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THE ASSESSMENT OF ACOUSTIC EFFECTS OF EXPLOITED ROAD VEHICLES WITH THE USE OF SUBJECTIVE FEATURES OF SOUND

OCENA EFEKTÓW AKUSTYCZNYCH EKSPLOATOWANYCH POJAZDÓW DROGOWYCH Z WYKORZYSTANIEM SUBIEKTYWNYCH CECH DŹWIĘKU*

The article proposed an original way to assess the acoustic effects of road vehicles in the environment, with the use of selected methods of sound modeling and simulation. The taken solution presents a way of estimating the acoustic emission to the environment, from the exploited road vehicles, using subjective sound features. In ongoing studies, it is assumed to analyze and evaluate the sound features in the following order: source - propagation way - receiver. The distribution of these features in the time and frequency domains depends on generation, propagation and immission of acoustic energy, by the partial sources of the vehicle. The obtained information in the form of an acoustic signal can be represented by physical and subjective features of the sound. The undertaken research include the use of subjective features of sound in the assessment of acoustic effects of road vehicles exploited in the environment. The developed method was verified using modeling and simulation methods based on recorded acoustic signals in an urbanized environment.

Keywords: *acoustic effect, sound features, road vehicles, modeling, vibroacoustics.*

W artykule zaproponowano oryginalny sposób oceny efektów akustycznych pojazdów drogowych w środowisku, z zastosowaniem wybranych metod modelowania i symulacji dźwięku. Podejmowane rozwiązanie przedstawia sposób oszacowania emisji akustycznej do środowiska od eksploatowanych pojazdów drogowych przy wykorzystaniu subiektywnych cech dźwięku. W realizowanych badaniach zakłada się analizę i ocenę cech dźwięku w układzie: źródło-droga propagacji-odbiornik. Rozkład tych cech w dziedzinie czasu i częstotliwości uzależniony jest od generowania, propagacji i immisji energii akustycznej przez źródła cząstkowe pojazdu. Otrzymana informacja w postaci sygnału akustycznego reprezentowana może być cechami fizycznymi i cechami subiektywnymi dźwięku. Podejmowane badania obejmują sposób wykorzystania subiektywnych cech dźwięku w ocenie efektów akustycznych eksploatowanych pojazdów drogowych w środowisku. Opracowany sposób zweryfikowany został za pomocą metod modelowania i symulacji na podstawie zarejestrowanych sygnałów akustycznych w środowisku zurbanizowanym.

Słowa kluczowe: *efekt akustyczny, cechy dźwięku, pojazdy drogowe, modelowanie, wibroakustyka.*

1. Introduction

Vibroacoustic processes belong to the destructive residual processes of exploited technical objects [1]. In many cases, the emission/propagation phenomena of vibrations and noise of machines and devices are analyzed together.

Depending on the research objective and regardless of the type of phenomena, vibroacoustic signals are widely used in the tasks of diagnosing, reliability and condition assessment of the exploited technical objects. They are also important information in assessing the impact of a technical object on the environment. Reduction of sources of this energy often is the effect of recognizing and assessing the generation of vibroacoustic energy to the environment. In realized tasks of the impact of the exploited technical objects on the environment it is based on the physical features of the signal. For this purpose, there are applied methods of identifying sources of vibroacoustic processes, assessment of technical condition, damage analysis of individual components or the whole technical object, e.g. intensity methods, reciprocity methods, the falk transformation [1, 3]. However, these methods do not take into account the subjective assessment of the vibroacoustic impact of the technical object on the environment.

The vibroacoustic processes occurring during the exploitation of road vehicles are multi-source effects of the object on the environment. The results of this impact may be considered in relation to the

sources and effects, that cause a certain condition of noise pollution. Research in this area focuses primarily on the use of physical features. Within tasks carried out in this area, there are used acoustic measurements, as well as sound modeling and simulation methods. The result of the acoustic evaluation obtained in this approach is represented is the energy indicator at a given point, or its spatial distribution in the modeled environment [4, 19]. The results of the undertaken research, in the field of developing road noise assessment in the external environment, indicate clearly that the expression of this assessment with noise indicators is limited and insufficient. It is stated, that significant impact on the subjective assessment of noise has, among others the time structure of the signal, or the distribution of subjective features in the domain of time and frequency [6, 18].

In the article, there is proposed a way of assessing the acoustic effects of road vehicles to rely on obtaining information from physical and subjective sound representation in the environment.

2. Sources of emissions of vibroacoustic energy in the exploitation of road vehicles

Conducted commonly research on exploitation processes of technical objects are most frequently focused on the assessment of the object itself or its environment. For this purpose, are used the advanced methods, e.g. [7, 9, 12, 13, 14].

