon, where a value of 86.8 dB (A) was obtained for the equivalent noise level.

Table 4 Results of measurements of noise levels at SL1

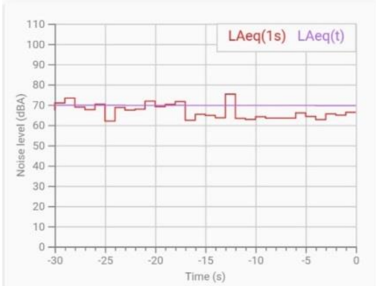
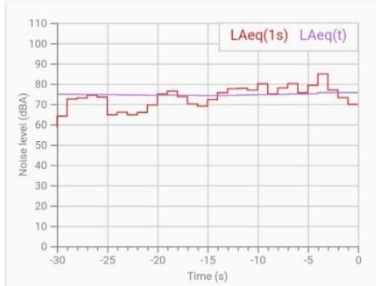
SL_1						
Time of measurement	**7 am – 8 am**			**3 pm – 4 pm**		
Noise level [dBA]	LA_{min}	$LA_{eq(t)}$	LA_{max}	LA_{min}	$LA_{eq(t)}$	LA_{max}
	46.9	**69.6**	**80.1**	**54.5**	**75.7**	**84.9**
Graphics						

Table 5 Results of measurements of noise levels at SL2

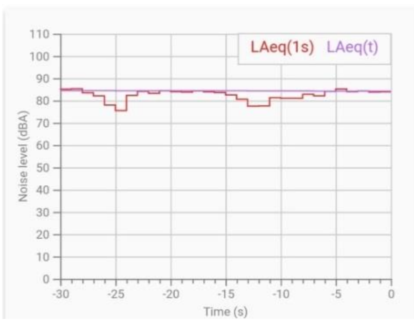
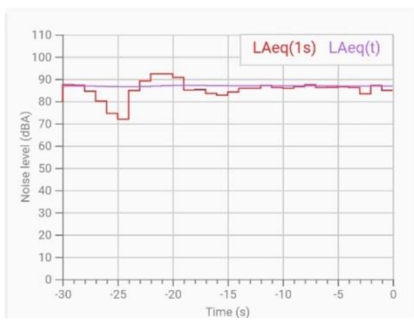
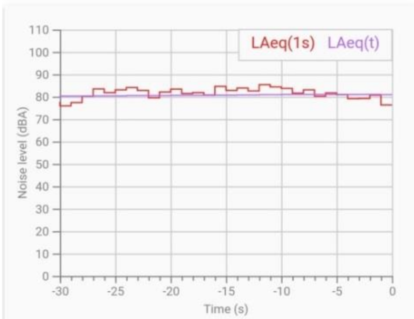
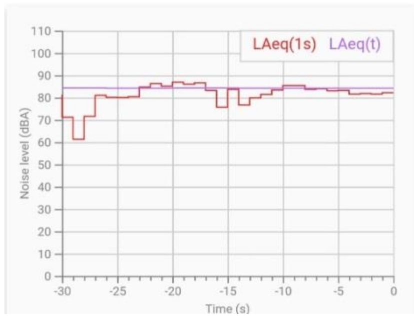
SL_2						
Time of measurement	**7 am – 8 am**			**3 pm – 4 pm**		
Noise level [dBA]	**LAmin**	**LAeq(t)**	**LAmax**	**LAmin**	**LAeq(t)**	**LAmax**
	46.0	**84.2**	**88.1**	**54.8**	**86.8**	**92.3**
Graphics						

Table 6 shows the results of noise monitoring at the third specified location. The equivalent noise levels used in the noise pollution simulation are 80.9 dB (A) for the morning peak's hours and 84.2 dB (A) for the afternoon peak's hours.

Table 6 Results of measurements of noise levels at SL3

	SL_3					
Time of measure ment	7 am – 8 am			3 pm – 4 pm		
Noise level [dBA]	LAmin	LAeq(t)	LAmax	LAmin	LAeq(t)	LAmax
	41.6	80.9	85.8	54.0	84.2	89.2
Graphics						

In the graphics shown in previous tables, the measurement time is the independent variable, and it belongs on the x-axis (horizontal line) of the graph. At the same time, measured noise level is the dependent variable and it belongs on the y-axis (vertical line). Negative values in the x-axis are useful for viewing the monitoring history of results. The zero value corresponds to the instantaneous data at the moment of measuring, while negative values correspond to the results in the past. Positive values would represent the future, but that is impossible to predict. It can be seen that graphs show significant variations in the noise level in a sampling rate of 1 second – LAeq(1s). Some noisy occurrences on the roads such as car horns, car alarms, etc. cause that the noise indicator at the moment of averaging exceeds the equivalent mean noise values.

Comparing the results shown in Tables 4, 5 and 6 with the values defined by Regulation on noise indicators, limit values, noise indicators assessment methods, annoyance and harmful effects of environmental noise and which are shown in Table 2, it is concluded that in critical periods at the analyzed locations in Kragujevac, the noise level LAeq(t) is significantly higher than allowed. The maximum permissible noise level for analyzed locations is 65 dB (A) for day/evening while LAeq(t) for night is 55 dB (A). As the primary source of noise at the analyzed locations, traffic stands out. This can be proven by measured traffic load during peak hours.

6. SIMULATION OF ROAD TRAFFIC NOISE POLLUTION

The software used for simulation of road traffic noise pollution on the territory of the Kragujevac territory was QGIS 3.10.2. This software presents a free and open-source cross-platform desktop geographic information system application that supports viewing, editing, and analyzing geospatial data.

Simulation of road traffic noise pollution starts with the importation of the orthophoto map of Kragujevac in the appropriate coordinate system. In this case, the coordinate reference system is set on EPSG:3909 - MGI 1901 / Balkans zone 7 – Projected.

To model the environmental noise generated by road traffic in Kragujevac, two essential layers are created [18]:

- Buildings, and
- Roads.

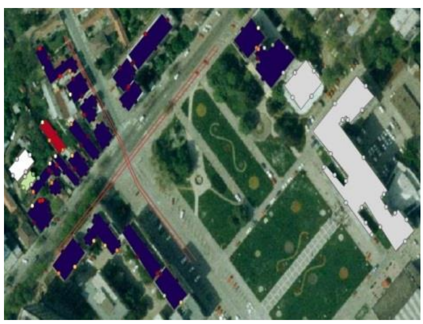
The first layer defined the buildings that were created as polygons. The buildings were drawn based on the already entered orthophoto map of the city of Kragujevac. The purpose of the building was not taken into account when drawing it. The roads are defined as the second layer. This layer represents the emission source of the traffic noise, and the type of the roads layer is a line type. When defining the second layer, it was necessary to define the traffic load for each direction using the attribute table.

Software QGIS has many plugins. One of them is opeNoise, which allows users to compute the noise level generated by point source or by road source at fixed receiver points and buildings used in this research. The first step in noise modeling is to make receiver points. These points are chosen automatically by software. Receiver points can bw created for each facade or equidistant receiver point along the facade. The facade is a layer created as a polygon, i.e., buildings. In this case, receiver points were determined on half of each building's facade in the vicinity of analyzed intersections.

Then, it is necessary to determine the noise level at receiver points generated by road sources (a line layer). For each road, the sound pressure level is calculated based on the data already mentioned (noise level, traffic load, road slope, type of terrain, etc.). The results are written in the attribute table of the receiver point layer and expressed in dB(A). If the level is not calculated or is less than zero, the value -99 is assigned [19]. In the last step, the noise levels are calculated for each receiver point to the corresponding building. The value assigned to the building is the maximum value among all the receiver points for that building.

Simulations were performed for different periods, more precisely for data from the morning hours and for data from the afternoon hours.

The simulation of road traffic noise pollution in Kragujevac at three specific locations is shown in Figure 8.

