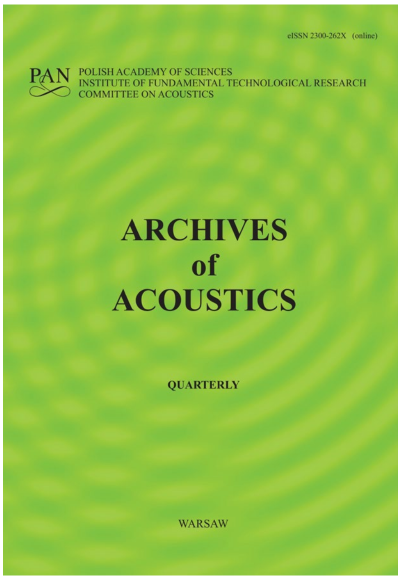
JOURNAL PRE-PROOF



eISSN 2300-262X (online)

PAN POLISH ACADEMY OF SCIENCES
INSTITUTE OF FUNDAMENTAL TECHNOLOGICAL RESEARCH
COMMITTEE ON ACOUSTICS

ARCHIVES
of
ACOUSTICS

QUARTERLY

WARSAW

Title: Verification of the CNOSSOS traffic noise prediction model – a case study

Author(s): Remigiusz Pyffel, Maciej Buszkiewicz, Roman Gołębiewski

DOI: https://doi.org/10.24423/archacoust.2026.4159

Journal: *Archives of Acoustics*

ISSN: 0137-5075, e-ISSN: 2300-262X

Publication status: In press

Received: 2024-12-06

Revised: 2026-04-26

Accepted: 2026-04-28

Published pre-proof: 2026-05-11

Please cite this article as:

Pyffel R., Buszkiewicz M., Gołębiewski R. (2026), Verification of the CNOSSOS traffic noise prediction model – a case study, *Archives of Acoustics*, https://doi.org/10.24423/archacoust.2026.4159

Verification of the CNOSSOS traffic noise prediction model – a case study

Remigiusz Pyffel, Maciej Buszkiewicz, Roman Gołębiewski

Department of Acoustics

Faculty of Physics and Astronomy

Adam Mickiewicz University in Poznań

Umultowska 85, 61-614 Poznań, Poland

Corresponding author:

Roman Gołębiewski, email: roman.golebiewski@amu.edu.pl

Key words: traffic noise, noise source, noise prediction method

1. Abstract

Pursuant to Commission Directive (EU) 2015/996 of 19 May 2015, which establishes common methods for noise assessment under Directive 2002/49/EC of the European Parliament and of the Council, EU Member States have been required to use the CNOSSOS method for noise mapping since the beginning of 2019. Consequently, from that year, the standardised CNOSSOS noise prediction method has been used to assess noise generated by moving vehicles. This method introduced a specific vehicle classification that differs from the classification proposed in the traffic noise prediction method recommended until 2019, i.e. the French NMPB-Routes-96 method. This paper compares the relationships between sound power level as a function of vehicle velocity according to the classifications adopted in the two traffic noise prediction methods.

In addition, using the determined corrections to the sound power level, the CNOSSOS noise prediction method is verified by comparing measured and calculated equivalent sound levels.

2. Introduction

The prediction of environmental noise is based on the determination of noise levels using daily or annual average noise assessment indicators.

According to the Regulation of the Minister of the Environment of 16 June 2011 (Regulation of the Minister of the Environment of 16 June 2011, 2011), to determine and monitor environmental conditions over a 24-hour period, the daily average sound level A should be used: $L_{Aeq,D}$ for the day period and, $L_{Aeq,N}$ for the night period.

The A-weighted time-average sound level is defined as follows:

$$L_{Aeq,T} = 10\log\left(\frac{\langle p_A^2(t)\rangle_T}{p_o^2}\right), \quad p_o = 2\cdot 10^{-5}\mathrm{Pa}, \tag{1}$$

where

$$\langle p_A^2(t)\rangle_T = \frac{1}{T}\int_0^T p_A^2(t)dt, \tag{2}$$

is the A-weighted squared sound pressure for the time interval T. For the traffic noise, the time interval T equals 16 hours for the daytime period (6^{00} and 22^{00}), and 8 hours for the nighttime period (22^{00} and 6^{00}).

For the purposes of strategic noise maps and noise protection programs, the day-evening-night level should be used:

$$L_{DEN} = 10\log\left(\frac{1}{24}\left(12\cdot 10^{0.1\cdot L_D} + 4\cdot 10^{0.1\cdot L_E} + 8\cdot 10^{0.1\cdot L_N}\right)\right), \tag{3}$$

where L_D is the A-weighted long-term average sound level determined over all the day periods of a year (between 6^{00} and 18^{00}), L_E is the A-weighted long-term average sound level determined over all the evening periods of a year (between 18^{00} and 22^{00}) and L_N is the A-weighted long-term average sound level determined over all the night periods of a year (between 22^{00} and 6^{00}).

The quantities L_D, L_E and L_N are calculated as follows:

$$L_D = 10\log\left(\frac{1}{N_D}\sum_{i=1}^{N_D} 10^{0.1\cdot L_{Aeq,T_i}}\right), \tag{4}$$

$$L_E = 10\log\left(\frac{1}{N_E}\sum_{i=1}^{N_E} 10^{0.1\cdot L_{Aeq,T_i}}\right), \tag{5}$$

$$L_N = 10\log\left(\frac{1}{N_N}\sum_{i=1}^{N_N} 10^{0.1\cdot L_{Aeq,T_i}}\right), \tag{6}$$

where N_D is the number of hours of all daytime periods during a year and equals ($N_D = 365\cdot 12$), N_E is the number of hours of all evening time during a year ($N_E = 365\cdot 4$), and N_N is the number of hours of all nighttime periods during a year ($N_N = 365\cdot 8$). The quantity $L_{Aeq,Ti}$ in the above equations is an average sound level of the i-th hour, during the day, evening and nighttime ($T_i = 1h = 3600s$).

The noise prediction consists of determining the value of the equivalent sound level A, $L_{Aeq,T}$, based on either noise measurements or acoustic calculations using noise prediction methods.

The determination of $L_{Aeq,T}$ from noise measurements is based on the measurements of short-term equivalent sound level values [(Makarewicz & Gołębiewski, 2006)], or on measurements of single noise events [(Makarewicz & Gołębiewski, 2016), (Makarewicz & Gołębiewski, 2016)].

The $L_{Aeq,T}$ can also be determined on the basis of acoustic calculations using specific prediction methods, after assuming specific input data, i.e. parameters affecting the generation and propagation of noise from a specific source (e.g. traffic noise, railway noise, aircraft noise, industrial noise, etc.).

Traffic noise is considered one of the most annoying noise sources. The largest number of inhabitants in Poland and Europe are exposed to it. This is evidenced by the results of the calculations and the acoustic analyses carried out as part of noise maps for public roads and agglomerations prepared over the past several years in Poland and European Union countries.

There are currently several traffic noise prediction methods. These methods differ mainly in the degree of accuracy with which the noise source is described (e.g. by means of one or several point sources), the propagation parameters and the noise indicators determined.

From a practical point of view, the choice of a specific method for describing the generation and propagation of traffic noise depends on several factors. The most important criterion that determines the choice of a specific method is the accuracy of the prediction. Unfortunately, in many cases the so-called exact methods are very complicated and almost impossible to use [(Nijland & Van Wee, 2005)]. Accurate models of the generation and propagation of traffic noise require the estimation of a number of parameters that are not accessible in practice. They cannot be determined from field measurements, as they require complicated procedures (e.g. determining the quantities describing the interaction with the ground surface, the profile of changes in temperature and wind speed with height, etc.).

Another factor characteristic of accurate methods is the very high sensitivity to changes in input parameters. Even a small change in the source-receiver geometry results in very large changes in the calculated sound level. In fact, precisely determining the position of the source and the receiver, especially over a long distance, is a very difficult task. Consequently, even a slight inaccuracy in the description of the source and/or receiver location can result in large changes in the value of the calculated sound level. A phenomenon that is very sensitive to the source – receiver geometry is the interaction of the acoustic wave with the ground surface (the so-called ground effect) (Gołębiewski, 2007).

Determining the height of the substitute noise source and describing the acoustic properties of the ground surface between the source and the receiver is also a major problem. Information about the properties of the ground surface should be available for the entire distance between the source and the receiver, as the type of ground surface may vary – for example, some areas may be covered by asphalt, while others may be covered by grass. The most sophisticated computational methods (e.g. Nord2000 (Kragh et al., 2023)) additionally require the determination of vertical distributions of air temperature, wind speed and direction, and turbulence. These distributions, as well as the type of ground surface, should be known over the entire distance between the source and the receiver, as the vertical profile of air temperature change and wind speed depends on the type of surface covering the ground.
Of course, a number of computational methods use simplified methods to describe the ground effect (Makarewicz & Kokowski, 1997), (Gołębiewski & Makarewicz, 2002), (Attenborough et al., 2007).

The paper by (Wilson et al., 2006) showed that "the main source of uncertainty in calculations using sophisticated calculation methods are the limitations in the description of the atmosphere's parameters".

In this paper, an analysis of the traffic noise source model adopted in the CNOSSOS method (Kephalopoulos et al., 2012) is performed. The vehicle categories adopted in the CNOSSOS method were compared with the vehicle categories used in the French method for predicting traffic noise(Hamet et al., 2010) – previously recommended by the European Union.

The study also compared the relationships of the sound power level as a function of vehicle velocity, $\mathrm{L_{WA}(v)}$, based on field noise measurements for light and heavy vehicles (vehicle categories defined by the French method), with the theoretical dependencies of the sound power level, $\mathrm{L_{WA}(v)}$, for individual vehicle categories adopted in the CNOSSOS method.

3. Traffic noise generation and propagation

The traffic noise level at a specific point (receiver) located at a given distance from the road is influenced by the noise generation and propagation process.

The generation of traffic noise depends on many factors:

- traffic volume;
- traffic speed;
- traffic structure;
- the type of road surface and vehicle tyres;
- the temperature of the road surface and vehicle tyres;
- the technical condition of the road;

The noise propagation depends on:

- the source-receiver geometry;

- the type of ground surface between the source and the receiver;
- air temperature and humidity;
- the distribution of air temperature over the ground surface;
- the wind direction and speed;
- the presence of obstacles in the path of noise propagation from the source to the receiver;

The application of a specific calculation procedure requires verification of the calculation results by means of acoustic measurements. The verification (calibration) consists in comparing the results of measurements and calculations made, assuming the same generation and propagation conditions that occurred during the measurements and maintaining the same measurement scenario, i.e. the same source-receiver geometry.