Exploited transport devices as technical objects belong to complex sources of emission of vibrations and noise to the environment. In the research problem being undertaken, analysis and assessment of signal features refers to distant acoustic field, in which there is usually a significant distance from the source of vibroacoustic energy to the recipient. With this assumption, the acoustic energy in the form of a signal reaches the recipient as a result of the emission of vibroacoustic sources of the vehicle and parts transmitting vibrations of the vehicle.

The main sources of noise in vehicles, which have an impact on its emission to the environment, have been identified on the basis of literature research [10]. The emission of these sources in various numbers and intensities significantly influences shaping the acoustic climate of the environment. Existing processes of generation and propagation of acoustic effects of road vehicles are very complex. Generating acoustic effects depends on many factors, including:
- traffic intensity,
- vehicle traffic speed,
- traffic structure (the number of light and heavy vehicles),
- type of road surface,
- roadway temperature,
- condition of roadway (dry or wet).

The following factors influence the propagation of acoustic effects of road vehicles:
- the type of ground surface between the source and the observation point,
- temperature and humidity of the air,
- temperature distribution over the surface,
- obstacles on the way of propagation,
- the geometry of the source-observation point.

In the process of generating acoustic effects of a moving vehicle, there are distinguished partial sources. The main sources of noise emission from the vehicle to the environment can be included: the drive unit, the contact area of the wheels with the road surface and the irregularities of the air flow around the car [8]. In particular, the acoustic effects of the drive system result from the work of the following systems and components:
- engine,
- gearbox,
- exhaust system,
- air conditioning system.

Sources of acoustic effects caused by the interaction of the car's wheels and the road surface depend on:
- type of road surface,
- type of tires,
- tire impacts on the road surface, as a result of surface irregularities.

It should be noted, that at the speed of passenger vehicles greater than 40-50 km/h and truck speeds greater than 60-70 km/h, the main component of the vehicle's total noise is the noise generated at the interface between the tire and the surface [5]. With the increase in speed, rolling noise begins to dominate.

The vibroacoustic effects, induced by the vehicle body, depend mainly on the quality of materials, connections of parts and clearances (related to the vehicle class) and on the exploitation wear. These effects worsen when driving over uneven surfaces and driving at high engine rotate speeds. In some cases, vibroacoustic effects may also occur during downtime, while the engine is idling (resonance vibrations of parts).

Generating vibroacoustic energy from the engine, transmission and chassis is also carried by through the vehicle body. Generally, acoustic effects reaching the recipient are a superposition of the acoustic background and noise of vehicles traffic, which includes the

phenomena occurring at the contact between tire-surface, as well as within the vehicle's power unit. The level of noise emitted by moving vehicles in road traffic is the resultant of engine and exhaust noise, aerodynamic noise and tire/road interaction noise. Analyzing the noise source in such an arrangement, it must be noted that the noise of the engine and exhaust system depends on the type of vehicle and engine rotate speed. On the other hand, the noise of the tire/road depends on the type of tire, the type of surface and the type of vehicle and its speed. With the increase of the driving speed, there increases the share of noise at the contact between the tire and the road in the total noise emission of the vehicle and at high vehicle speed can become dominant.

Within realized SVEN project, road noise measurements using "artificial head" were applied. Virtual listener position has been determined in relation to the vehicle (i.e. without a transfer function depended on the location and without the Doppler effect). The obtained simulation results showed that the noise of the tires, especially the sounds of the "front wheel" and "rear wheel" were dominant. The impact of the exhaust pipe and inlet was significant at low frequencies, the engine influence was insignificant [20].

3. Review of research on the noise assessment of road vehicles in the environment

The acoustic effects from road noise include noise coming from the vehicle's partial sources, phenomena accompanying the propagation of acoustic waves and many other factors, including: geometry and cross-section of the road, traffic parameters and conditions, vehicle speed, road surface features, type and the shape of the environment, weather conditions.

3.1. The assessment of physical sound features

The directive [4] relating to the assessment and management of noise in the environment indicates, among others, on the term of noise in the environment, which is defined as unwanted or harmful sounds caused by human activities in the open air, including noise emitted by transport devices, road traffic, rail traffic, aircraft traffic and noise originating from industrial activity.

In the noise assessment, there are used accordingly noise indicators, that apply to conduct the long-term environmental protection policy against noise (L_{DWN}, L_N) and to establish and control the conditions of use of the environment in relation to one day (L_{Aeq}, L_{AeqN}) [19]. In the applied assessment and management of noise in the environment, a physical approach is implemented, in accordance with national legal regulations [21]. Depending on the needs, classical energy indicators are used to assess external noise (descriptors), such as L_{Aeq} or L_{DWN}. These indicators inform about the total sound level, giving an average value of acoustic events evaluation, regardless of the temporal structure of the acoustic signal. In addition it should be noted, that the obligatory requirements in this regard, respond to the use of energy indicators only in the time domain and omit many important sound information in the frequency domain. An equivalent level, also known as an equivalent, is the most widespread indicator of noise assessment with varying levels over time. The idea of this indicator is to determine the average level of the sound pressure (at the time considered).