	7 am – 8 am	3 pm – 4 pm
SL1		

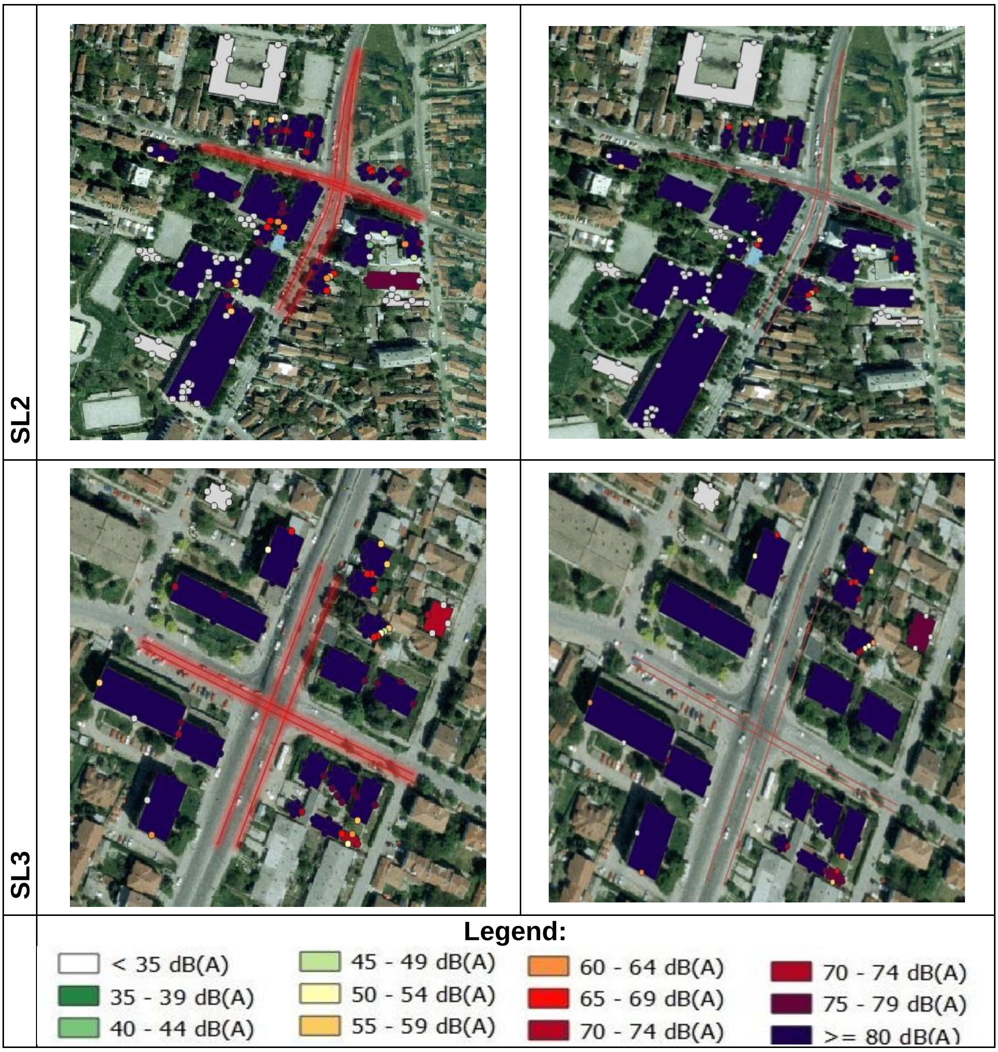


Figure 8 Simulation of road traffic noise pollution in Kragujevac at three specific locations

Buildings are marked with different colors depending on noise levels. According to the previous picture, it can be concluded that the highest noise level is noted at the points of the facades of buildings located at the intersection as well as the noise level of these buildings is at the highest level. Buildings that are at intersections are exposed to noise levels that are over 80 dB(A) during peak hours. This fact leads to the conclusion that analyzed locations are very polluted by the noise.

Accompanying the legal regulations in the Republic of Serbia, the noise on the facade of analyzed facilities should not exceed 65 dB (A). The analyzed buildings are classified as the most noise-endangered buildings due to their location along the city's busiest roads.

The comparison of measured and modeled data is performed. In that case, it can be concluded that there are certain deviations due to which this simulation cannot be officially proposed for noise assessment and planning.

Representative Figure 9 shows the building at the specific location 1 during the morning hours. It is noticed that the receiver points on one building have different noise levels. For example, on the shown building in Figure 9, there are a total of three receiver points where the noise level is higher than 80 dB(A), then one point where the noise level is 75 - 79 dB(A), one where the level is the noise of 65 - 69 dB(A) and one receiver points to which the software assigned a noise level of 50 - 54 dB(A). The simulation shows that the entire analyzed building is exposed to a noise level greater than 80 dB(A) because the noise assigned to the building is the maximum value among all the receiver points for that building.

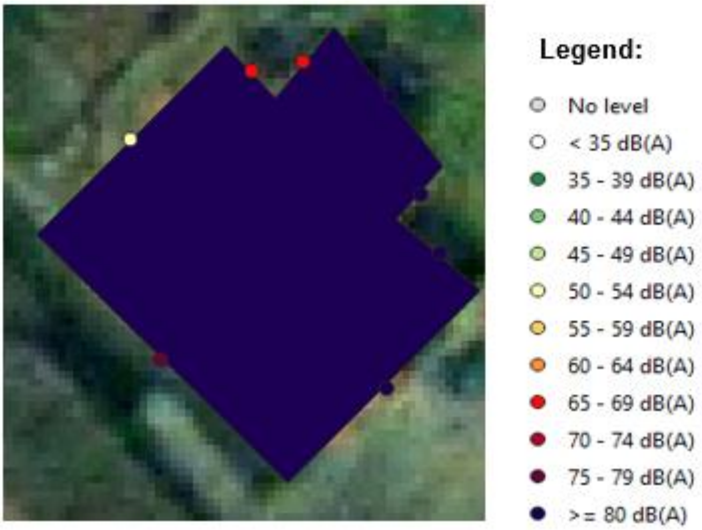


Figure 9 Representative building with receiver points

This type of simulation is sometimes not suitable because in this way it would be concluded that the inhabitants of a building are exposed to equal, maximum levels of traffic noise, which is not correct. In order to avoid these deviations and irregularities, it is recommended that in future research, noise measurements be performed in several different places at specific locations in order for the simulation to be valid.

Anyhow, people living in the buildings covered by this research are exposed to high noise levels. The population which lives at analyzed locations represents a vulnerable group which is affected by noise pollution. Simulated noise levels can have permanent and temporary consequences for public health. Noise-induced health disorders are an expression of a physiological response to stress, most of which are transient and short-lived (disorders of the cardiovascular, digestive and immune systems, decreased attention and memory, narrowed visual field), but which can become chronic (insomnia, high blood pressure, anxiety, depression). All of the above severely impairs the general health of individuals, quality of life, and social communication. To avoid the potential consequences for public health, it is necessary to undertake specific measures to reduce noise in the analyzed locations.

CONCLUSION

Road traffic noise pollution has been recognized as a new threat to the population in urban areas.

For the needs of simulation of noise pollution on the territory of the city of Kragujevac, noise monitoring in the environment was performed.

Noise levels were measured at three specific locations, more precisely at intersections formed by roads characterized by intensive road traffic. The measurement was performed for 10 minutes during peak hours of 7am - 8 am and 3 pm - 4 pm. In the same period, manual measurement of traffic load was performed.

The results of measuring noise levels in Kragujevac show that the levels of communal noise are high. In almost all measuring points, noise levels exceed the prescribed values for the areas of purpose - The city center, craftsman, commercial and administrative areas with housing, zones along highways, main roads and city traffic arteries which are 65 dB (A) for day/evening. The absolute highest noise was found at the measuring point of the specific location SL2, where the equivalent noise level reaches the value of 86.8 dB (A) in the afternoon. Using the results of field noise measurements and analysis of the traffic regime, i.e., traffic load at the observed locations, a simulation of noise pollution was performed. The simulation was performed in QGIS software using the opeNoise plugin. After the simulation, receiver points were determined on half of each building's facade located in the vicinity of the intersection, and the noise level was determined on the same. After that, a certain noise level was added to each building. The value assigned to the building is the maximum value among all the receiver points for that building.

Research like this shows the traffic noise modeling that reveals the areas where the environmental noise values are high enough to disturb different aspects of residents' lives in the analyzed city.

In order to improve the existing situation and minimize noise pollution in the city of Kragujevac, which was observed by modeling, it is considered that it is necessary to take specific measures. By reducing noise levels at sources altogether with methods to protect the urban population from noise exposure, practical actions can be done [20].

Measures that can be applied in order to reduce noise primarily are: control and change of traffic regime. This measure can be implemented through compliance with speed limits, improvement of pedestrian zones, the formation of so-called ecological traffic lights with notification for drivers - "Please turn off the engine", etc. There are also high-budget measures that would significantly reduce the current noise pollution in Kragujevac, such as the construction of a bypass for trucks, which will direct all freight traffic outside the central zones.

As the primary source of noise is road traffic, it is necessary to pay attention to the level of noise emissions emitted by each vehicle. Today, vehicles are manufactured in accordance with the standard that meets the maximum levels of noise emissions from vehicles. However, there is a problem with old vehicles that are still moving on the streets, and it is necessary to apply stricter restrictions in technical inspections of vehicles. Also, it is possible to introduce special taxes for noisier vehicles at the local level or to apply exclusion from the traffic of vehicles with excessive noise.