The condition of equivalence between the calculation model and the measurements is met (Regulation of the Minister of the Environment of 16 June 2011, 2011):

$$\frac{1}{n-1}\sum_{i=1}^{n}\left(L_{m,i}-L_{calc,i}\right)^{2} \leq 2.5\mathrm{dB} \tag{7}$$

where $L_{m,i}$ is the measured value of the noise indicator (i.e. equivalent sound level), $L_{calc,i}$ is the calculated value of the noise indicator, and n is the number of noise measurements.

Until the end of 2018, in accordance with Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002, Member States without national calculation methods were advised to use the following methods (Directive 2002/46/EC of the European Parliament and of the Council of 10 June 2002, 2002):

- for road traffic noise: the French national computation method NMPBRoutes-96 (Hamet et al., 2010), (Dutilleux et al., 2008);
- for aircraft noise – ECAC.CEAC Doc 29 "Report on standard method of computing noise contour around civil airports" (ECAC.CEAC Doc 29 4th Edition, 2016);
- for industrial noise – ISO 9613-2: Acoustics – Abatement of sound propagation outdoors, Part 2: General method of calculation [(ISO 9613-2:2024, 2024);
- for railway noise – the Netherlands national computation method published in Reken en Meetvoorschrijft Railverkeerslawaai 1996 (Ministry of Housing & the Environment (VROM), 2001);

As can be seen, the existing method for traffic noise prediction was the French NMPB-Routes-96 method. According to this method, all vehicles were divided into light vehicles (LV, below 3.5 T)) and heavy vehicles (HV, 3.5T and above) (Hamet et al., 2010).

In 2008, the Commission initiated the process of developing a common methodological framework for noise assessment through a project called "Common Noise Assessment Methods in the EU" (CNOSSOS-EU), led by the Joint Research Centre. According to the European Commission Directive 2015/996 of 19 May 2015 establishing common methods for noise assessment under Directive 2002/49/EC of the European Parliament and of the Council, the CNOSSOS method should be used by EU Member States for noise mapping purposes from the beginning of 2019 (Commission Directive (EU) 2015/996 of 19 May 2015, 2015). The CNOSSOS method is a unified method for predicting noise from different sources (Kephalopoulos et al., 2012).

The method allows calculations to be carried out under favourable and homogeneous conditions. The noise levels for road traffic, rail traffic and industrial activities are calculated in octave bands. For traffic noise, rail noise and industrial activities, the long-term average A-weighted sound pressure level is calculated, based on the results obtained for octave bands, for daytime, evening and nighttime, by summing the data from all frequencies:

$$\mathrm{L_{Aeq,T}} = 10\log \sum_{\mathrm{i=1}} 10^{(\mathrm{L_{eq,T,i}}+\mathrm{A_i})/10} \tag{8}$$

where $L_{eq,T,i}$ – is the equivalent noise level for the i–th frequency band, whereas A_i – denotes the A-weighting correction according to IEC 61672-1 (IEC 61672-1, 2013) and i is the frequency band index.

The accuracy of the noise prediction method is determined by the values of the input parameters affecting the source emissions, which are determined with an accuracy of at least ±2dB.

4. CNOSSOS method – source description

In the CNOSSOS noise prediction method, all vehicles are grouped into four separate categories with regard to their noise emission characteristics. The details of each vehicle category are given in Tab. 1.

Tab. 1. Vehicle classes (Kephalopoulos et al., 2012)

Category	Name	Description
1	Light motor vehicles	Passenger cars, delivery vans ≤ 3.5 tons, SUVs$^{1)}$, and MPVs$^{2)}$, including trailers and caravans

2	Medium heavy vehicles		Medium heavy vehicles, delivery vans > 3.5 tons, buses, touring cars, etc., with two axles and twin tyre mounting on the rear axle
3	Heavy vehicles		Heavy-duty vehicles, touring cars, buses, with three or more axles
4	Powered two-wheelers	4a	mopeds, tricycles or quads ≤ 50 cc
		4b	motorcycles, tricycles or quads > 50 cc
5[3]	Open category		To be defined according to future needs

[1] Sport Utility Vehicles

[2] Multi-Purpose Vehicles

[3] A fifth category is foreseen as an open class for new vehicles that may be developed in the future and may be sufficiently different in their noise emission to require an additional category to be defined. This category could cover, for example, electric or hybrid vehicles or any futuristic vehicle not defined in categories 1-4.

For the calculation of noise propagation, real sources should be modelled by a substitutive (equivalent) source (one or several point sources) for which the height above the ground and the sound power level must be determined. The source height of road traffic noise is a very important factor in the calculations of the ground effect and the parameters of acoustic barriers. In the CNOSSOS method, each vehicle (categories 1 – 4) is represented by one single point source placed 0.05 m above the road surface (Fig. 1 – Fig. 3).

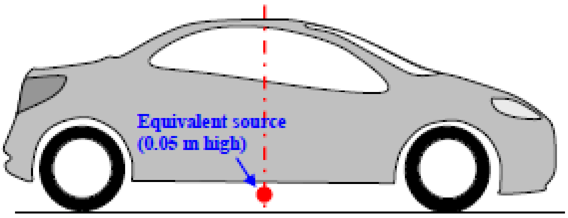


Fig. 1. The location of the equivalent point source for light motor vehicles (category 1)

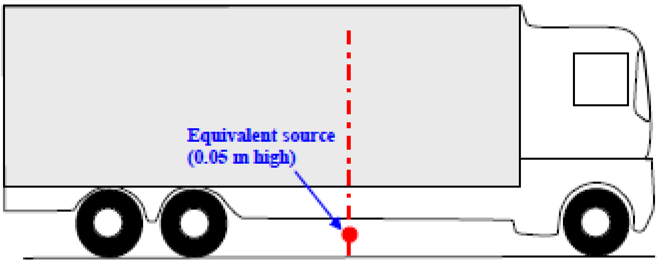


Fig. 2. The location of the equivalent point source for medium heavy vehicles and heavy vehicles (categories 2 and 3)

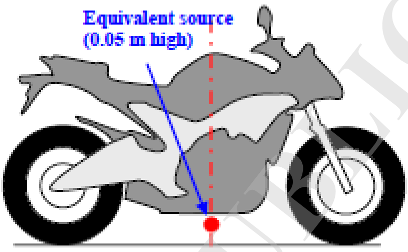


Fig. 3. The location of the equivalent point source for two-wheelers (category 4)

Other noise prediction methods model the real noise source in different ways.

In the SONRoad method (a Swiss method for predicting traffic noise), the equivalent noise source is located at a height of 0.45 cm above the road surface and does not depend on the type of vehicle (Heutschi, 2004).

In the NORD 2000 method, all vehicles are assigned to the following categories: category 1 (light – passenger cars and vans), category 2 (medium – lorries and buses with two axles), and category 3 (heavy – vehicles with more than two axles for which the number of axles is an input parameter). Each category of vehicle is represented by two separate point sources, each of which has a sound power level representing tyre/road noise and propulsion system noise, respectively. The source heights used are 0.01, 0.30, and 0.75 m, situated at 1.0 m from the vehicle centerline towards the receiver. The lowest source height is used to represent all vehicle categories, whereas a height of 0.30 m is used for category 1, and 0.75 m is used for vehicle categories 2 and 3. For heavy vehicles with a high exhaust opening, a fourth source height is used at 3.5 m (Kragh et al., 2023).

In the IMAGINE method, all vehicles are assigned to the following categories: category 1 (light motor vehicles – passenger cars, delivery vans ≤ 3.5 tons, SUVs, MPVs including trailers and caravans), category 2 (medium heavy vehicles – medium heavy vehicles, delivery vans > 3.5 tons, buses, touring cars, etc. with two axles and twin tyre mounting on rear axle), category 3 (heavy vehicles – heavy-duty vehicles, touring cars, buses, with three or more axles) and category 4 (powered two-wheelers – mopeds, tricycles or quads with 50 cc and motorcycles, tricycles or quads with > 50 cc).

Each vehicle is represented by two point sources, placed at two different heights. The lowest source is located at 0.01 m above the road, and the highest source is located at 0.3 m for light motor vehicles and at 0.75 m for heavy motor vehicles. The lowest carries 80% of the rolling sound power and 20% of the propulsion sound power, whereas the highest represents 20% of the rolling noise and 80% of the propulsion noise (Peeters & v.Blokland, 2007).

The CNOSSOS method considers two main dominant noise sources:

- Rolling noise due to the tyre/road interaction;
- Propulsion noise produced by the driveline (engine, exhaust, etc.) of the vehicle.

Aerodynamic noise is incorporated in the rolling noise sources.

For light, medium and heavy motor vehicles (category 1, 2 and 3) the sound power is equal to the sum of the acoustic energy of the rolling and the propulsion noise:

$$\mathrm{L_{W,i,m}(v_m) = 10\log\left(10^{0.1\cdot L_{WR,i,m}(v_m)} + 10^{0.1\cdot L_{WP,i,m}(v_m)}\right)} \quad (9)$$

where $L_{WR,i,m}$ is the sound power level for rolling noise and $L_{WP,i,m}$ is the sound power level for propulsion noise (for all velocity ranges).

For speeds lower than 20 km/h, the sound power level is identical to that defined in equation (9) for v_m = 20 km/h.

For rolling noise, the sound power level $L_{WR,i,m}$ is expressed by the following relation:

$$\mathrm{L_{WR,i,m} = A_{R,i,m} + B_{R,i,m} \cdot \log\left(\frac{v_m}{v_{ref}}\right) + \Delta L_{WR,i,m}} \quad (10)$$

where the coefficients $A_{R,i,m}$ and $B_{R,i,m}$ are given in octave bands for each vehicle category and for a reference speed v_{ref} = 70 km/h, v_m is vehicle velocity and $\Delta L_{WR,i,m}$ – the sum of the correction coefficients to be applied to rolling noise emission for specific road or vehicle conditions deviating from the reference conditions:

$$\mathrm{\Delta L_{WR,i,m} = \Delta L_{WR,road,i,m} + L_{studdetyres,i,m} + L_{WR,acc,i,m} + L_{W,temp}} \quad (11)$$

where

- $\Delta L_{WR,road,i,m}$ accounts for the effect on rolling noise of a road surface with different acoustic properties from those of the virtual reference surface and includes both the effect on propagation and the effect on generation;
- $\Delta L_{studded\ tyres,i,m}$ is a correction coefficient to be applied to the proportion of light motor vehicles (m = 1) equipped with studded tyres;
- $\Delta L_{WR,acc,i,m}$ accounts for the effect on rolling noise of a crossing with traffic lights or a roundabout. This correction considers the impact of changes in traffic speed on noise;

- $\Delta L_{W,temp}(\tau)$ is a correction term for an average temperature τ different from the reference temperature τ_{ref} = 20°C.