In studies of environmental noise, there are used equivalent continuous sound levels L_{Aeq} and its statistical levels L_{10}, L_{50} i L_{90} emitted by road traffic. There are also made attempts on the application of mathematical models in the estimation of road noise level. Research on the application of mathematical models takes into account the functions of vehicle flow along with the estimation of heavy vehicles [2]. As part of the research, in the area of physical assessment of acoustic effects of road vehicles moving on the motorway, it was proposed beyond measure L_{Aeq} additionally statistical measures of sound levels

(quasi-maximum), ie. L_{10}, L_{90}. The results obtained from the proposed models in the calculation of levels L_{Aeq} and L_{10} were more accurate than the results obtained from the models for the calculation of L_{90}. It should be noted that during measurements, vehicle flows were not continuous, which meant that the impact of other noise sources was higher on L_{90}, than on L_{10} and L_{Aeq} [2].

In the case of road noise, there is often a time variation noise events. This means, that information about the signal features can be searched in the amplitude-frequency spectrum of the acoustic signal [11].

3.2. The assessment of subjective sound features

Taking into account the perception of sound, in the issues of assessing the acoustic effects of noise sources, extends significantly the assessment method, currently used, for listening experience. Sound perception in the frequency domain includes hearing experiences, i.e. the height and timbre of the sound. The timbre is connected in a complex way with various physical parameters and includes subjective features individually perceived, i.e. sound sharpness, sound roughness, fluctuation strength, tonality [22]. The common feature of the sound, which in various ways influences on mentioned above is loudness.

The confirmed results of the research on the assessment of human hearing experiences in the range of received sounds prove, that the highest sensitivity is for the medium frequencies 500-5000 Hz (hearing curves). In addition, these results indicate significantly the occurrence of frequency variation of hearing experiences of sounds, in the area of audibility, in relation to the sound level value [14]. For the purpose of subjective noise assessment, nonlinear dependence of the loudness variation in the frequency domain is used.

In relation to the above, the loudness is taken into account, as the basic subjective feature of the sound describing the listening experience. It is a function of variables of acoustic stimulus (i.e. the level of sound pressure, frequency, bandwidth, spectral structure of the stimulus, its duration, etc.) and also variables of the recipient. It should be noted, that the loudness has the greatest impact on the noise annoyance, among all the subjective features of the sound.

Unfavorable effect of acoustic effects of the road vehicles exploited in the environment can be treated in the category of noise annoyance, too. In particular, the directive [4] introduced common noise indicators, i.e. common index L_{DWN} for the general assessment of annoyance and L_N for the assessment of sleep disturbance.

In work [18], it was examined, how the time change of the structure of road traffic influences the assessment of noise annoyance. Different grades of annoyance for the same L_{Aeq} were obtained, which was due to the varying average percentile of loudness in sons (N_{10} or N_5). It was found, that the average loudness N better correlates with the annoyance, than the percentile of the loudness N_5. In this approach, it was assumed that different annoyance is caused by different loudness (N_{10} or N_5), at the same L_{Aeq}. Four traffic noise structures were tested, for which acoustic signals from recordings were assessed by respondents in laboratory conditions.

As part of my own research [15], the task consisted of finding relationships between noise indicators and subjective features of sound for the purpose of assessing traffic noise annoyance. The obtained results showed, that there is a strong correlation between the loudness, and L_{Aeq}. However, this correlation did not take into account the statistical loudness, i.e. N_5, N_{10} - as Zwicker suggests. In addition, the results of the distribution of subjective features, expressed in the Bark scale, can be useful in the impressions assessing tasks, caused by the type of road surface, especially if the surface differs in texture. There were observed the sound tone changes, which were noticeable in the distribution of sound roughness and sharpness.

In another approach of own research, it was proposed modeling of traffic noise risk assessment, using information from: spatial distributions of features of objects in the environment, noise indicators and psychoacoustic tests of residents. Based on the obtained results of spatial distributions of objects features, L_{Aeq} and information obtained from psychoacoustic tests, there was applied a neural network method in the modeling of the noise risk assessment [17].

The expression proposed in [22] as a psychoacoustic annoyance (PA) is a combination of loudness (N_5), fluctuation strength (F) and roughness, with respect to sharpness (S):

$$PA = N_5(1 + \sqrt{w_s^2 + w_{FR}^2})\qquad(1)$$

for S>1.75

$$w_s = (S - 1.75) \cdot 0.25 \lg(N_5 + 10)\qquad(2)$$

S≤ for 1.75

$$w_s = (S - 1.75) \cdot 0.25 \lg(N_5 + 10)\qquad(3)$$

$$w_{FR} = \frac{2.18}{N_5^{0.4}}(0.4F + 0.6R)\qquad(4)$$

The use of the psychoacoustic annoyance model (1), as part of own research, did not confirm the results obtained from noise annoyance assessments in laboratory conditions. There were divergences between the results of the use of the above model and received assessments, in different classes of values L_{eqA} of played acoustic signals of road noise sources.