In addition to the above measures, it is possible to install protective sound barriers along congested roads and to implement zoning with the greening of settlements, which, in addition to improving the microclimate, also affects the protection of the population of Kragujevac from noise. In order to protect against noise, the residents of Kragujevac can install sound insulation on their buildings. Also, they can use personal protective equipment for reducing noise exposure, but that is not a long-term solution.

This kind of research represents the beginning and the base for further elaborating noise pollution mapping on the territory of the entire city of Kragujevac and the development of strategic noise maps.

The development of a strategic noise map in Kragujevac would greatly facilitate noise management at the local level. Namely, strategic noise maps contain data on the state of noise in the environment, such as the current, previous and estimated noise level in the environment expressed by noise indicators, places of exceeding the prescribed limit values, but also an estimate of the number of people and households, schools and hospitals in a specific area that are exposed to noise above the prescribed limit values, etc. The creation of a strategic noise map would significantly help and facilitate the further planning of traffic development in Kragujevac, which needs to be implemented as soon as possible because the current Traffic Development Strategy lasts until 2022.

ACKNOWLEDGMENTS

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WHEEL OF VEHICLE INCREASED SURVIVABILITY

Liubov Sladkova[1]*

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RESEARCH ARTICLE

ABSTRACT: The article, based on the analysis of technical solutions of tyres of various kinds, proposes a fundamentally new constructive performance of high-traffic and survivability tires. The design and operation of the bus is described. The proposed design is theoretically and experimentally justified. Based on the experimental studies of the interaction of the pneumatic tyre with the road surface, the process of traction-clutch characteristics of the airwheeled engine with the ground is simulated. Experimental studies of the pneumatic engine allowed to assess its performance on roads of different condition, depending on the mass and changes in pressure in the event of damage to flexible elements of the wheel. The resulting indicators allow to sufficiently assess not only the survivability of the wheel, its geometric characteristics, but also to describe the physical nature of the interaction of the engine with the road surface, and to confirm the results of theoretical studies. Practical recommendations are given to determine the rational parameters of the tyre of the proposed design. The design of the pneumatic wheel will expand the technological capabilities of the base machine and use it more widely in extreme conditions. The provision of high traffic vehicles proposed in the article pneumatic wheels is conditioned by the need: in the transportation of heavy large cargoes with the exception of separate transportation processes and the subsequent assembly of components.

KEY WORDS: pneumatic wheel (tyre), design, experiment, passability, survivability, contact spot

[1] *Lyubov Sladkova1 Moscow, Russia. Russian University of Transport. Moscow, 9 Obraztsova Street, b. 9. 127994, rich.cat2012@yandex.ru*

TOČAK VOZILA POVEĆANE IZDRŽLJIVOSTI

REZIME: Ovaj rad je baziran na analizi tehničkih rešenja pneumatika različitih vrsta i predlažu se nove konstruktivne performanse pneumatika sa dugim radnim vekom i izdržljivosti. Analiza dizajna i operabilnosti je urađena za pneumatike autobusa. Predloženi dizajn je teorijski i eksperimentalno opravdan. Na osnovu eksperimentalnih studija interakcije pneumatika i podloge, simulira se proces uključivanja spojnice i sprega motora i sistema kretača sa podlogom. Eksperimentalne studije omogućile su da se procene performanse na putevima različitog stanja, u zavisnosti od mase i promene pritiska u slučaju oštećenja fleksibilnih elemenata točka. Dobijeni indikatori omogućavaju da se u dovoljnoj meri proceni ne samo održivost točka, njegove geometrijske karakteristike, već i da se opiše fizička priroda interakcije točka sa površinom puta i da se potvrde rezultati teorijskih studija. Daju se praktične preporuke za određivanje racionalnih parametara pneumatika predloženog dizajna. Dizajn pneumatskog točka proširiće tehnološke mogućnosti baznog vozila i može se koristiti u ekstremnim uslovima eksploatacije. Opremanje vozila koja se intenzivno koriste u transportu pneumaticima prikazanim u radu je uslovljeno potrebom za prevozom teških velikih tereta sa izuzetkom odvojenih procesa prevoza i naknadnog sklapanja komponenata.

KLJUČNE REČI: pneumatski točak (guma), dizajn, eksperiment, prohodnost, izdržljivost, zona kontakta

WHEEL OF VEHICLE INCREASED SURVIVABILITY

Liubov Sladkova

INTRODUCTION

Problems related to the level of support traversability occur when moving vehicles on an uneven road, and solutions that have bumps and potholes. This involves the risk of a tyre being broken or one of the car's wheels entering a pothole, diverting it and risking an accident. The provision of high-traffic vehicles with air wheels is conditioned by the need to transport heavy large and special goods when working in areas remote from civilization. The introduction of the developed wheel will reduce the cost of refurbishing existing vehicles and reduce them for the production of new vehicles that meet modern security requirements. To solve the problem of modernization of the pneum-wheeled engine of the vehicle, the method of systemic search for a solution on the materials of scientific and technical literature was used, methods of calculating the strength and assessment of economic performance indicators of the modernized pneumoper [1-3].

The goal is to modernize the air-wheeled engine of a high-traffic vehicle is the ability to operate vehicles in extreme conditions in the winter and summer season and the ability to continue driving after the wheel break. The use of a pneumatic engine for special purpose vehicles, which allows to preserve the operational properties of the machine, while maintaining a minimum pressure in the tire, depending on the extent of its damage in various road conditions is relevant and meets the requirements of the federal target program "Research and development on priority areas of development of the scientific and technological complex of Russia for 2007-2015

1. ANALYSIS OF THE DEVELOPMENT OF PNEUMO-WHEELED ENGINES AT THE CURRENT STAGE

One of the main elements of ensuring the durability, mobility and traversability of wheeled vehicles are tires, which are the main element of the wheel engine. Their classification features include the form of a section: traditional (toroid), wide-profile, arched, pneumococcal, large tires, top-balloon tires.

The main ways to improve tyre safety are divided into two groups [4-6]:

- ensuring that the car is short-lived on a damaged bus;
- ensuring long-term movement of the car on a damaged tire.

The first group includes: cameraless tyres equipped with various sealing compositions; Tires with special spongy layers on the inner cavity; Multi-layered tyres; tires with elastic filler of the inner cavity; tires with rubber-metal inserts. The second group of designs of safe tire, can be attributed tires with special inserts - rims of magnesium or aluminium alloys. Modern combat wheels and military vehicles have been widely used with combat-resistant wheels with cameraless pneumatic tyres, capable of maintaining their functions in the face of through damage from the mechanical action of bullets or pellets of small arms, fragments of artillery shells and striking factors of anti-vehicle mines or grenades [7, 8].

2. TIRE DESIGN AND OPERATION

The purpose of the tire upgrade is to improve the survivability and reliability of the tyre when driving with the maximum allowable low pressure, which is possible if the tyre integrity is violated during the job.

The existing chamber-type pneumatic tyre (Figure 1. a, b) contains a tire that is not conventionally shown, and an inflatable camera 1, which is pressurized by air, creating the required pressure in the tires. The disadvantage of this design is that in the case of violation of the integrity of the camera there is a reduction in pressure, leading to the inability of the latter to move on the surface of the road. To eliminate this shortcoming, we are offered a camera (Figure 1, a, b), consisting of separate contact cells 2, made in the form of lengthy cavities and filling all chamber space. At the same time, the length of each cell is 2 at least the length of the chamber's internal surface 1 on its longitudinal section. In order to maintain the required pressure, each cell 2 is subject to a separate pressure supply.

Each cell, made in the form of a cavity, contains a reverse valve 3 and has its own output of 4 on the main nipple 5.

Cell 2 location can be concentric relative to another (Figure 1, a), or spiral in the radial direction relative to the outer limiting path 1 in which these cells are located (Figure 1). Also, cells 2, made in the form of separate cavities can be twisted at an angle relative to each other. The problem is solved by the fact that in the famous design on Figure 1 - cavities are twisted at an angle to each other.

In the proposed pneumatic tyre design, lengthy cavities can be replaced by spherical cavities. Such a constructive solution will allow to maintain a more stable pressure in the event of a break out of the wheel. However, such a constructive solution has significant drawbacks if it is necessary to apply pressure to each cavity autonomously. The proposed pneumatic tyre design with long cavities is made and works as follows.