The quantity $L_{WP,i,m}$ is defined by the following equation:

$$L_{WR,i,m} = A_{P,i,m} + B_{P,i,m} \cdot \log\left(\frac{(v_m - v_{ref})}{v_{ref}}\right) + \Delta L_{WP,i,m} \tag{12}$$

where the coefficients $A_{P,i,m}$ and $B_{P,i,m}$ are given in octave bands for each vehicle category and for a reference speed v_{ref} = 70 km/h, v_m is vehicle velocity, and $\Delta L_{WP,i,m}$ corresponds to the sum of the correction coefficients to be applied to propulsion noise emission for specific driving conditions or actual regional conditions deviating from the reference conditions:

$$\Delta L_{WP,i,m} = \Delta L_{WP,road,i,m} + L_{WP,grad,i,m} + L_{WP,acc,i,m} \tag{13}$$

where $\Delta L_{WP,road,i,m}$ accounts for the effect of the type of road surface on propulsion noise. It includes the effect of a porous surface on the local propagation of propulsion noise, and $\Delta L_{WP,acc,i,m}$ and $\Delta L_{WP,grad,i,m}$ account for deviations related to the driving conditions.

The corrections $A_{R,i,m}$, $B_{R,i,m}$, $A_{P,i,m}$ and $B_{P,i,m}$ are given in the paper by (Kephalopoulos et al., 2012).

The A-weighted sound power level of rolling noise, propulsion noise and total noise for passenger cars and heavy vehicles under reference conditions according to the road traffic noise emission model in CNOSSOS is presented in Fig. 4 (for passenger cars) and in Fig. 5 (for heavy vehicles).

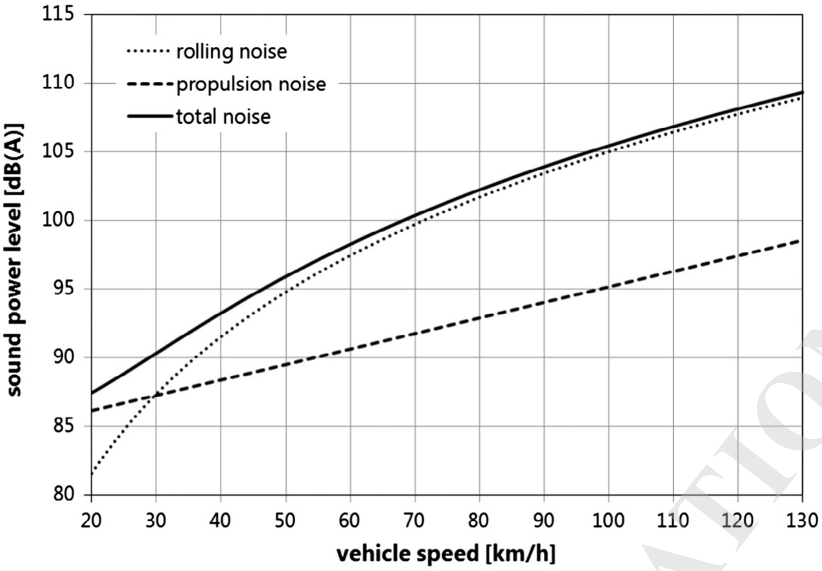


Fig. 4. The A-weighted sound power level of rolling noise, propulsion noise and total noise for passenger cars under reference conditions according to the road traffic noise emission model in CNOSSOS (Heutschi, 2004)

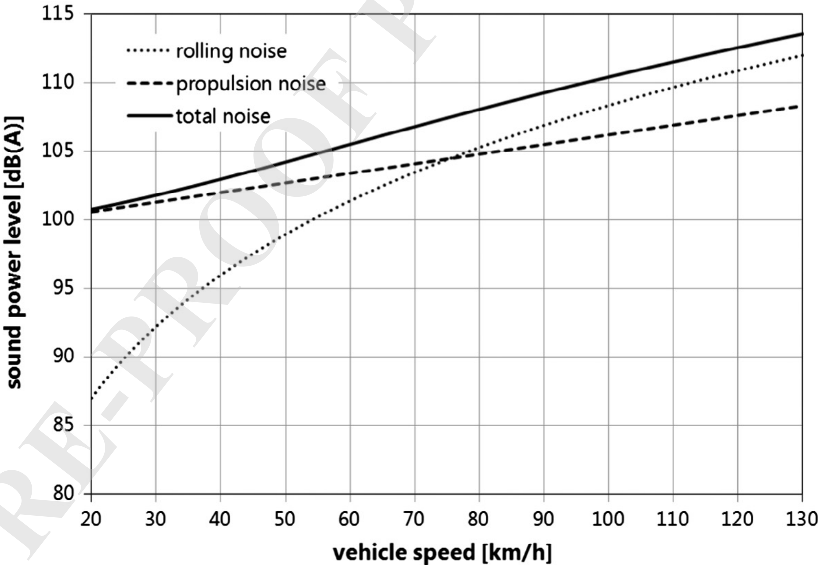


Fig. 5. The A-weighted sound power level of rolling noise, propulsion noise and total noise for heavy vehicles under reference conditions according to the road traffic noise emission model in CNOSSOS (Heutschi, 2004)

As can be seen from the presented relationships, the contribution of rolling noise and propulsion noise to the total noise level depends very strongly on the vehicle velocity. For both light and heavy vehicles, there is a certain limit speed below which propulsion noise dominates and above which rolling noise dominates. For light vehicles, the limit speed is about 30 km/h (Fig. **4**), while for heavy vehicles it is about 75 km/h (Fig. **5**). According to other sources, the limit speeds take different values (Tab. 2) (Sandberg & Ejsmont, 2002).

Tab. 2. Crossover speeds for light and heavy vehicles in steady state motion **(Sandberg & Ejsmont, 2002)**

Vehicle type		Crossover speed [km/h]
Light	Cars made 1985 – 1996	30 – 35
	Cars made 1996 –	15 – 25
Heavy	Cars made 1985 – 1996	40 – 50
	Cars made – 1996	30 – 35

Of course, there are other studies that clearly show that cross-over speeds are lower (Pallas et al., 2024), (Hammer et al., 2016). This means that rolling noise dominates at very low velocities. The paper (Pallas et al., 2024) shows that the crossover speed equals 20 km/h for category 1 and 40 km/h for category 3. The paper by (Hammer et al., 2016) shows that the range of crossover speeds for all vehicle groups is within the range of 14.8 to 33.7 km/h. The lowest crossover speed results for hybrid cars, which can be explained by the rather low propulsion noise at low speeds due to the electric engine. Petrol and diesel cars show fairly similar crossover speeds, with values of 15.2

and 15.9 km/h. The highest crossover speed was found for diesel light-duty commercial vehicles, at 33.7 km/h.

Using equations (9) – (13) and the values of the corrections $A_{R,i,m}$, $B_{R,i,m}$, $A_{P,i,m}$ and $B_{P,i,m}$ presented in the paper by (Commission Directive (EU) 2015/996 of 19 May 2015, 2015), the spectra of the sound power level were calculated for the different vehicle categories (light motor vehicles, medium heavy vehicles and heavy vehicles) and for specific vehicle velocities. All calculations were made for the so-called reference surface (a virtual reference road surface, consisting of an average of dense asphalt concrete 0/11 and stone mastic asphalt 0/11, between 2 and 7 years old and in a representative maintenance condition). The results of the calculations are presented in Fig. 6 – Fig. 17.

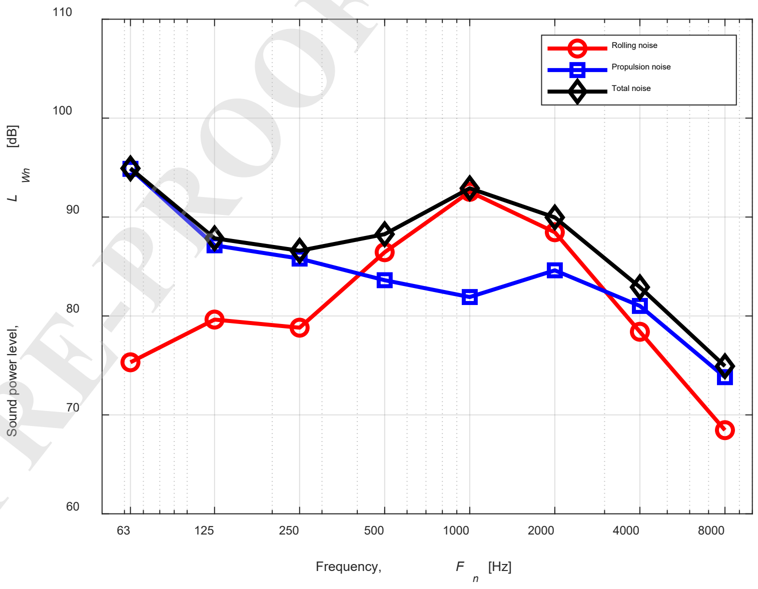


Fig. 6. The sound power level in 1/3-octave frequency bands of light motor vehicles at a velocity of v = 50 km/h

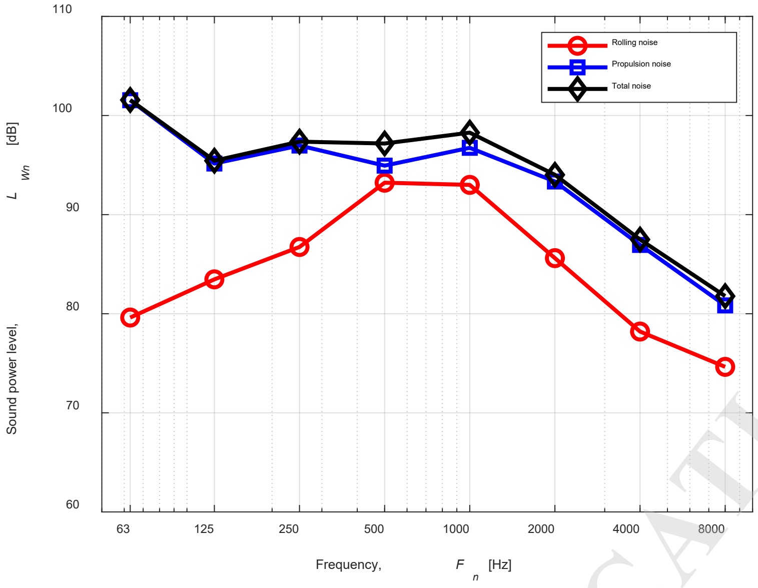


Fig. 7. The sound power level in 1/3-octave frequency bands of medium heavy vehicles at a velocity of v = 50 km/h