Obtained noise annoyance assessment results have a satisfactory level as a result of using the neural network model for this task [16].

4. The way of assessing the acoustic effects of road vehicles using the subjective features of sound

The dynamic nature of the impact of noise sources of a road vehicle, subjective aspect of the location of perception of sounds, as well as the multiplicity of factors accompanying this process cause, that despite many attempts in this area, there has not been developed any universal assessment model, which would take into account a wide spectrum of generating acoustic effects. The assessment models used in this area do not take into account the coexistence of many variables (factors) of a physical and subjective nature and interactions between them. In particular, the complexity of processes related to the emission and propagation of the acoustic effects of sources, psychophysical aspects accompanying the perception of sound and the occurrence of non-acoustic factors significantly complicate the development of a standardized assessment model.

Developed for many years, research on a holistic approach to assessing the acoustic environment concerns the possibilities of soundscape mapping. They are based on simultaneous consideration of the physical and perceptual aspects of sound sources in the environment. They extend the approach to the mapping of noise, they allow to take into account the context of the sound perception for areas of various purposes, e.g. recreational, residential, commercial centers. For the needs of acquiring from residents information on the perception of different types of sounds, there are used surveys for the assessment of sounds, among others, road noise. In the attempts made in this field, there is a lack of a standard method of noise annoyance assessment in acoustic maps, which would take into account the direct relationship between physical and psychoacoustic sound features.

The results of undertaken research on the assessment of the subjective sound features distribution in the frequency domain in the external

environment, exhibit diverse and non-linear variation, as a function of distance from the source [6]. In addition, there is a lack of a known mathematical formula of the model describing the shaping of the variation distribution of these features in the external environment.

The method of assessing acoustic effects developed by the author assumes the combined use of sound evaluation methods, i.e.:
- physical,
- subjective.

It was assumed, that physical evaluation of acoustic effects will be carried out using sound modeling and simulation methods, as part of applied acoustic maps. As part of the subjective assessment of these effects, it was proposed to determine the subjective features of the sound for the resolution of 1/2 bark from the acoustic signal, using software *Pulse Reflex 21.0.0.567*. It should be noted, that these features refer to critical bands and include the masking sound phenomena. The developed assessment method has been verified by acoustic tests in an environment of noise from vehicles.

4.1. Modeling of physical sound features

In order to assess the acoustic effects from road sources for a selected urbanized area, it was carried out the simulation analysis of the distribution of the assessment index L_{Aeq}, with using acoustic maps. Based on the information obtained from the environment, the terrain model was modeled along with the object models. The input data for the simulation were the values of the measured intensity of vehicles together with the share of trucks, for each lane within 1 hour in daytime. Acoustic measurements were carried out simultaneously at all measuring points, among others in order to ensure the same conditions for the structure and intensity of vehicle traffic.

In the simulation of the sound level of traffic noise, there was applied calculation method recommended by the noise directive [4] according to the French standard XPS 31-133.

At the same time, for the calibration of the model, there were carried out acoustic measurements L_{Aeq} with using the measurer SVAN 971, at three representative reference points P1, P2, P3, corresponding to the traffic measurement locations (Fig. 1.).
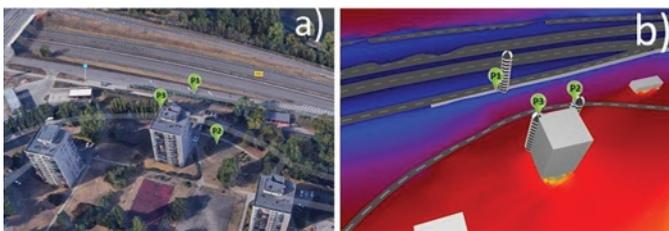
Fig. 1. Illustrations of the examined area: a) the photo with the measuring points, b) a part of the acoustic map of the distribution L_{Aeq} with the measuring points

There were some acoustic variables associated with the measurement location points, related, among others, with:
- distances between the source and the measuring points,
- occurring, near the measuring points, natural objects and environmental infrastructure facilities (i.e. acoustic screen P1, residential building P3, tree stands P2), which were potential surfaces of generating wave phenomena. It should be noted that point P2 was significantly lower located, i.e. approx. 1.5 [m] compared to point P1, due to the natural terrain.

Applicable methods of modeling and simulation of sound distribution in the external environment allow, among others on the assessment from direct and reflected waves. For this purpose, variant solutions have been developed for which the following assumptions of object modeling were made, i.e.:
- Variant no. 1 - real sound absorption coefficients were assigned to object models,
- Variant no. 2 – the same value of the sound absorption coefficient α=1 was assigned to the modeled objects,
- Variant no. 3 - the same value of the sound absorption coefficient α=0 was assigned to the modeled objects.