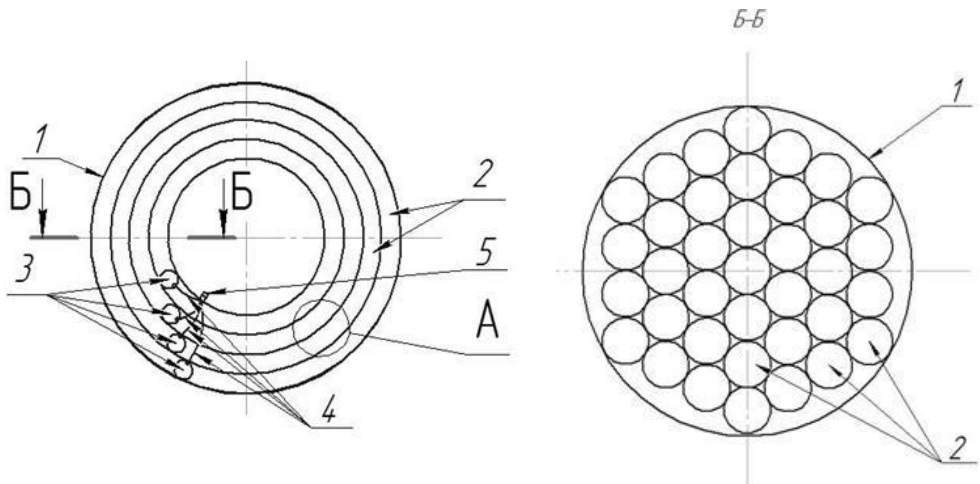

Figure 1 *Pneumatic tyre of the proposed design:*
a - the location inside the camera; b - by section of the Tires

The inner surface of the tyre 1 (Figure 1 a, b) is filled with separate contact cells 2, made in the form of lengthy cavities, such as tubular, rectangular, etc. closed section, or the tire is made by casting with simultaneous formation in its inner cavity of these cells 2. To ensure the assembly of the tyre, the 1 length of each cell 2 must be at least the 232 length of the tyre forming the inner surface of the tyre 1 on its longitudinal section. To ensure the battery life of the 2 cells, each of them is subject to a separate pressure supply through reverse valves 3 with its own outputs of 4 to the main nipple 5. After creating pressure in Cell 2, they are pressed against the inside of tire 1, and, touching their walls, are pressed against each other. At the same time, each cell 2 can be located concentrically relative to the other (Figure 1, a), or spiralin the radial direction relative to the outer limiting contour of tire 1, in which these cells 2 are located. Cell 2, made in the form of cavities, can be twisted at an angle relative to each other, similar to the execution of a rope swirl. The minimum number of cells is two.

The pressure in each cell 2 is fed through nipple 5. In the case of tyre damage, only part of the cells are damaged, while the rest continue to operate thanks to the autonomous pressure liner and the presence of a reverse valve 3 on each cell 2. The pressure in undamaged cells 2 remains sufficient to keep the tyre 1 healthy and maintain its profile.This solution will improve the survivability and reliability of 1 tyre when the breakdown of any of the cells 2.

Options for laying cells in a tire does not have a significant impact on its traction-clutch characteristics.

The size of the flexible wheel (cells) was chosen on the basis of statistical analysis of wheel parameters for different types of cars. It has been established that the geometric characteristics of the wheel (the diameter and width of the tire) vary in close correlation. The weight of the wheels in 6 cases out of 22 has an "outlier." Therefore, when selecting model parameters for theoretical and experimental studies, it is possible to extend the values obtained for the study version to other known models without introducing any corrective factors on the type of tyres used. It has been established that the change in the deformation of the tire is not linear, but hyperbolic in nature and changes in the form of vectors of changes in gravity, vibrations of the machine, rigidity and elasticity of the wheel. The higher the rigidity and plasticity of the wheel, the smaller the size will occur joint deformation of the wheel and road.

3. EXPERIMENTAL STUDIES OF THE INTERACTION OF PNEUMATIC TYRES WITH THE ROAD SURFACE

The purpose of experimental research is to study the processes of interaction of the pneumatic wheel of the proposed design with the road during its direct movement. Given the directness of the movement of the machine, during the experiment will be considered the rolling of a single wheel on the surface of the road of different states. The process of researching the upgraded pneumatic wheel in straight motion in start-up and braking modes consists of two stages. The first is logical, which explores the mechanism of interaction of the pneumatic wheel with the road surface and determines the choice of restrictions imposed. The second stage is the laboratory. The experiment was conducted in three variants on dry - A, wet sand - B and on solid coating - C depending on the mass of X1 and pressure in the wheel X2. according to the planning matrix. The results of the experiment were evaluated by a 3D change in the contact spot (a and b, the depth of the H wheel dive) in the form of P = f (a, b, H) functionality.

Before the experiment, the density of the soil was determined during the experiment, on the solid coating it was 0.98, on the loose sand 1440 kg/m3, on the wet sand 1920 kg/m3. The variability of ground density in each series of experiments did not exceed 4.7%, which is permissible, as such a change in density within these limits does not have a significant impact on the traction-chain characteristics of the ground. A large percentage of the error will lead to change in the physical process on the modes of acceleration and braking of the wheel.

Given the parameters of the wheel-ground modeling system, the boundaries of the input parameters will be inversely proportional to the limits of the original parameters and the scale of the simulation. The results of the definition of the boundaries of research on the model are presented in Table 1.

Table 1 *Limits of Research on Model*

Option name	Symbol	Border	
		Maximum value	Minimum value
Pressure in the wheel, X_1, Pa	p	101325	202650
Weight of the wheel, X_2, kg	m	50	100

The results allow us to assess the performance of the proposed pneumatic wheel design in the event of a breakdown of one of the elements of the wheel. In addition, the experiment will describe the physical nature of the interaction of the proposed PC with the road surface.

The input parameters (factors to be investigated) are the parameters that characterize the condition of the pneumatic wheel when moving it along the road: the weight of the m wheel; Pressure in the p wheel; the condition of the road (loose, loose, hard cover); modes of movement (established movement, acceleration, braking, time for this process 233and the length of the braking path). Weekends - a spot of contact and the depth of the wheel's immersion in soft ground.

In the experiment, a self-propelled dynamometric trolley with an adjustable rev frequency was used to move the wheel and create the necessary traction. To control the change in the parameters of the contact spot above the wheel, a camera was rigidly fixed, allowing to record its change from the same height on different modes of operation of the machine (rest, acceleration, braking are brought to Figure 1) on the model of the road of different state.

During acceleration (Figure 2, b) at the very beginning of this process on the imprint of the tread (contact spot) there is a detachment of soil particles with the formation of a kind of burtic. Moreover, the depth of the contact spot in this place is greater than on the rest of the way of the machine. A similar phenomenon is observed in the process of braking the car (Figure 2, a). In both cases, the rear of the wheel or in front of it is formed a shift shaving of the ground.

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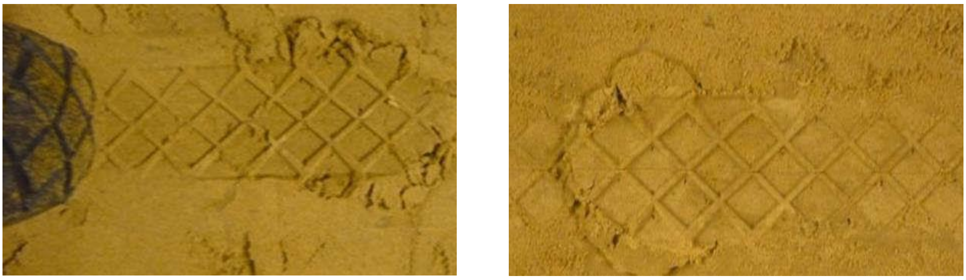

Figure 1 Interaction of the tyre with the ground (wet sand):
a braking process; b - the process of dispersal

The reason for this is the shift of the forces of the clutch of soil particles with the surface of the tire in the direction, directed in the opposite direction of the machine, comparable to the inertial force acting on the machine in the mode of unidentified motion. The physical nature of the change in the depth of the imprint lies in the difference in the speeds of the rotating wheel and soil particles at the moment of braking and touching from the place. In the first case, the ground particles in contact with the wheel have a speed commensurate with the circular speed of the wheel, so when braking they throw forward, forming a drill in front in the course of movement. In the process of acceleration, on the contrary, the wheel begins to gain speed, giving the stationary particles of the ground a commensurate speed, throws the particles back, forming a drill behind itself. In the mode of established movement, the tread print is even lye for the entire length of the car.

The test of the reproducibility of the experiments was carried out on the Cohron Criterion with a confidence probability of 0.95.

The results of the experiment are presented in the form of regression dependence of the species [9]:

$$y = b_0 x_1 + b_1 x_1 + b_{12} x_1 x_2 , \quad (1)$$

The significance of the regression equation (Table 2) was assessed by the Trident criterion, and adequacy by Fisher's criterion with a confidence probability of 0.95.

Using the values of the regression coefficients for Option A (Table 1), we will build regression models that will be put together in Table 3.

During the experiment, it was found that on dry and wet sand, which in fact represent the interaction of the hard wheel and the base, the X1 factor (change in pressure p) has a direct effect only on the change in performance during the experiment on variant A. The mass of the machine has a significant impact only on the change of the large axis of the ellipse. On the wet sand there is a joint effect of pressure in the tire and the mass of the machine in the modes of acceleration and braking.