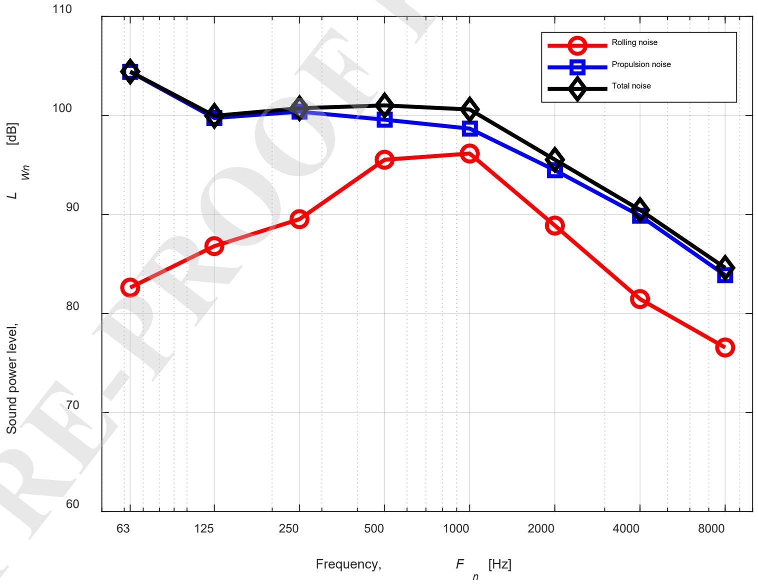


Fig. 8. The sound power level in 1/3-octave frequency bands of heavy vehicles at a velocity of v = 50 km/h

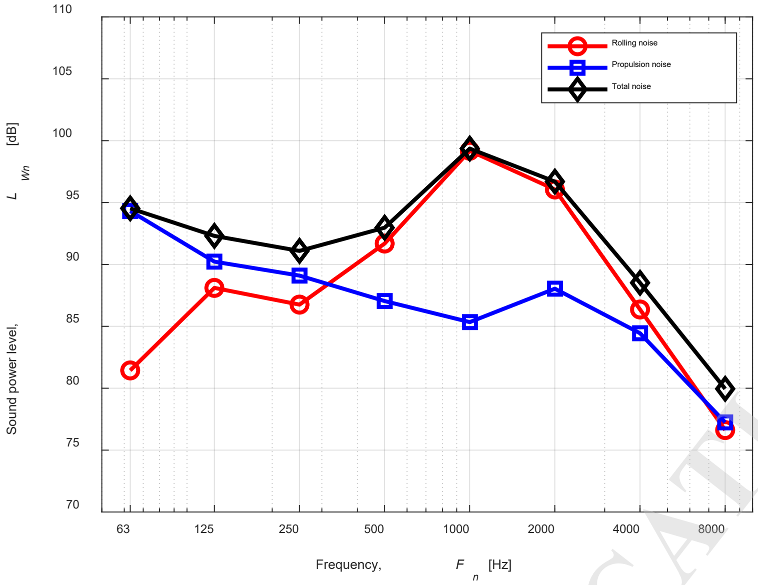


Fig. 9. The sound power level in 1/3-octave frequency bands of light motor vehicles at a velocity of v = 80 km/h

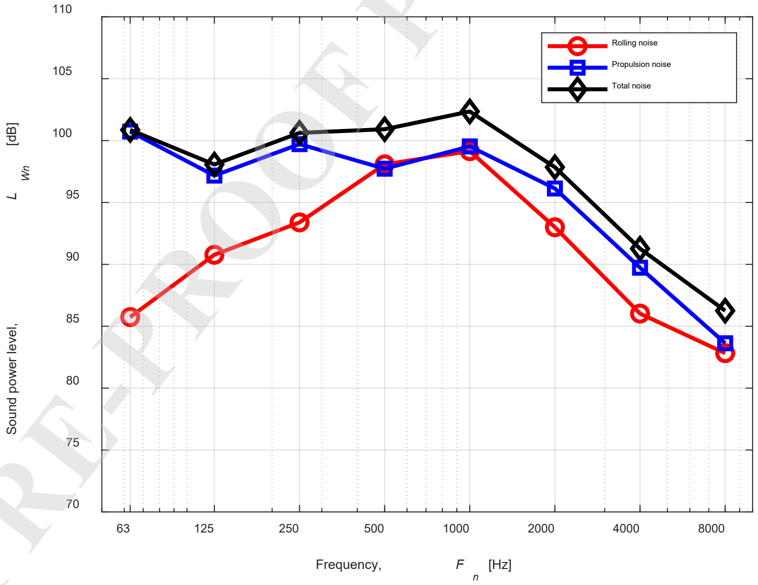


Fig. 10. The sound power level in 1/3-octave frequency bands of medium heavy vehicles at a velocity of v = 80 km/h

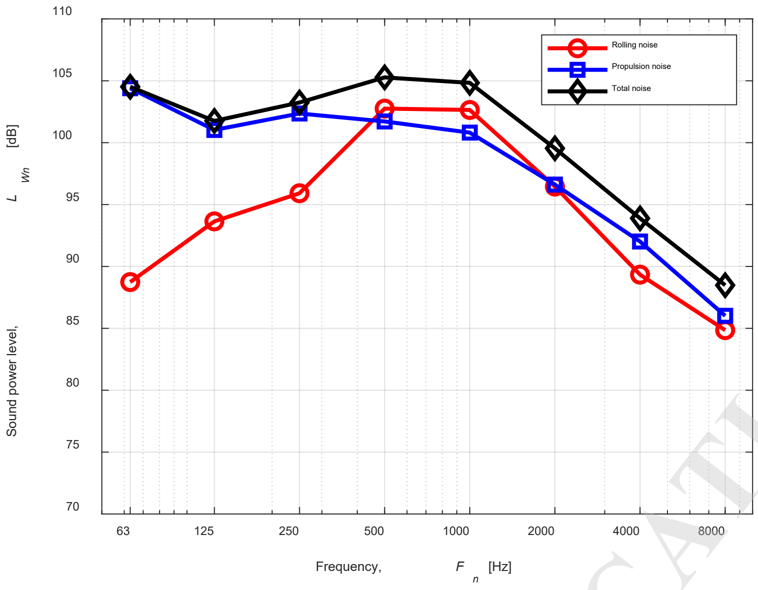


Fig. 11. The sound power level in 1/3-octave frequency bands of heavy vehicles at a velocity of v = 80 km/h

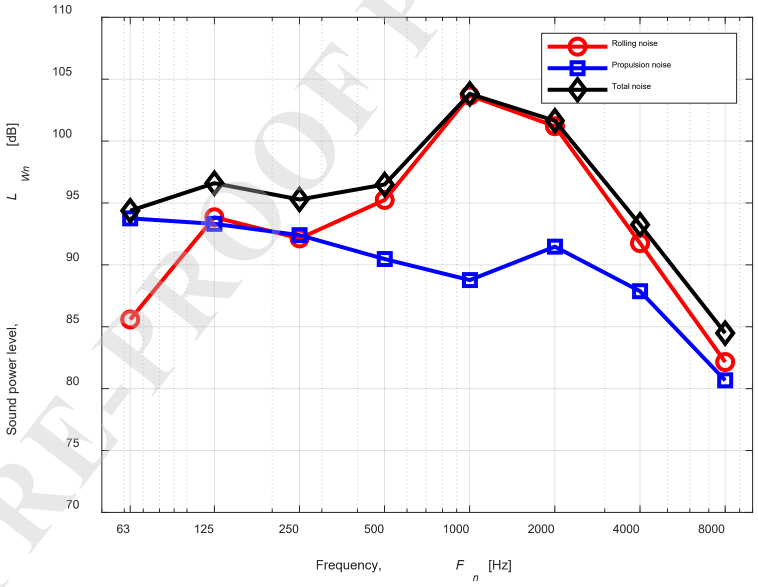


Fig. 12. The sound power level in 1/3-octave frequency bands of light motor vehicles at a velocity of v = 110 km/h

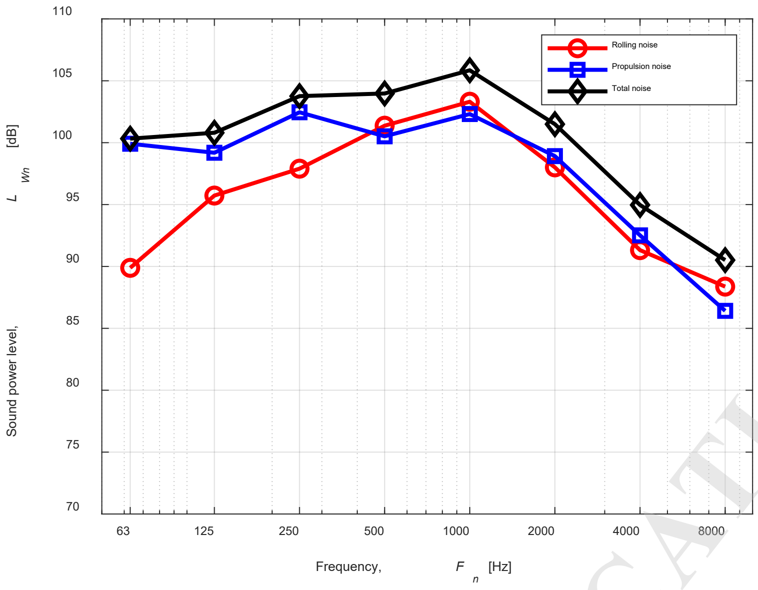


Fig. 13. The sound power level in 1/3-octave frequency bands of medium heavy vehicles at a velocity of v = 110 km/h

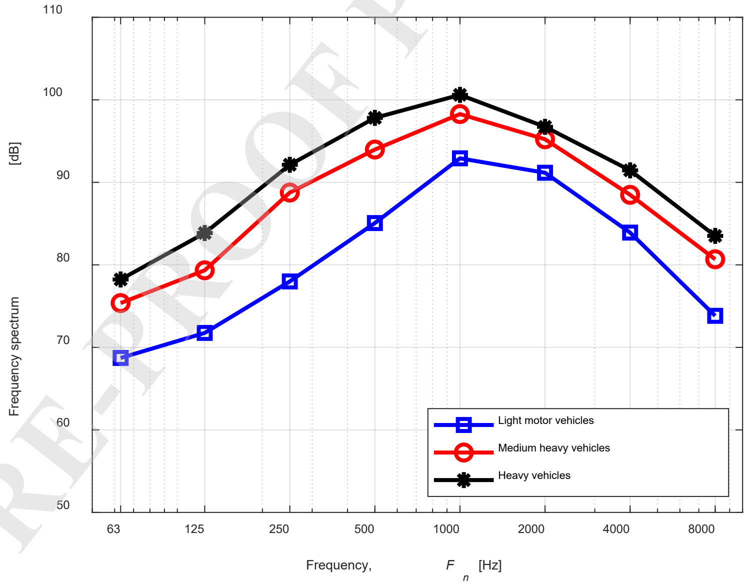


Fig. 14. Comparison of the sound power level in 1/3-octave frequency bands for three vehicle categories at velocities of v = 50 km/h