In the tab.1 there was presented information on the determined measurement points, in relation to the established variants.

Table 1. A summary of information about measuring points

Point number	The height of the point above the ground/measured value L_{Aeq}	Variant no.1 (L_{Aeq})	Variant no.2 (L_{Aeq})	Variant no.3 (L_{Aeq})
P1	1,7 [m]	78,4[dB(A)]	78,2[dB(A)]	79,2[dB(A)]
	77,1[dB(A)]			
P2	1,7 [m]	61,7[dB(A)]	59,5[dB(A)]	68,5[dB(A)]
	58,4[dB(A)]			
P3	27 [m]	71,5[dB(A)]	71,4[dB(A)]	72,2[dB(A)]
	71,2[dB(A)]			

Based on the prepared variants, in modeled reference points, there was obtained information on the distribution of acoustic energy to direct and reflective sounds. Information about acoustic energy from direct sounds gives the opportunity to estimate the generated acoustic effects, from traffic emission sources. From the values presented in tab. 1 follows, that:
- in the designated reference points, there were slight differences between the measured and simulated values,
- for particular variants, there were slight differences between the measured and simulated values in the reference points (P1) and (P3),
- for the variant no.3, in the reference point (P2) There was a significant difference between measured and simulated values (i.e. for the establish of an „ideal" reflection of sound waves from the modeled surfaces of objects). This difference may result from the strengthening of reflections from the modeled building surfaces.

According to the author, a large variation between measured and simulated values L_{Aeq} (for variant no.3) in the point (P2), it results mainly from the location of this point relative to noise sources. Occurring at this point for variant no.1, slight exceeding simulated values in relation to the measured ones, lies within the range of acceptable error, which can occur in the modeling of similar source-receiver systems.

4.2. Analysis of the subjective features of sound

In the examined points (P1)-(P3) audio acoustic signals have been recorded (one channel) with a duration of 20 minutes, except measurement L_{Aeq}. For recorded samples, a time and frequency analyzes of the L_{Aeq} value distribution was carried out. A sample distribution L_{Aeq} at the point (P3) are shown in (Fig. 2), corresponding for time and frequency domains.

a)

b)
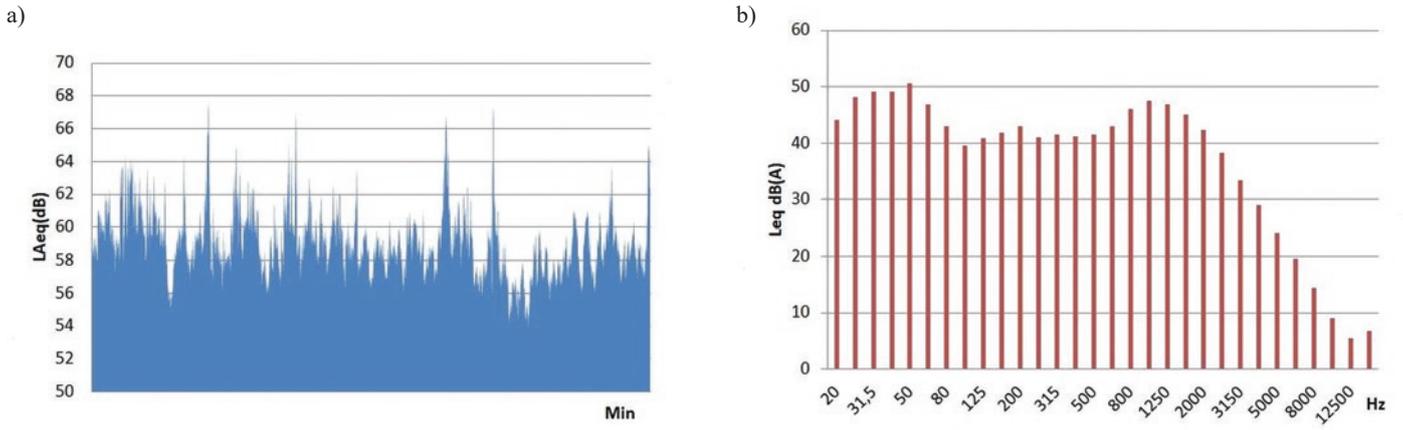
Fig. 2. Distribution L_{Aeq} at the point P3: a) a time domain, b) a frequency domain.