On the hard coating, the mutual influence of factors is excluded, as is the X1 pressure factor in the wheel. Experimental studies of the pneumatic engine allowed to assess its performance on roads of different condition, depending on the mass and changes in pressure in the event of damage to flexible elements of the wheel. The resulting indicators allow to sufficiently assess not only the survivability of the wheel, its geometric characteristics, but also to describe the physical nature of the interaction of the engine with the road surface, and to confirm the results of theoretical studies.

Table 2 *Values of regression equation sand ratios*

Regression equation ratio	The parameter under investigation								
	$y_1 \sim a$ – large diagonal of the ellipse			$y_2 \sim b$ – small diagonal of the ellipse			$y_3 \sim H$ – print depth		
	Options for experimentation A								
b_0	1	2	3	1	2	3	1	2	3
b_1	14.49	18.49	17.96	7.8	8.6	8.8	1.49	3.52	3.28
b_2	-0.84	-1.00	-1.14	-0.32	-0.21	-0.4	-1.17	-0.01	0.10
b_{12}	-0.16	0.67	0.23	0.07	0,17	0,03	0,06	-0,48	-0,44

It has been established that during the acceleration there is a detachment of soil particles with the formation of a kind of burtic, and the depth of the contact spot in this place is greater than on the rest of the way of movement of the machine. A similar phenomenon is observed in the process of braking the car. In both cases, the rear of the wheel or in front of it forms a shift shaving of the ground as a result of the shifting of the forces of the clutch of soil particles with the surface of the tire in the direction, directed opposite the direction of the machine, comparable to the inertial force acting on the machine in the mode of unaccumulated movement.

The physical nature of the change in the depth of the imprint lies in the difference in the speeds of the rotating wheel and soil particles at the moment of braking and touching from the place. In the first case, the ground particles in contact with the wheel have a speed commensurate with the circular speed of the wheel, so when braking they throw forward, forming a drill in front in the course of movement. In the process of acceleration, on the contrary, the wheel begins to gain speed, giving the stationary particles of the ground a commensurate speed, throws the particles back, forming a drill behind itself. These phenomena are not present at rest.

It has been established that the actual depth of the track is determined not only by the properties of the soil at the time of its interaction with the engine, but also by the loss of pressure in the pneumatic engine as a result of its damage.

In the vast majority of cases, the size of the print is influenced by the vertical component of the force on the wheel, i.e. the weight of the machine. The exception is an experiment on dry sand, where the size of a large diagonal depends on the pressure in the tire, and small from the mass. Moreover, the increase in pressure leads to a decrease in the size of the large diagonal, and the increase in mass to increase the small diagonal, the depth of the imprint during the experiment on dry sand and in the mode of unidentified movement when moving on dry sand depends on the mutual influence of mass and pressure, leading to a decrease in the depth of the imprint.

Table 3 *Regression Equations for Different Versions of experiment - A*

No	Option for the experiment	Regression equation for contact spot
		Large diagonal of the ellipse

1	*Dry sand*	a = 14,85 – 0,84 x_1 + 0,91 x_2
2		a = 18,49 – 1,00 x_1
3		a = 17,96 – 1,14 x_1
		Small diagonal of the ellipse
1	*Dry sand*	b = 7,80 + 0,45 x_2
2		b= 8,60 + 0,33 x_2
3		b = 8,80 + 0,49 x_2
		Print depth
1	*Dry sand*	H = 1,49 + 0,28 x_2
2		H= 3,52 – 0,48 x_1x_2
3		H = 3,28 – 0,44 x_1x_2

When moving on wet sand, the depth of the print does not depend on changes in mass and pressure parameters, but only on the condition of the road. On wet sand in acceleration mode it is twice as high as at rest and braking, which is confirmed by the practice of driving cars when touching them from the place.

As a result of the tests conducted to select rational pressure, the equations of regression of distributions of normal pressures by the area of contact of the wheels of the vehicle under study with the supporting surface at different internal air pressures in the tyres have been obtained. The nomogram sections obtained allow a selection of rational parameters of the pneumo-wheeled engine.

The technique can be used in solving issues of forecasting the performance of cars being developed, improving the mobility of cars by rationally selecting the parameters of their wheeled engines with internal cavities.

4. CONCLUSIONS

As a result of the research carried out in this work, the actual technical task is to develop and justify the new rational design of the pneum-wheeled engine. Theoretical, experimental studies and calculations of the author made it possible to improve the efficiency of operation of cars with pneumo wheels, expressed in the most complete implementation of their performance in any conditions.

Mathematical description of the process of tire deformation when driving on the supporting surface at the specified values of the structural and operational parameters of the air-engine allows to determine the changes in the tyre's support ability depending on the pressure in the tyre and load. The use of pneumatic cameras provides the ability of the car to move when the car's tyre is damaged.

The use of wheels with pneumatic cameras will increase the rate of autonomy, passability and security, which in turn significantly increases the mobility of cars in critical conditions with damage to the wheel engine and allows you to continue driving. On serial wheels with tires when they are damaged and there is no excessive air pressure in them the car on deformed soils can not move independently.

ACKNOWLEDGMENTS

DYNAMICS AND INTELLIGENT SYSTEMS OF THE RIGHT TO THE WORLD DYNAMICS AND INTELLIGENT SYSTEMS OF THE MANAGEMENT (Tires)

The solution method developed in the paper, based on free vortex design, involves the linking of meridional and blade-to-blade solutions. The method which employs a finite element techniques has been developed for determining the blade-to-blade flow of an incompressible non-viscous fluid through a rotating turbomachine blade row.

In accordance with Bauersfeld method, the design of impeller blades is performed in iterative manner by using relationships between velocity components and geometrical blade parameters. The applied procedure allows a very fast design of the blade of the hydrodynamic transmissions for the defined input data.

The presented method is shown in case of pump impeller blade, but with minor changes it can be used for the design of the turbine which is the second component of hydrodynamic torque converter.

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RELIABILITY AND VIABILITY OF THE VEHICLES IN THE CONTEXT OF THE FUTURE TECHNOLOGY - IoT

Marian Florin Mitroi [1]*

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RESEARCH ARTICLE

ABSTRACT: The multitude of high performance equipment, as well as modern technologies integrated in the structure of vehicles, have led to an important change in their area of viability. These changes also have effects on maintenance work. Due to sensitivity of the electronic equipment to environmental, temperature and working conditions, it is necessary to adopt effective solutions to protect them and maintain their state of operation. The major challenge among classic vehicles, but also hybrid or electric is the thermal management of this equipments. IoT is a strategic concept for the future of communications between the various functional systems of society, which will adapt and regulate vehicle traffic in relation to the environment. IoT technology will generate certain job opportunities for predictive vehicle maintenance.

The research is a subjective, well-documented analysis, based on which some appropriate measures are proposed for the future, regarding the maintenance process of vehicles. In this direction, the preventive nature of actions and the implementation of 5G / 6G technologies at a global level are pursued. Also, the implementation of hardware and software solutions in the structure of vehicles is considered. They aim to adapt the operation of vehicles to the optimal parameters, by applying preventive corrections.

KEY WORDS: reability, viability, IoT

Reliability and viability of the vehicles in the context of the future technology

POUZDANOST I ODRŽIVOST VOZILA U KONTEKST BUDUĆE TEHNOLOGIJE – IoT

[1] *Lyubov Sladkova1 Moscow, Russia. Russian University of Transport. Moscow, 9 Obraztsova Street, b. 9. 127994, rich.cat2012@yandex.ru *(Corresponding author)*

REZIME: Mnoštvo opreme visokih performansi, kao i moderne tehnologije integrisane u struktura vozila, doveli su do važne promene u njihovom području održivosti. Ove promene takođe imaju uticaja na poslove održavanja. Zbog osetljivosti elektronske opreme na životnu sredinu, temperaturu i radne uslove, neophodno je usvojiti efikasna rešenja za njihovu zaštitu i održavanje njihovog stanja rada. Glavni izazov među klasičnim vozilima, ali takođe i hibridnim ili električnim je termičko upravljanje ovom opremom. IoT je strateški koncept za budućnost komunikacije između različitih funkcionalnih sistema društva, koji će se prilagoditi i regulisati saobraćaj vozila u odnosu na životnu sredinu. IoT tehnologija će stvoriti određene mogućnosti za poslove za prediktivno održavanje vozila.

Istraživanje je subjektivna, dobro dokumentovana analiza, na osnovu koje se predlažu neke odgovarajuće mere za budućnost, a u vezi sa postupkom održavanja vozila. U ovom pravcu preventivna prirodna akcija je primena 5G / 6G tehnologija na globalnom nivou. Takođe, implementacija hardvera i razmatraju se softverska rešenja u strukturi vozila. Cilj im je prilagoditi rad vozila optimalnim parametarima, primenom preventivnih korekcija.