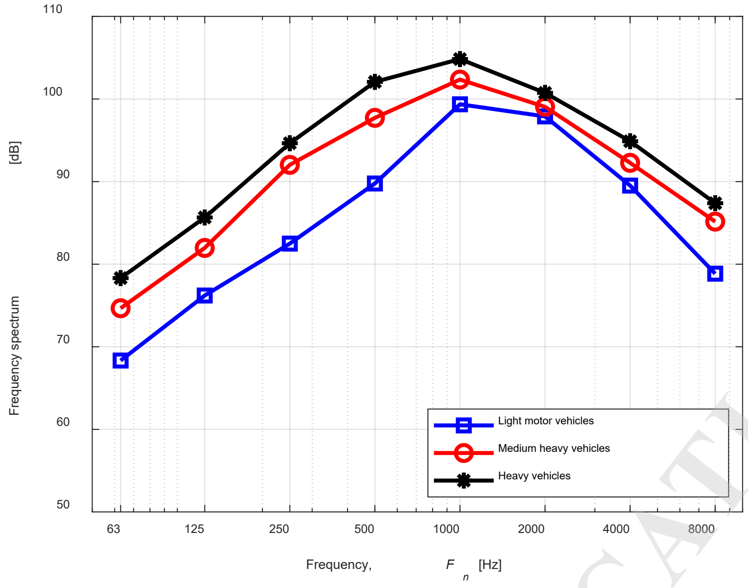


Fig. 15. Comparison of the sound power level in 1/3-octave frequency bands for three vehicle categories at velocities of v = 80 km/h

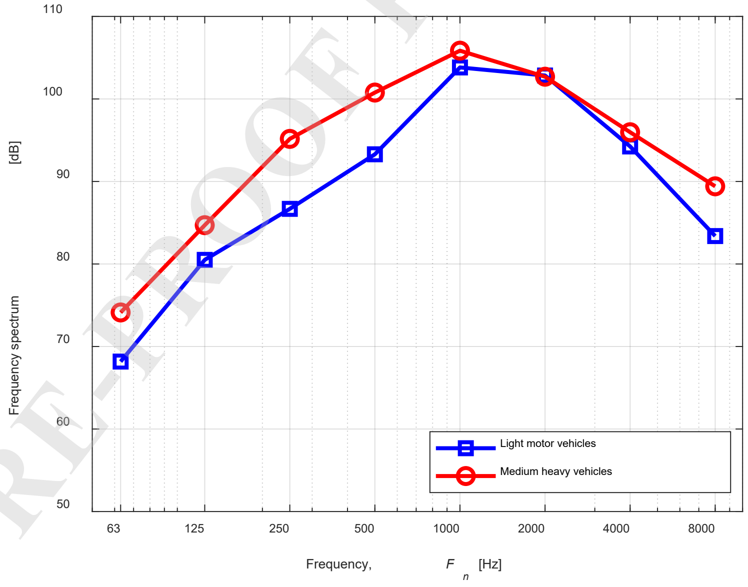


Fig. 16. Comparison of the sound power level in 1/3-octave frequency bands for two vehicle categories at velocities of v = 110 km/h

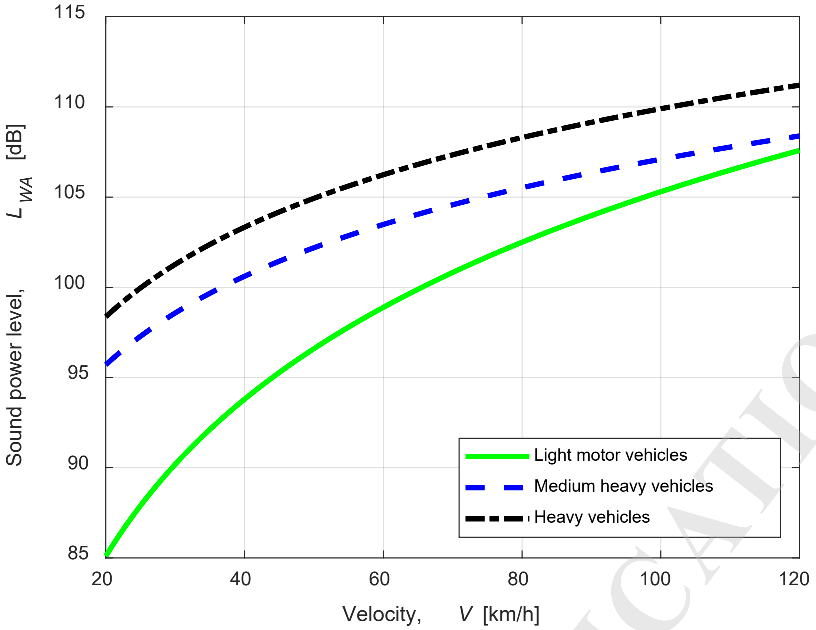


Fig. 17. The A-weighted sound power level as a function of vehicle velocity, $L_{WA}(v)$ for three vehicle categories

As can be seen from the presented spectra, for light motor vehicles, the proportion of propulsion noise and rolling noise changes as the speed changes. The higher the velocity, the wider the frequency range in which the rolling noise dominates (for $\mathrm{v} = 50\ \mathrm{km/h}$ – in the range from 500 Hz to approx. 2000 Hz, while for $\mathrm{v} = 110\ \mathrm{km/h}$ – in the range from 250 Hz to approx. 8000 Hz).

For medium heavy and heavy vehicles, for low traffic speeds $\mathrm{v} = 50\ \mathrm{km/h}$, propulsion noise dominates the entire frequency range. For higher velocities, rolling noise makes an increasing contribution.

The comparison of the spectra presented in Fig. 17 shows that the shape of the spectra for all three vehicle categories is similar.

Using the previously presented relationships (equations (9) – (13)) and by calculating the sound power level for different traffic speeds, it is possible to determine the relationship of the sound power level as a function of vehicle velocity, $\mathrm{L_{WA}(v)}$. The following relationships were obtained for the specific vehicle categories (Fig. 17):

- light motor vehicles

$$\mathrm{L_{WA}^{LMV}} = 28.9 \cdot \log(\mathrm{v}) + 47.5; \qquad (14)$$

- medium heavy vehicles

$$\mathrm{L_{WA}^{MHV}} = 16.3 \cdot \log(\mathrm{v}) + 74.5; \qquad (15)$$

- heavy vehicles

$$\mathrm{L_{WA}^{HV}} = 16.5 \cdot \log(\mathrm{v}) + 76.9; \qquad (16)$$

As can be seen from the presented $\mathrm{L_{WA}(v)}$ relationships, the biggest differences in sound power levels occur at low traffic speeds (approx. 18 dB between light motor vehicles and heavy vehicles). As traffic speeds increase, the differences become smaller.

5. The acoustic measurements of single pass-by noise

To determine the dependence of acoustic power levels for light and heavy vehicles as a function of vehicle velocity, for motor vehicles travelling on Polish roads, noise measurements were performed.

5.1. The measurement setup

The noise measurements of single pass-by noise were performed at the distance D = 7.5 m from the nearest lane centre (Fig. 18). The microphone was located at the height H_o = 1.2 m above the ground surface. The measurements were performed in September 2018, close to National Road No. 11 (several kilometres from Poznań). The road surface was made of asphalt concrete with the maximum aggregate size of 11 mm (DAC11). Acoustic measurements were carried out at a single measurement point in an open area, away from any sound-reflecting objects and without any obstacles that could interfere with the propagation of noise from a moving noise source.

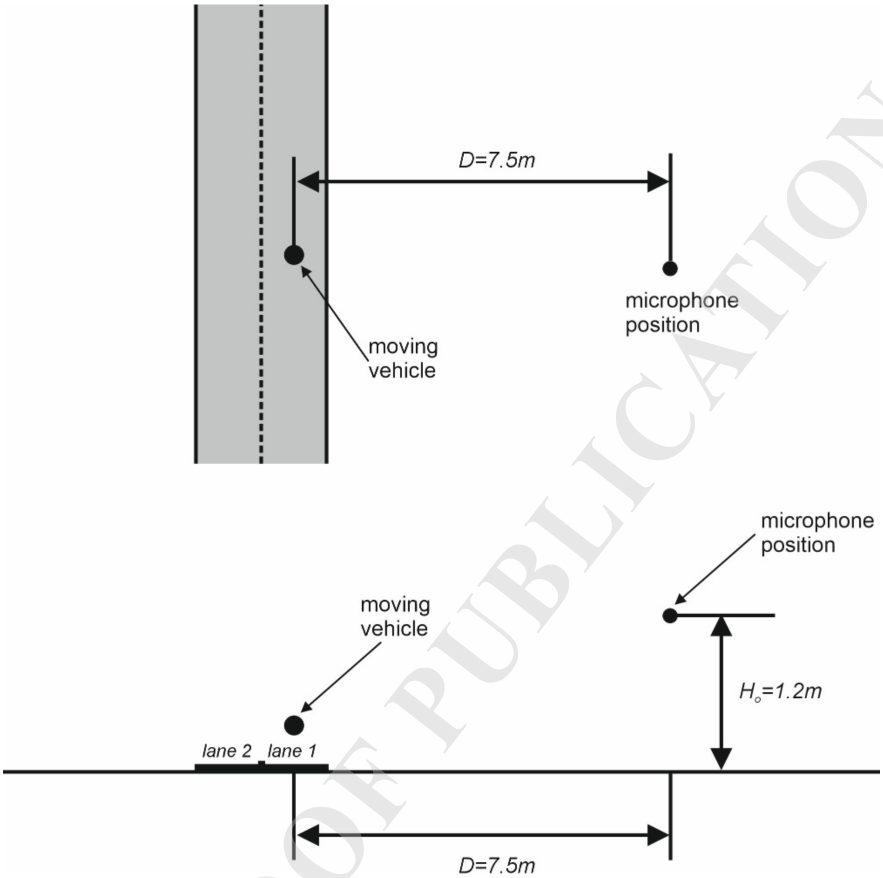


Fig. 18. The measurement setup

5.2. The measurement equipment

In the measurements, the following measurement equipment was used: the sound level meter SVAN 945 A and the calibrator SONOPAN type KA 50.