a)

b)
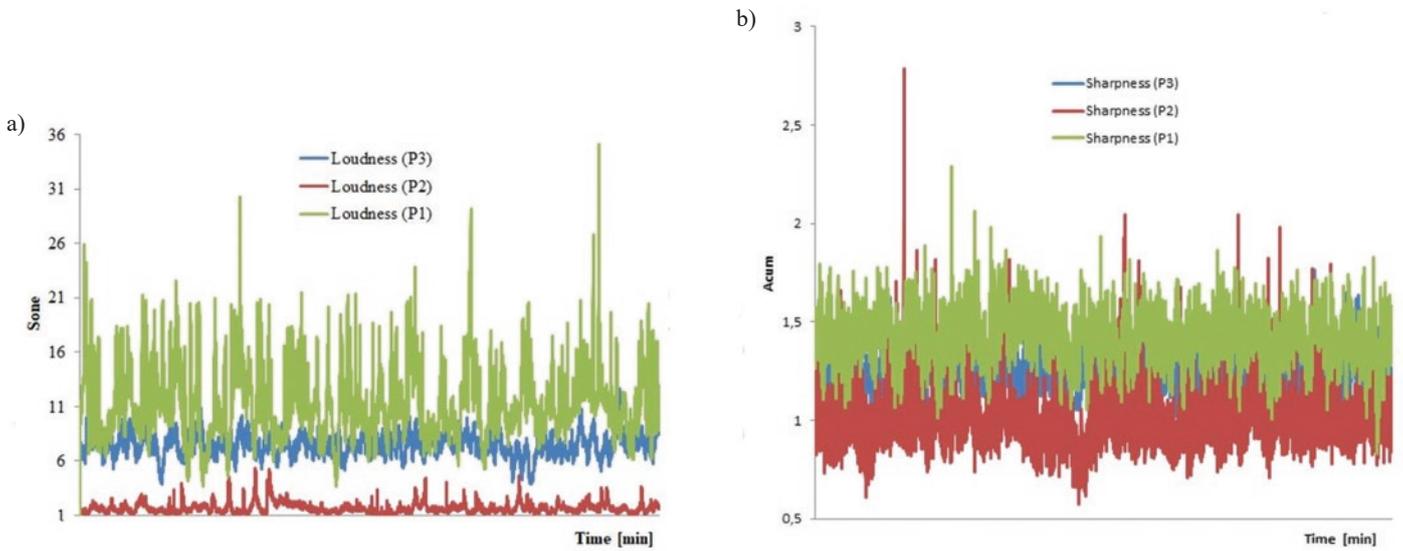
Fig. 3. The distributions in time domain of the sound loudness and sharpness in the tested points

a)

b)
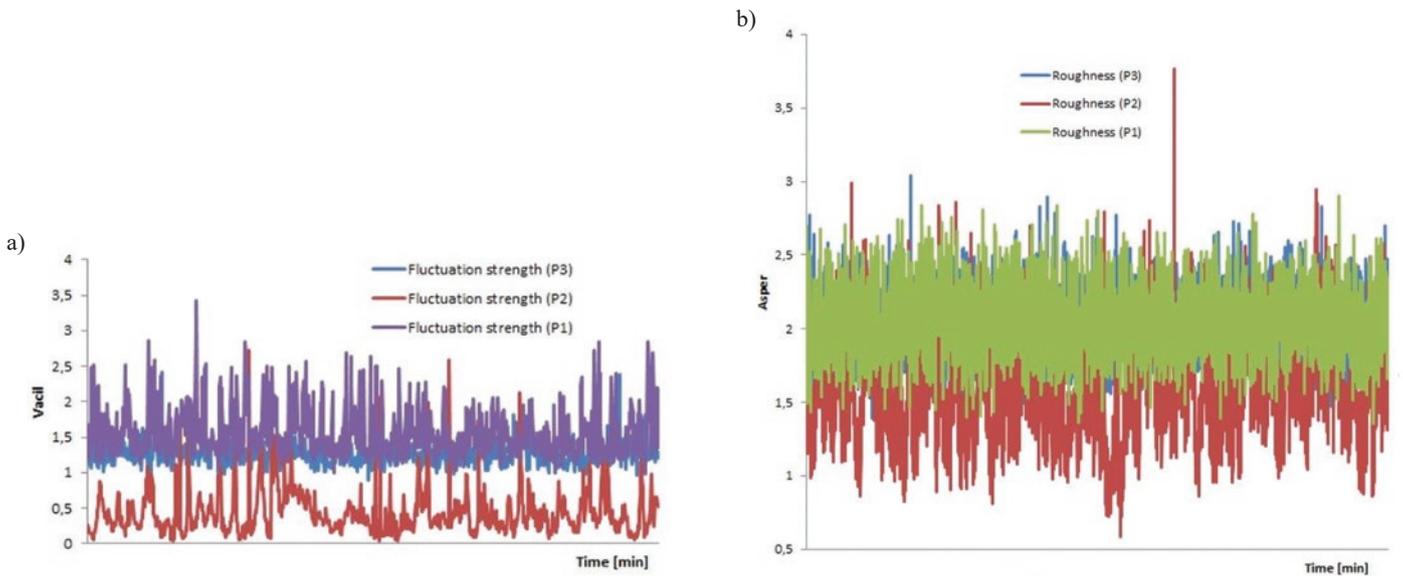
Fig. 4. The distributions in time domain of the sound roughness and fluctuation strength in the tested points