KLJUČNE REČI: izvodljivost, održivost,IoT

RELIABILITY AND VIABILITY OF THE VEHICLES IN THE CONTEXT OF THE FUTURE TECHNOLOGY - IOT

Marian Florin Mitroi

INTRODUCTION

Vehicles, regardless of the category to which they belong, have a certain period of operation within the parameters set by the manufacturer. This is determined by a number of factors: the driver's driving style, driving conditions, the environment and temperature in which the journeys are made, the quality of the parts and consumables. Maintaining the state of operation in normal parameters, is a mandatory condition of each owner, both for road safety and for the environment. In the context of the demands generated by ecological mobility, technological developments and also the evolution of data transmissions, various changes are needed so that maintenance processes ensure a high degree of vehicle viability.

Modern 5G / IoT data technologies are making their presence felt more and more in the automotive field, so strategies for raising the viability of vehicles are approached, but also for optimizing the maintenance process.

The paper is a cross-sectional and objective analysis of the road transport system. She highlights current vehicle maintenance methods in the context of future transport technologies and concepts. The proposed solutions are adapted to future eco-mobility conditions.

1. ECONOMIC CONSIDERATIONS REGARDING THE MAINTENANCE OF VEHICLES

Maintaining the technical and qualitative performance of vehicles is an imperative requirement established by technical regulations, but also by economic factors. The operation of vehicles without defects, a period as long as possible is directly related to the possibilities of the owner, to maintain or repair them, in case they have failed.

Economically speaking, maintenance processes are associated with the defects that occur. They are influenced by the operating conditions and the quality of the components used in the manufacturing process of the vehicle.

In other words, for the lifetime of the vehicle, until its cassation, there are different periods of operation, which are associated with certain conditions of the vehicle:

- initial - Defects that occur are due to hidden defects in the manufacturing process. They appear from the first requests.
- useful life (maturity) - Defects occur accidentally and can be sudden and / or total. They occur instantly and are generated by overload, which exceeds the permissible strength limits of the components. Not to be confused with those damages, which require periodic replacements due to wear.
- final (aging) - It is short or does not exist at all for many vehicles, because the moral wear that usually occurs before the appearance of this period, take them out of use. It is characterized by the rapid increase in the duration of failures, due to the pronounced wear of the vehicle.

Figure 1 shows the distribution of defects of a vehicle throughout the period of use.

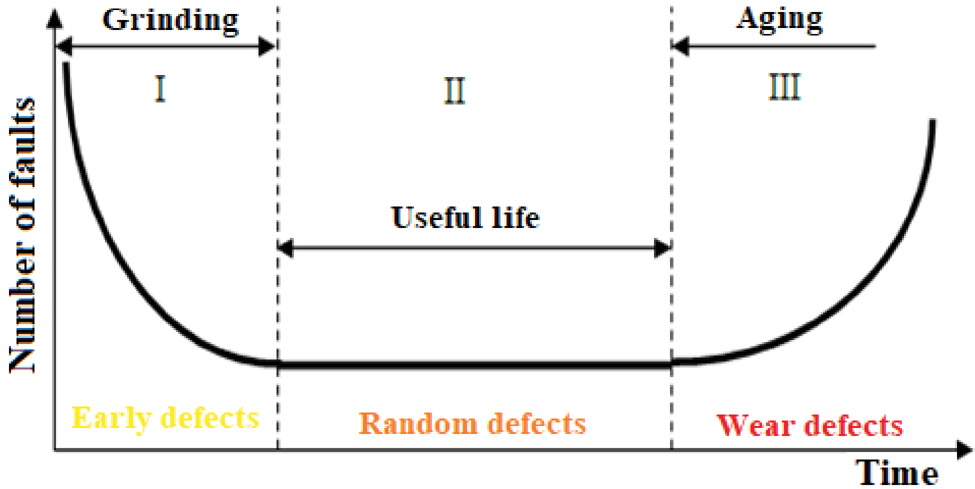

Figure 1 Distribution of vehicle defects in the unit of time

By definition, maintenance is, in general, the totality of operations through which reliability is performed and maintained. Therefore, we can say that, the maintainability of a vehicle during the period of operation is the property of being kept in working order or to be restored, to the state that ensures its normal working parameters.

The maintenance operation must be carried out in accordance with the rules and technical processes prescribed by the manufacturer. The entire maintenance process has implications for maintaining the reliability throughout the life of the vehicle. Taking into account the maintainability indicators of a vehicle, the economic diagram of its reliability can be drawn (Figure 2) [1].

The analysis of the diagram highlights the connection that is created between the different activities and conceptual processes, in order to maintain the safe operating condition of a vehicle. These generate complex action processes, which lead to the restoration of the normal functionality of the vehicle. Maintaining road safety and eco mobility are the main objectives of decision-makers and workers.

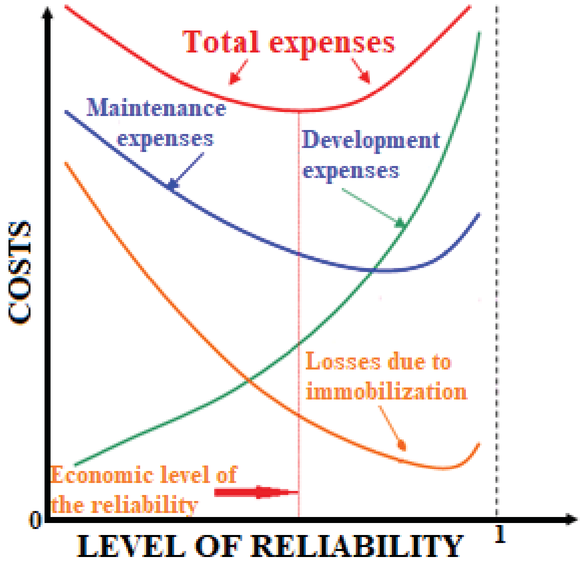

Figure 2 The economic level of reliability of the vehicle

2. VIABILITY AND RELIABILITY OF MECATRONIC SYSTEMS

2.1 Mechatronic Systems of Automobiles

The mechatronic equipment introduced in the structure of vehicles has become more and more numerous and complex. Currently, the level of development of the sensory capabilities of a mechatronic system is generally determined by the way in which it manages to perform recognition functions similar to those of humans. However, there are two major differences:

- man has multiple possibilities of recognition, being endowed with complex sense organs, which in a mechatronic system are neither necessary nor possible;
- a mechatronic system can be equipped with sensory facilities, which we do not find in humans (example: inductive, capacitive, fluid proximity sensors, or those investigation based on ultrasonic radiation or laser radiation etc).

Mechatronic systems must be able to identify, under certain conditions and limits, the working parameters and react to their changes. The electronic assistance of the steering, braking, suspension systems, as well as of the enginetransmission group are subject to an integrated control (management) concept so that the safety of the occupants and the goods, but also their comfort is at the highest possible level. This implies a permanent exchange of information and the possibility of combining system of conventional functions pre-established with some new ones, realizing a unitary system of management, control and command, called global management (integral). Its optimal operation can be achieved through a compromise between dynamic performance, security, comfort, pollutant emissions and economy of automobile. This compromise is in constantly changing, depending on the current intentions of the driver and the conditions of travel.

The analysis of the reliability of a mechatronic system can be performed at a structural level or at a global level.

1. At the structural level, when the structure of the system is known, a series of internal variables can be highlighted that determine its state (X).

$$\dot{X} = f_{(t,u,x)}, \qquad (1)$$

The input variables are the demands taken over by the system to perform the function (currents, voltages, pressures), as well as disturbing demands (electromagnetic interference, vibrations, temperatures, humidity). Thus, the output variables are assimilated to the performance of the equipment and its reliability.

2. Globally, the reliability of the system is described by the relationship created between the output vector and the input vector:

$$Y = A_{(u)}, \qquad (2)$$

If the system requirements are deterministic and controllable, the evolution of performance and total reliability are not predictable. Taking into account the structure of a vehicle and the complexity of its mechatronic systems, the analysis of reliability can be performed based on series and mixed. By observing the working method of the mechatronic elements, it can be appreciated that, the analysis of reliability based on mixed layout systems is the most relevant (Figure 3).