During the measurements, the temporal changes of the sound level of a single pass-by noise in 1/3-octave frequency bands were measured. In addition, the speed of each vehicle was measured.

5.3. The results

Based on the recorded temporal changes of sound level in the octave frequency bands, $L_{pAn}(t)$, the relative noise exposure was determined using the following equation:

$$e_{An} = \int_{-\infty}^{+\infty} 10^{0.1L_{pAn}(t)}\,dt. \tag{17}$$

Using the determined relative noise exposure, the sound exposure level was calculated in the octave frequency bands for each pass-by noise. The following equation was used:

$$L_{AEn} = 10\log(e_{An}). \tag{18}$$

To obtain the sound power level the following relationship was used:

$$L_{WAn} = L_{AEn} - 10\log\left(\frac{s_o}{4vDt_o}\right), \tag{19}$$

where L_{AEn} denotes the sound exposure level in the octave frequency bands, v denotes vehicle velocity (in m/s), D denotes the source-receiver distance, and $s_o = 1m^2$.

In Poland the vehicles' classification is compatible with the existing method for traffic noise prediction, i.e. the French NMPB-Routes-96 method.

The sound power level of light and heavy vehicles obtained from the field measurements are presented in Fig. 19 and Fig. 20. In the figures, the regression curves are presented of the form:

$$L_{WA} = A \cdot \log\left(\frac{v}{v_o}\right) + B, \tag{20}$$

where A and B are the coefficients of the regression curve, and $v_o = 1\mathrm{km/h}$.

The statistical parameters of the determined regression curves are shown in Tab. 3.

As can be seen from the results presented in Fig. 12 and Fig. 13, a large spread of traffic speed measurements was obtained. It should be emphasized that the measurements were taken on different days of the week (including weekends) and at different times (morning, afternoon, and evening). For this reason, it was possible to record single pass-by noise of light and heavy vehicles moving at different speeds.

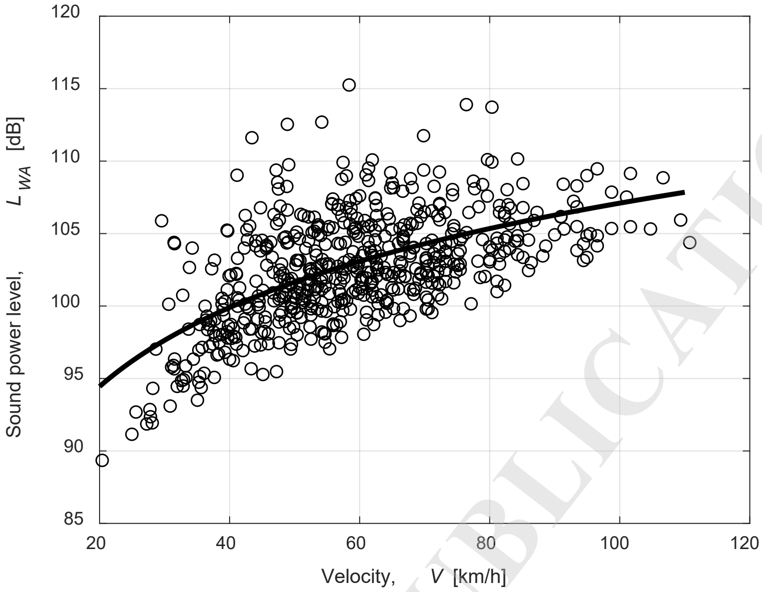


Fig. 19. The determined A-weighted sound power level as a function of vehicle velocity, $L_{WA}(v)$, of light vehicles

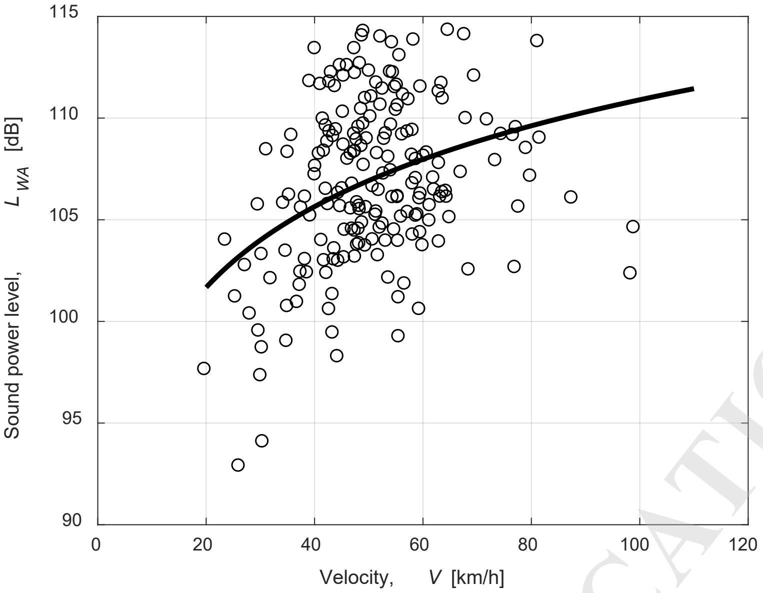


Fig. 20. The determined A-weighted sound power level as a function of vehicle velocity, $L_{WA}(v)$, of heavy vehicles

Tab. 3. The regression parameters (A, B – regression coefficients, R – correlation coefficient, N – number of measurements)

Category	Parameters of regression			
	A	B	R^2	N
Light vehicles (LV)	18.1 (16.1, 20.1)	70.9 (67.3, 74.4)	0.35	576
Heavy vehicles (HV)	13.2 (8.5, 18.0)	84.5 (76.4, 92.5)	0.14	196

Using the definitions of the vehicle categories according to the French noise prediction method (NMPB-Routes-96) and CNOSSOS (Tab. 1), it should be stated that, in order to compare the acoustic parameters of vehicles in both noise prediction methods, light vehicles from NMPB-Routes-96 should be compared with light motor vehicles from the CNOSSOS method. According to the provided descriptions, this is the same vehicle category. However, the heavy vehicle category according to CNOSSOS corresponds to heavy vehicles in the NMPB-Routes - 96 method. The medium heavy vehicle category should also be included in the heavy vehicle category according to the French method, as there is no direct equivalent in this method.

The sound power level as a function of vehicle velocity, $L_{WA}(v)$, obtained on the basis of the performed noise measurements and calculated using the CNOSSOS method is presented in Fig. 21 – Fig. 22. Fig. 21 presents the relationship $L_{WA}(v)$ of light vehicles (our measurements) and that for light motor vehicles and medium heavy vehicles (CNOSSOS). On the other hand, Fig. 22 shows the comparison of the sound power level of heavy vehicles (our measurements) and heavy vehicles (CNOSSOS).

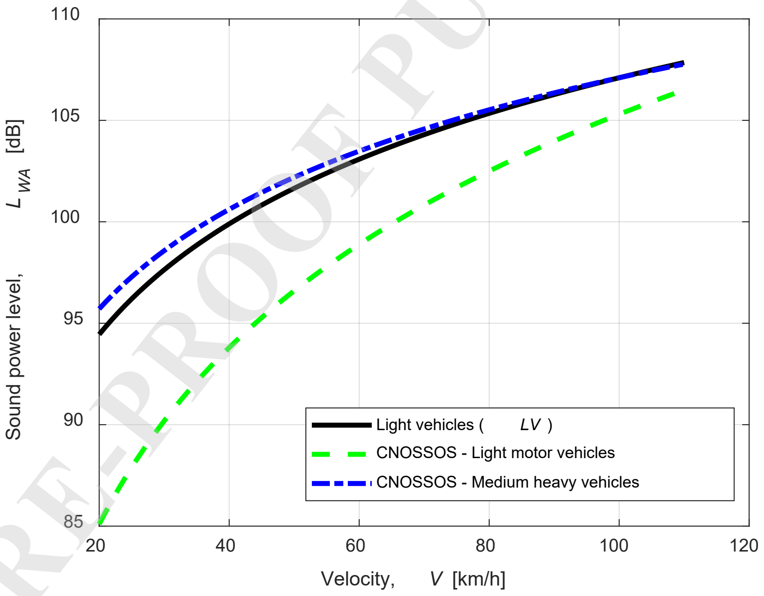


Fig. 21. The A-weighted sound power level as a function of vehicle velocity, $L_{WA}(v)$, of light vehicles (determined on the basis of noise measurements), light motor vehicles and medium heavy vehicles (CNOSSOS method)

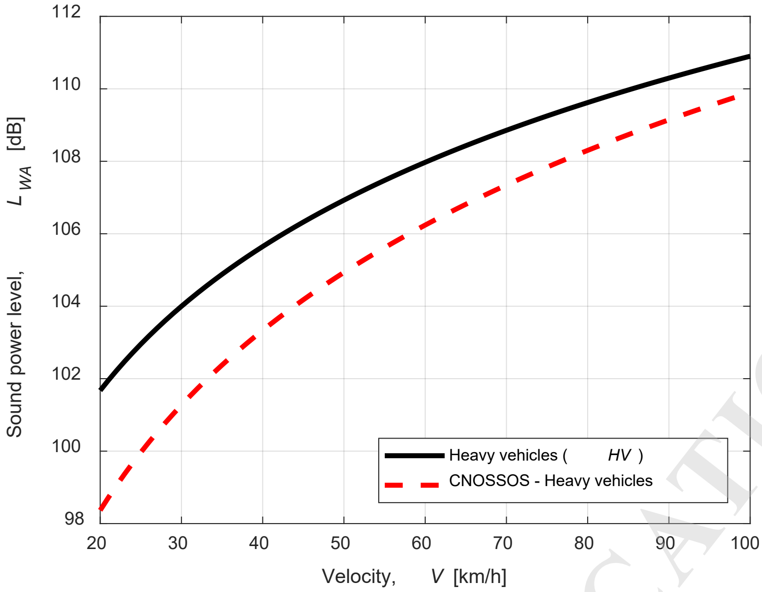


Fig. 22. The A-weighted sound power level as a function of vehicle velocity, $L_{WA}(v)$, of heavy vehicles (determined on the basis of noise measurements) and heavy vehicles (CNOSSOS method)

As can be seen, significant differences were obtained between the relationships obtained from our measurements and those proposed in the CNOSSOS method. These differences depend very strongly on the vehicle velocity and the type of vehicles. The largest differences apply to light vehicles (our measurements) and light motor vehicles (CNOSSOS), while there are smaller differences between the sound power levels for light vehicles (our measurements) and medium heavy vehicles (CNOSSOS). By comparing the obtained regression curves (for light vehicles and light motor vehicles), a calibration correction is obtained as a function of vehicle velocity:

$$\Delta L_{WA}^{LV-LMV} = -10.8 \cdot \log\left(\frac{v}{v_o}\right) - 23.4. \qquad (21)$$