The analysis of registered acoustic signals enables the assessment of distribution of the subjective sound features in the time and frequency domains. Applying a correction filter (A) in the spectral distri-

bution L_{Aeq} allows to assess the physical features of an acoustic signal, with consider hearing curves. Accordingly, the physical assessment of the acoustic effects of sound sources takes into account the influence

a)

b)
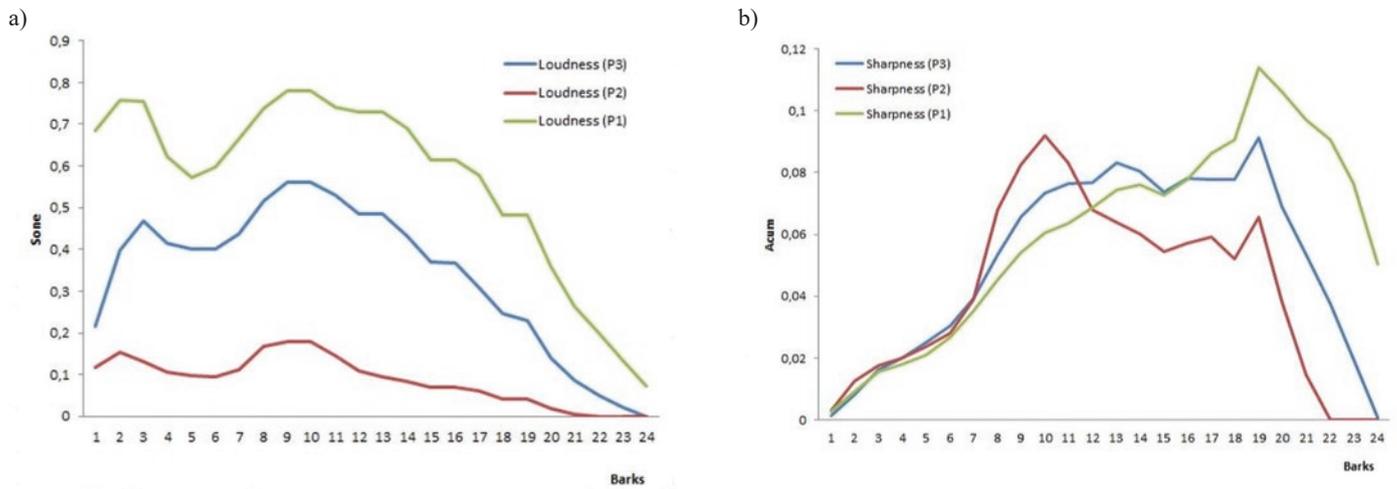
Fig. 5 The distributions in frequency domain of the sound loudness and sharpness in the tested points

a)

b)
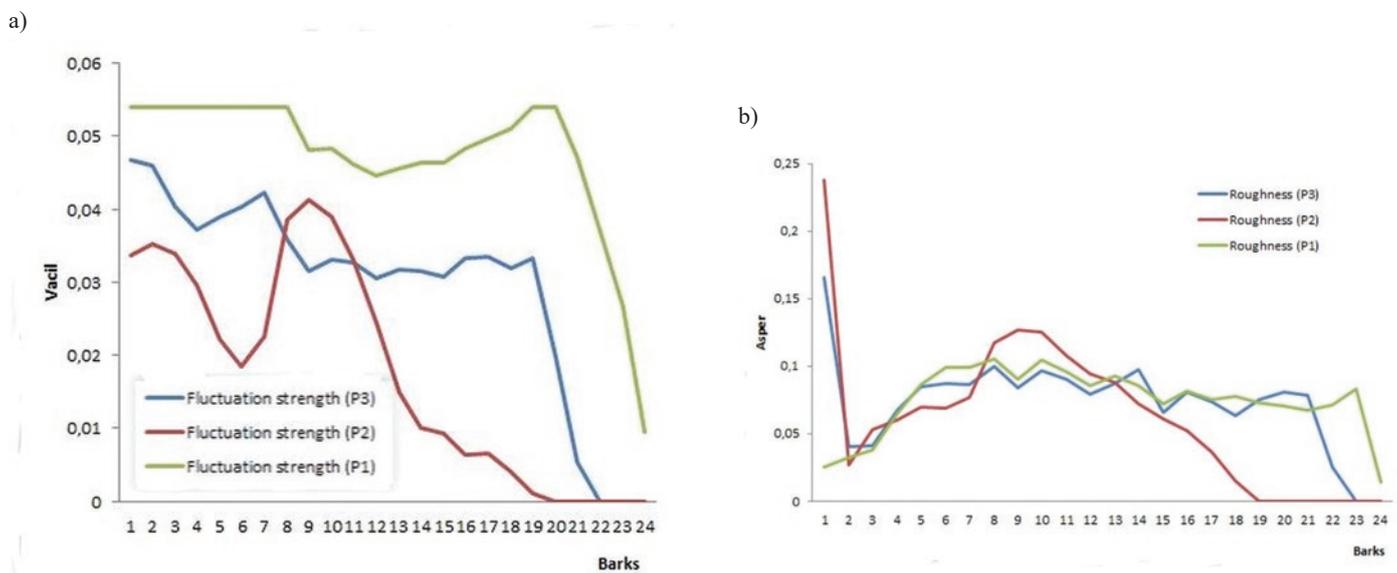
Fig. 6 The distributions in frequency domain of the sound roughness and fluctuation strength in the tested points

of frequency variation associated with the aspect of sound perception. Information about the spectrum distribution itself L_{Aeq} is insufficient in this assessment, it does not take into account features of auditory impressions.