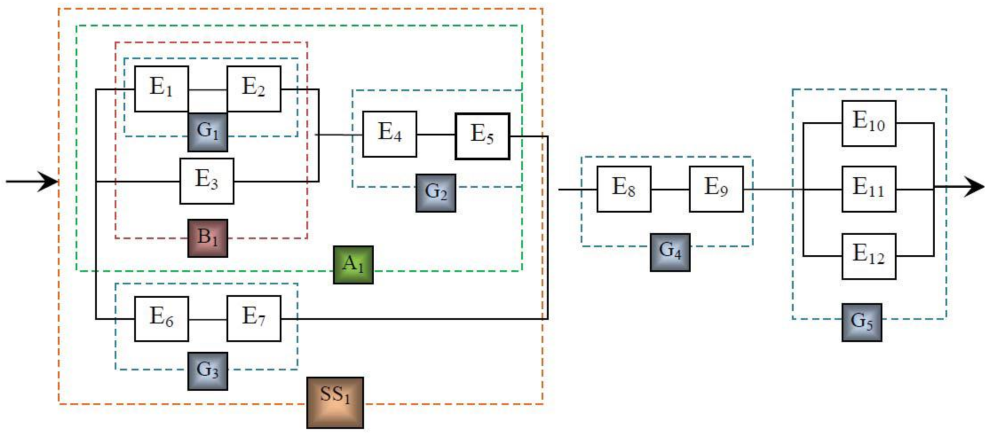

Figure 3 Scheme of vehicle reliability analysis based on the mixed connection of mechatronic equipment

E = equipment; G = group of components; B = control block; SS = subsystem

So it is determined by successive components, groups and subassemblies, reaching the establishment of the general level of the system and the vehicle.

2. 2 Viability and Reability of Automobiles

The increase of the technical level and complexity of the vehicles determined some operating characteristics such as reliability, maintainability, preservability to acquire a major importance, they being followed throughout the life cycle. The reliability of a vehicle is that characteristic that allows its safe use by the owner, for as long as possible, for the intended purpose (for which it was built). A number of concepts associated with reliability are known, such as:

- probability - is determined based on mathematical methods of statistics and probability, contains values of 0 and 1;
- function - involves the satisfaction of a required function (purpose);
- operating conditions - the set of conditions for which it was built (environment and use);
- operating time - involves a period of operation in conditions of maximum safety and security;
- characteristic - determined by the technical working characteristics (power, speed, etc.).

The reliability of vehicles is determined and inseparable from the maintenance process. She can be observed under two aspects: qualitative and quantitative [2]. By analyzing these characteristics, it can be stated that the availability of a vehicle represents its ability to fulfil its constructive purpose, for the established time interval, in terms of reliability and maintainability. So, its availability is higher the higher the reliability, and the lower the maintenance work and the better the quality. By analyzing those presented, as well as Figures 1 and 2, it can be established that, the availability of a vehicle is affected by:

- the probability of functioning without problems in a certain period of time;
- the probability of its failure and the restoration of working capacity, in safe conditions, in some a period oftime.

The availability of a vehicle is obtained by corroborating four characteristics: reliability, maintainability, modernization and conservation (Figure 4).

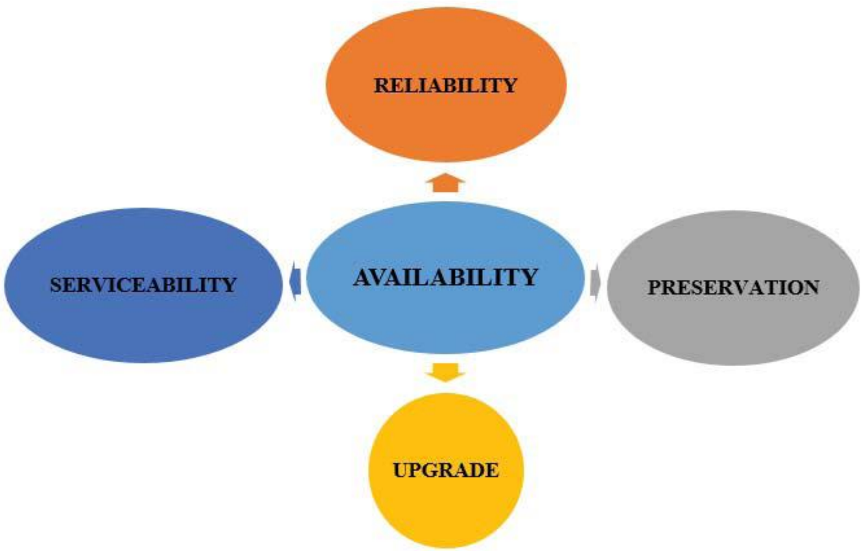

Figure 4 Characteristic elements of the availability and safety in operation of vehicles

The lifetime failure ratio of the vehicle is calculated with the relation:

$$\lambda_{(t)} = \lambda_{(p)} + \lambda_{(n)} + \lambda_{(c)}, \tag{3}$$

where: $\lambda_{(p)}$ = early failures; $\lambda_{(n)}$= accidental malfunctions; $\lambda_{(c)}$ = critical failures (period a-3a).

The frequency of failures is:

$$f(t_i) = \frac{k_i}{\sum_{i=1}^{n} k_i}, \quad (4)$$

where: i = calculated time interval.

Reliability is calculated with:

$$R_{(t)} = e^{-\int_0^t \lambda(t)dt} = e^{-\int_0^t \lambda\left[\lambda_{(p)}+\lambda_{(n)}+\lambda_{(c)}\right]dt}, \quad (5)$$

3. THE MAINTENANCE FACTOR IN THE 5G&IOT CONTEXT MAINTENANCE FACTOR IN THE CONTEXT OF 5G & IOT

The 5G communications will amplifying their presence in the technologies implemented on vehicles. Their advantages are undeniable. From safety and comfort, to the environment and mobility, these technologies bring economic and social benefits to citizens, cities and states. Their working possibilities are multiple. They bring major improvements to vehicle safety systems, as well as facilities to road traffic monitoring systems. The multitude of data and information received-analysed and transmitted from sensors to control units and actuators are crucial in the operation of vehicles and the achievement of a safe, fluent and ecological traffic. Essential data is sent to the cloud, processed and retransmitted to various end stations, which ensures a good traffic flow and safe. At the cloud level, flexibility and proper management are needed to be able to manage the flow of data locally, which is related to traffic safety and the operational needs of vehicles. The development of the most automated solutions among the vehicles, determines that the technical infrastructure systems can ensure, filter and manage the essential information from the traffic. The ability of these systems to process different vehicle-specific applications at the same time is crucial, with a multitude of users in parallel (Figure 5). These characteristics require exemplary concordance and lead to a high

The research aims to implement hardware and software solutions, adapted to new technologies, so as to ensure a fast and efficient maintenance process. This is achieved through a unitary and integrated conception of action of the responsible factors, as well as through the efficiency of service activities. Figure 6 shows the scheme of dependence of the process of maintenance of vehicles, on related services.

Vehicles maintenance will permanently require an optimization of solutions for predictability of mechatronic systems operation. She must include sensors and high-performance software, but also adequate connectivity system. Any mechatronic system works based on working parameters. The interconnection of data from various sensors of these systems, can highlight the functional anomalies of the vehicle's equipment (systems). The use of appropriate software can predict the malfunction of a system, or the time left until maintenance operations.