Then, by comparing the sound power level relationships for heavy vehicles (our measurements) and heavy vehicles (CNOSSOS method), a calibration correction is obtained in the form of:

$$\Delta L_{WA}^{HV-HV(CNOSSOS)} = -3.3 \cdot \log\left(\frac{v}{v_o}\right) + 7.6 \,. \tag{22}$$

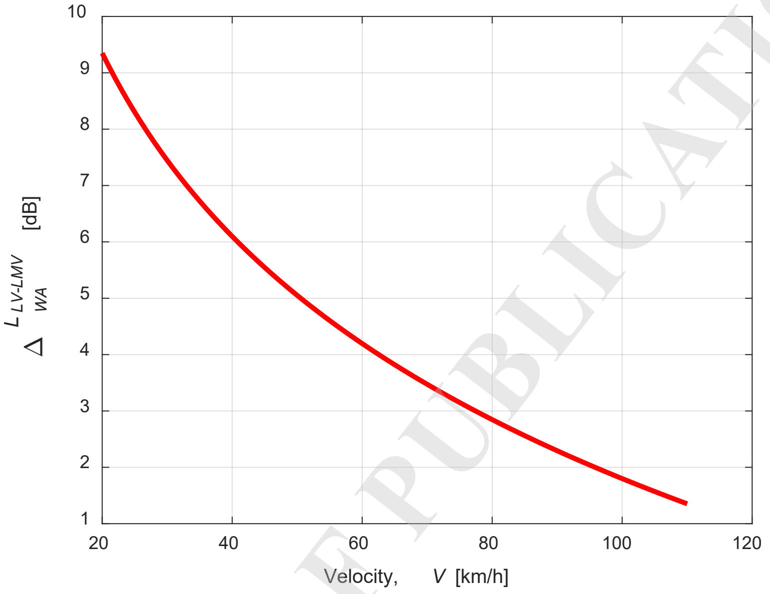


Fig. 23. The values of the correction $\Delta \mathbf{L}_{\mathbf{WA}}^{\mathbf{LV-LMV}}(\mathbf{v})$ (eq. (21))

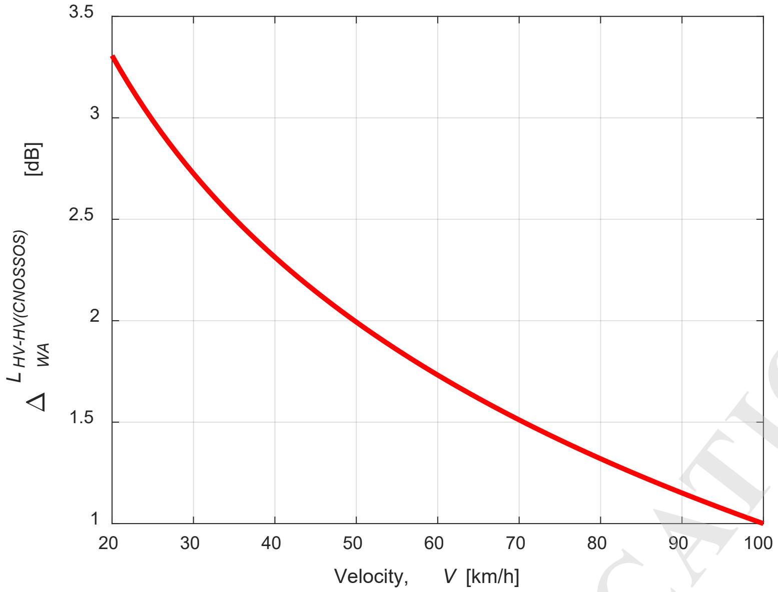


Fig. 24. The values of the correction $\Delta\mathbf{L}_{\mathbf{WA}}^{\mathbf{HV-HV(CNOSSOS)}}(\mathbf{v})$ (eq. (22))

In this paper, a detailed analysis of the sound power level spectra obtained from the noise measurements – for selected vehicle velocity ranges – and the L_{WA} spectra determined from the CNOSSOS method was performed (Fig. 25 – Fig. 29).

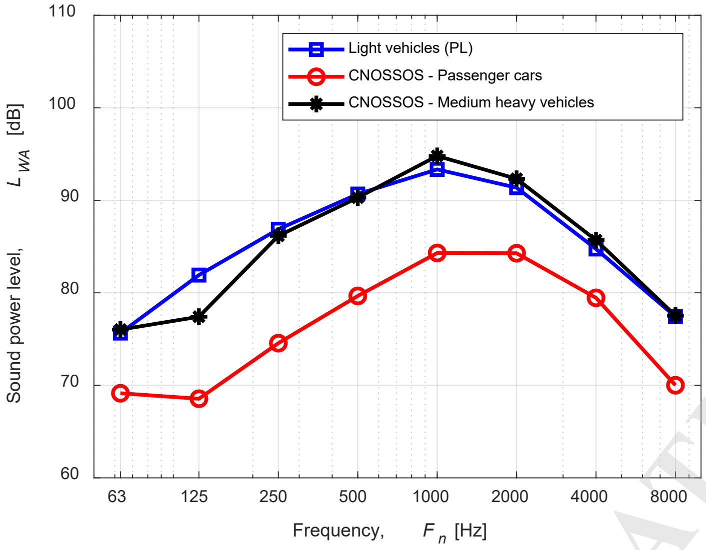


Fig. 25. The A-weighted sound power level in octave frequency bands of light vehicles (determined on the basis of noise measurements, PL) and medium heavy vehicles (CNOSSOS method), at the velocity of v = 35 km/h

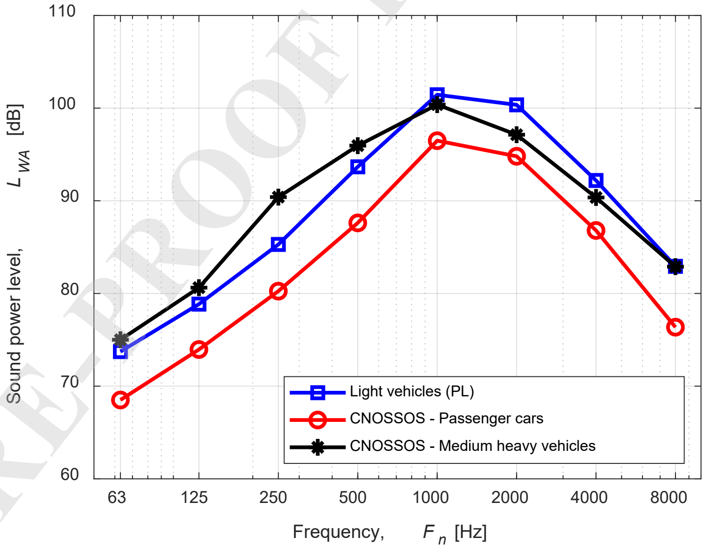


Fig. 26. The A-weighted sound power level in octave frequency bands of light vehicles (determined on the basis of noise measurements, PL) and medium heavy vehicles (CNOSSOS method), at the velocity of v = 65 km/h

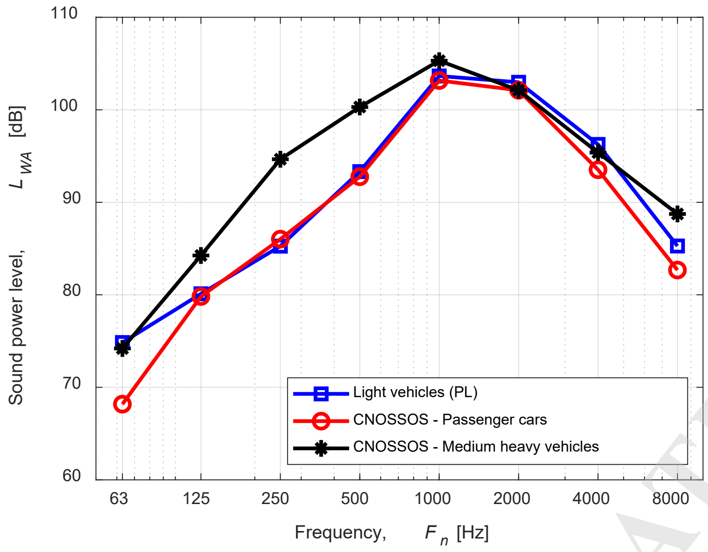


Fig. 27. The A-weighted sound power level in octave frequency bands of light vehicles (determined on the basis of noise measurements, PL) and medium heavy vehicles (CNOSSOS method), at the velocity of v = 105 km/h

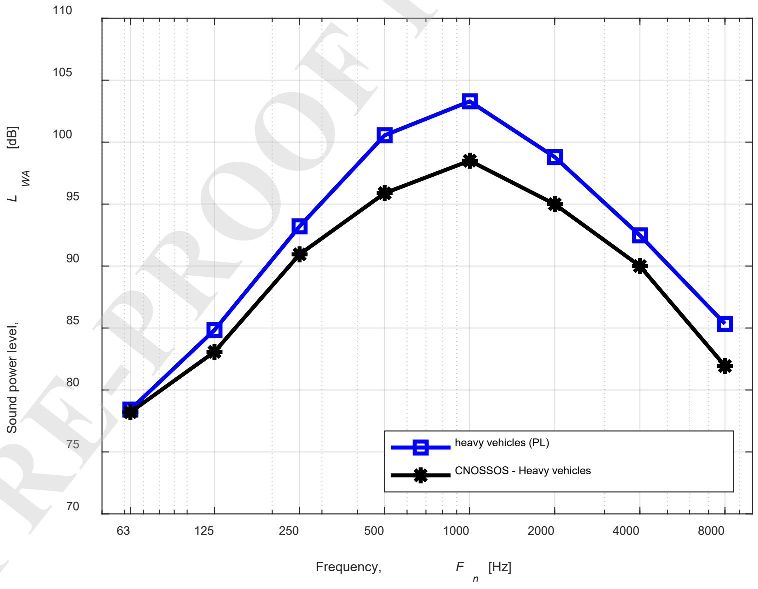


Fig. 28. The A-weighted sound power level in octave frequency bands of heavy vehicles (determined on the basis of noise measurements, PL) and heavy vehicles (CNOSSOS method), at the velocity of v = 35 km/h