It is assumed that the use of subjective sound features will allow to take into account the complexity of acoustic effects in an approximate way. In the study, the subjective features of sound in the examined points in the time and frequency domains were determined. Examples of shaping the subjective features of sound at the points (P1)-(P3) in the time domain are presented in Fig. 3 and Fig. 4.

The comparison of the results the shaping of the subjective features in the time domain follows, that L_{Aeq} is the decisive influence on the volume distribution. From Fig. 3 and Fig. 4 it can be concluded, that shaping of the subjective values of sound features at the point (P1) was dominant, in relation to other measuring points. This is mainly due to the nearest location of this point from the noise sources. In addition, it can be concluded, that for short periods of time, the determined values of some of the sound subjective features were the largest at the point (P2).

The analysis carried out for the designated subjective features of the sound in the frequency domain was related to the Bark scale. According to Zwicker [22], the width of the critical band can be determined by the scale expressed in the Bark scale. It is treated as an auditory filter with such a frequency bandwidth, beyond which the some of the perceptual features of the sound are clearly changing [14].

The obtained distributions of subjective sound features in the frequency domain (Fig. 5, Fig. 6) strongly indicate the occurrence of variability in critical frequency bands. This is important information in assessing the acoustic effects of a perceived acoustic signal. In the case of feature analysis, i.e.: sharpness, roughness and fluctuation strength, it can be observed increase of their value at the point (P2), especially for the perceived range (8÷12 Bark), which corresponds to the center frequency bands 840÷1600 Hz. The increase in the value of the above features in the point (P2) can be justified by the possible occurrence of local wave phenomena.

5. Discussion of results and conclusions

The research topics discussed in the article is an important and original approach to the tasks of assessing the acoustic effects of exploited road vehicles, understood as the combined physical and subjective impact of noise sources in the environment.

The article describes and presents the method of assessment in the external environment of used road vehicles, i.e. sources of road noise, with particular emphasis on the subjective features of sound. The solutions used in this context, in the form of assessment models,

are partial in nature, the multifaceted complexity of the process of acoustic signal perception and the lack of developed standards constitute a significant difficulty and a research limit.

In accordance with the legal guidelines and procedures, the applied noise assessment in the environment refers only to noise energy indicators. The subjective features of sound and psychophysical aspects accompanying the processes of sound perception are omitted in this assessment.

As part of the undertaken research there was carried out the analysis in the context of using subjective sound features for the proposed assessment method. For this purpose, verification acoustic tests in the environment were carried out. An assessment of acoustic effects in the environment was made using sound features. In particular, this assessment is represented:

• physically - with using noise indicators as cumulative values related to time domain, using acoustic map technology,
• subjectively - with using subjective features of sound in time and frequency domains.

Methods of simulation of physical sound features using acoustic maps allow to assess the acoustic effects of road noise sources in the external environment using energy indicators, including the possibility of modeling parameters related to the features of objects (e.g. sound absorption coefficients).

As part of the carried out physical assessment, the average values of the L_{Aeq} index were simulated, for the modeled area, including the division of energy of acoustic waves into direct and reflective sounds. Energy analysis of the division of simulated acoustic waves allowed to estimate the share of direct sounds of sources emission including the objects in the environment. The use of subjective sound features extends the currently applied approach to the problem of assessing the acoustic effects of used road vehicles in the environment.

Connection of the spatial distribution of physical and subjective sound features in the time and frequency domains, using acoustic map technology is considered a reasonable direction for further studies on the assessment of the impact of road vehicles in the environment. For this purpose, it will first be necessary to develop a mathematical model for the representation of the spatial distribution of the subjective features of sound. Detailed analysis and assessment of the distribution of sound features of the acoustic signal, allows to conclude about the cause of generating acoustic effects, for example, the impact of the condition/type of the surface, or the dominant source of vehicle noise, including occurrence of environmental objects.

Further research assumes the use of advanced methods of acoustic signal processing (e.g. spectrogram, wavelet analysis) for the purpose of assessing the variability of the distribution of the particular sound features in the time-frequency domain. Ultimately, the development of a mathematical model of spatial representation of sound in the environment using acoustic maps technology justifies the continuation of research into the noise annoyance assessment problem.

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