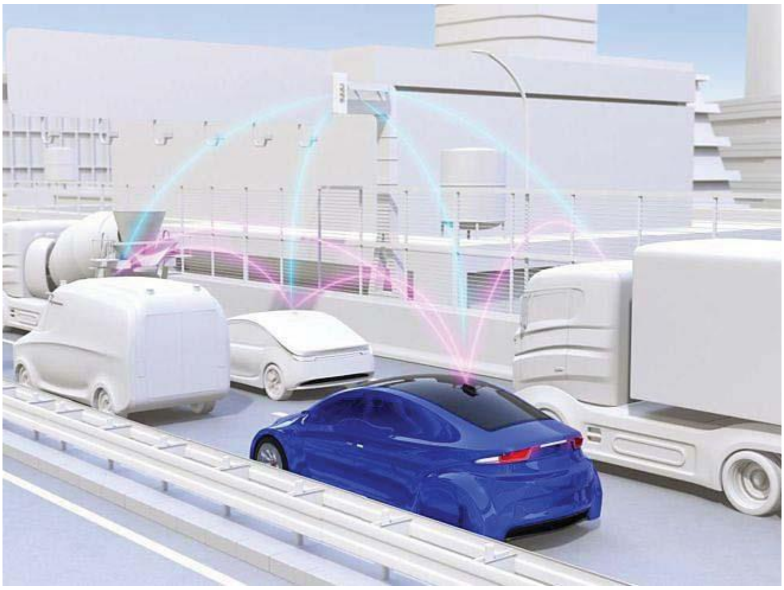

Figure 5 The way of communications in IoT era

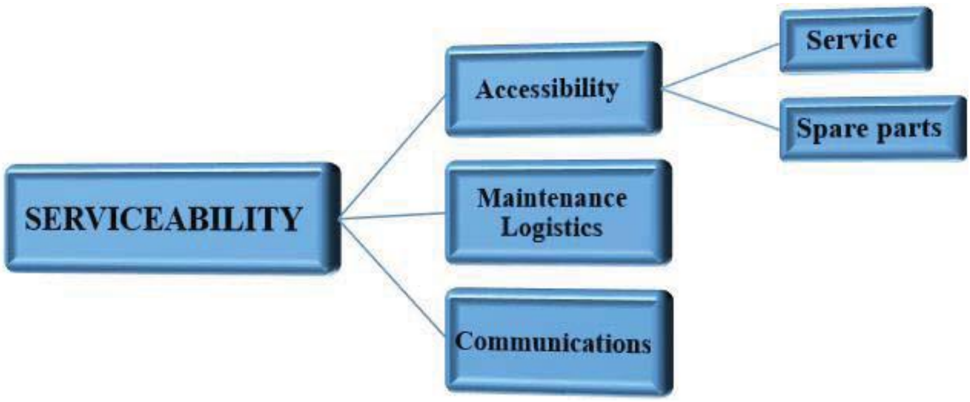

Figure 6 The factors that influencing the maintenance process

The analysis of the presented scheme shows that, the communication system is of major importance. It ensures through the software, the correlation of the information generated by the vehicle with the traffic monitoring and management system and from here with the technical assistance services (Figure 8). The companies specialized in providing maintenance services connected to satellite / cloud, will have at their disposal data regarding the dynamics of the vehicle that requires intervention, as well as data regarding the engine condition parameters and the malfunction situation. Thus, they will know its position, the level of failures, the time and the possibilities of intervention.

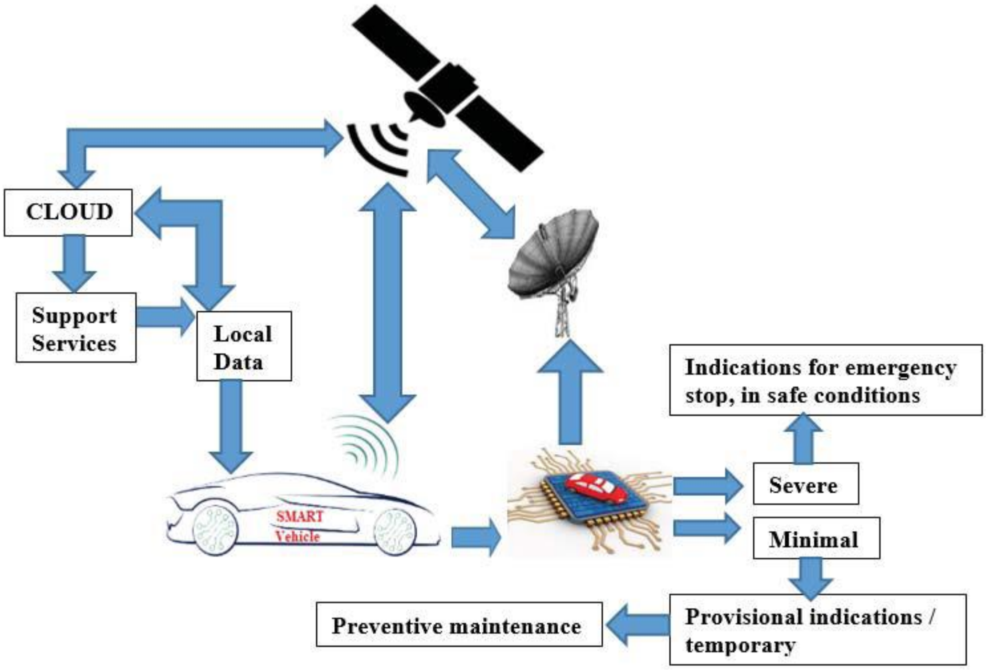

Figure 7 Block diagram with the proposed maintenance strategy for vehicles

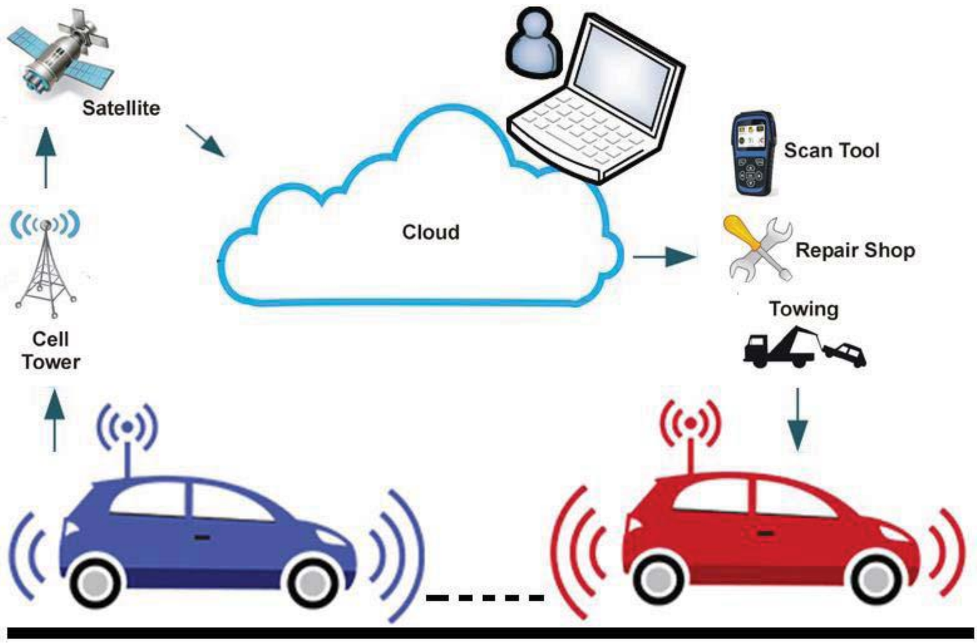

Figure 8 The strategy for maintenance

The information is analyzed and managed according to its importance, and then the answers are transmitted accordingly. Data transmission is performed over short distances (V2V, V2X), but also over long distances (V2C, V2S) – Figure 9. Therefore, there will be simple information processing (data comparisons) as well as complex (integrations, differentiations, mediations, etc.). This will require in high computing power for all systems involved in the traffic process. Progress cannot be achieved without information technology - software.

Figure 9 Show how vehicles interact with each other (V2V) and with the environment (V2X)

Considering the fact that, the evolutions in the field of electronics (microprocessors) and computer applications are very fast, we can appreciate that, for mechatronic systems can be developed other applications with / and other performances . Due to these factors, in the not too distant future, vehicles will become integrated structures of digital life.

The mechatronic command and control systems to be implemented will be able to ensure a safe travel with a high level of comfort, for all vehicles. The vehicle displacement management applications such as ADAS, LIDAR require highly developed system architectures, to increase vehicle performance and safety requirements. Also, in the context of IoT and AI, advanced computing solutions are needed, which to raise the level of data processing, improving algorithms and workflows. Thus, in terms of traffic flow and road safety, vehicles will influence each other and collisions between vehicles will no longer exist. The assistance and emergency services will react in a very short time, promptly, with appropriate solutions to the situation created. They will be able to provide real and accurate data on the evolution of the vehicle itself, as well as about the traffic, to integrated monitoring systems and in the cloud. With the implementation of these technologies, the level of road accident prevention, traffic efficiency increases, but also the level of pollution in the cities will also be reduced. As such, predictability solutions will have a major and positive influence on vehicles safety.

Looking ahead, it must be understood the fact that, the strategies adopted for the development of motor vehicles, infrastructure and road traffic need to work perfectly together. The traffic concepts developed must take into account the requirements of climate protection and air quality at city and country level. New directions, such as electro mobility, are also needed. This must be implemented by adopting renewable energy sources (wind, solar).

The intelligent connection of vehicles with the infrastructure and the service environment is the key to a sustainable and efficient development.

4. CONCLUSIONS

Vehicle reliability is a performance feature as well as a marketing parameter.

The modern car is one of the representative mechatronic products and an example of software integration of mechanical, electronic and computer components. Mechatronic equipment for vehicles will largely depend on the performance of the information and communication systems used. The implementation of mechatronics at the highest level aims to increase the operational safety of cars by over 30% compared to the present, as well as to streamline traffic by more than 25%.

The proposed work strategy, for the transmission of information to and from the vehicle, is a viable approach, but also a starting point for new solutions. The solution aims to streamline the maintenance of vehicles, by identifying a new opportunities to address work actions by service company teams. Vehicle to vehicle and vehicle to infrastructure communication will generate much higher road safety; reduce the number of accidents and road casualties. It will also allow, at the same time, the management and dynamic control of traffic in congested cities, as well as greener transport.

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