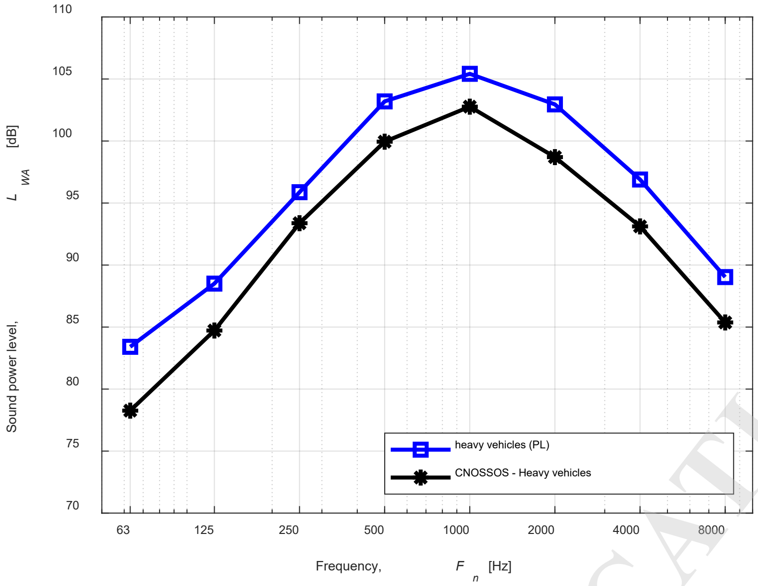


Fig. 29. The A-weighted sound power level in octave frequency bands of heavy vehicles (determined on the basis of noise measurements, PL) and heavy vehicles (CNOSSOS method), at the velocity of v = 65 km/h

The analysis of the presented data allows us to conclude that the shape of the spectra determined on the basis of measurements of the sound power level, L_{WAn}, is similar to the shape of the L_{WAn} spectra calculated on the basis of relationships from the CNOSSOS method. For low vehicle velocities, the spectrum of light vehicles (our measurements) is practically the same as that of medium heavy vehicles (Fig. 25). As the traffic speed increases (Fig. 27), the spectrum of the sound power level of light vehicles is similar to that of light motor vehicles.

In the case of heavy vehicles, the shape of the sound power level spectra determined from acoustic measurements and those determined using the CNOSSOS method are similar, but the spectra are shifted relative to each other. Larger values of sound power level are found for vehicles measured during acoustic measurements.

6. The verification of the CNOSSOS traffic noise prediction method

To verify the CNOSSOS noise prediction model, the short-term equivalent sound level, $L_{Aeq,Ti}$, measurements were performed for the time interval T_i = 15 min. Simultaneously the traffic volume was measured (the number of light and heavy vehicles).

In addition, for each measurement carried out at T_i = 15 min, several to a dozen pass-by times were measured (on a road section of known length) separately for light and heavy vehicles. Based on these measurements, the mean (arithmetic) traffic speed was determined for each equivalent sound level measurement. The number of measured equivalent sound levels was 101.

During the measurements, the atmospheric conditions were as follows: wind speed < 5m/s, air temperature: 15-26 °C, humidity 30-60%

The measurements were performed near the national road 11, at a distance of 7.5 m from the centre of the nearest traffic lane. The road surface was in good condition (several years since it was laid).

The acoustic calculations were carried out as follows: in the first step, the equivalent A-weighted sound level was calculated using measured traffic volume and average traffic speeds for light and heavy vehicles according to the CNOSSOS method. The values obtained were then compared with the equivalent sound level values measured during the measurements. The resulting relationship between the calculated and measured equivalent sound level values is shown in Fig. 30.

In the second step, the equivalent sound level was calculated again, taking into account the determined calibration correction for light and heavy vehicles, depending on the traffic speed and vehicle category (eq. (21) and (22)). The obtained values were also compared with the measured values. The resulting relationship between the calculated and measured equivalent sound level values is shown in Fig. 31.

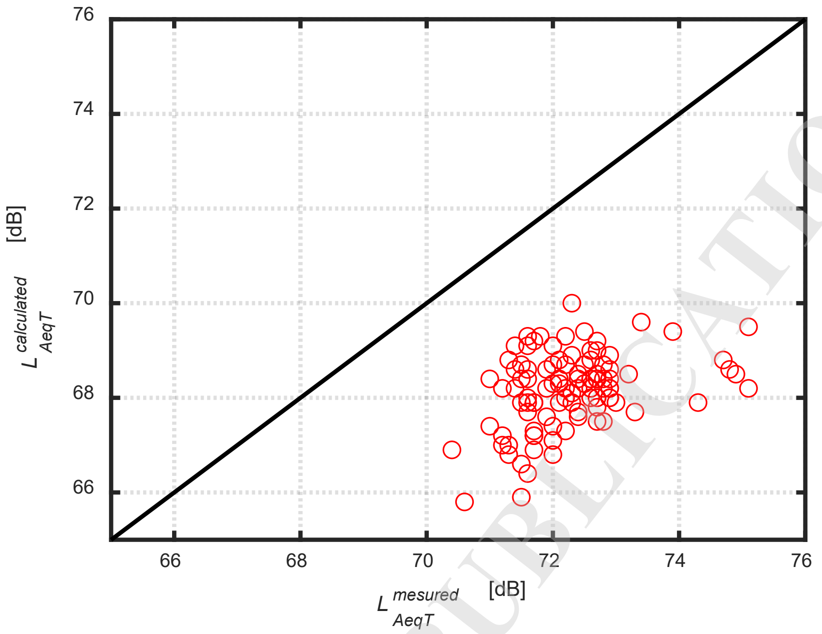


Fig. 30. Comparison of measured and calculated short-term A-weighted equivalent sound level (using the CNOSSOS method)

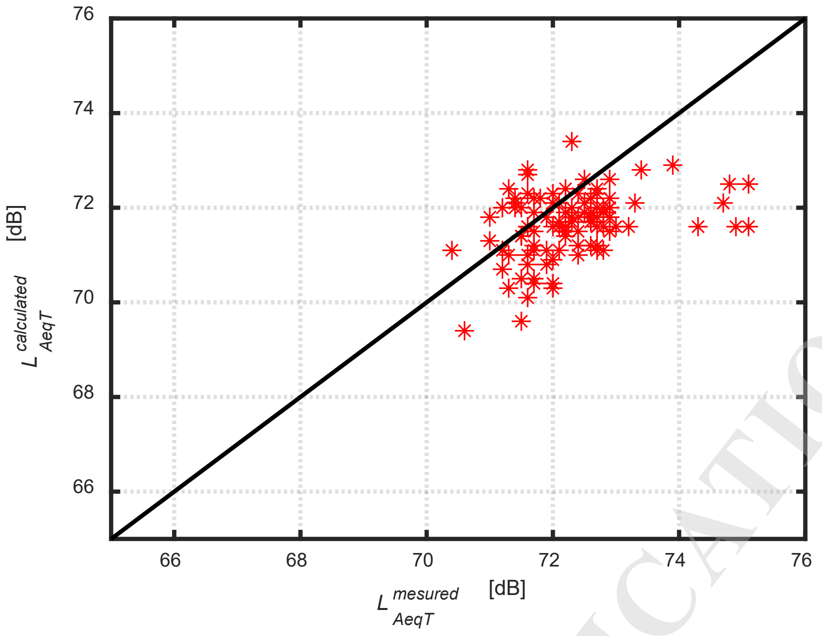


Fig. 31. Comparison of measured and calculated short-term A-weighted equivalent sound level (using the CNOSSOS method) – taking into account corrections determined in the paper

As can be seen from the presented data, the inclusion of a correction to the sound power level for light and heavy vehicles as a function of vehicle velocity in the calculation of the A-weighted equivalent sound levels significantly improves the agreement between the results obtained from acoustic measurements and calculations. The average error between measured and calculated values of equivalent sound level is 5.1 dB (Fig. 30), while when the correction for sound power level is taken into account, the average error is only 1.6 dB (Fig. 31).

Many studies have compared the results obtained using the CNOSSOS method.

In the paper by (Kokkonen et al., 2016), it was shown that the CNOSSOS method does not provide comparable results for Finnish vehicles compared to existing Nordic data. Nordic road surfaces are much rougher than those in Central Europe (due to winter conditions and studded tyres), resulting in higher overall noise levels. For light vehicles (category 1), the differences in rolling noise between Nord2000 and CNOSSOS-EU are up to 3.2 dB in total LWA at different speeds. For medium-heavy and heavy vehicles (categories 2 and 3), these vehicles have significantly higher sound power levels of rolling noise in the Nordic countries. The differences in drive noise for medium-heavy vehicles (Nord2000 vs. CNOSSOS-EU) reach 6.6dB in individual frequency bands, and the difference in total LWA is up to 4.6 dB.

In the paper by (Peeters, 2018), an attempt was made to apply and test the CNOSSOS method in Dutch conditions. The results clearly show that the differences between the sound power levels for vehicles traveling in the Netherlands and the LWA values obtained from the CNOSSOS method are significant. This study clearly recommends that Member States should not use the default sound power coefficients included in the CNOSSOS method.

The next paper by (Khan et al., 2021) shows that the CNOSSOS method differs from Nord2000 by 1.4–2.8 dBA, and in some cases, the differences reach 3–4 dBA. In Nordic countries, the differences in LWA between CNOSSOS-EU and Nord2000 range from 3 to 6 dB (rolling and propulsion noise). In the Netherlands and Denmark, the differences reach 2–4 dB, which confirms the need for local calibration of emission coefficients.

The above analysis of several selected articles and the results obtained in this study allow us to conclude that it is necessary to verify the sound power level of motor vehicles (of various categories) in each EU country in the context of applying the CNOSSOS method.

7. Conclusions

This paper compares the sound power levels, $L_{WA}(V)$, as a function of traffic velocity for light and heavy vehicles, determined based on noise measurements (vehicle classification according to the French noise prediction method), with the corresponding $L_{WA}(V)$ values obtained from the CNOSSOS noise prediction method for three vehicle categories. For this purpose, single pass-by noise measurements were conducted on several hundred light vehicles and several hundred heavy vehicles.

The obtained $L_{WA}(V)$ relationship for light vehicles was compared directly with the relationship for light motor vehicles and medium heavy vehicles determined by the CNOSSOS method. In both cases, the differences between these values were determined as a function of vehicle velocity.

Comparing the sound power level of light vehicles and light motor vehicles from the CNOSSOS method, the differences range from approx. 9 dB – for a vehicle velocity of 30 km/h to approx. 1 dB – for a vehicle velocity of 110 km/h. Comparing the sound power level of light vehicles and medium heavy vehicles from the CNOSSOS method, the differences range from approx. 1 dB – for a vehicle velocity of 30 km/h to approx. 0dB – for a vehicle velocity of 110 km/h.

As can be seen, smaller differences were obtained when comparing the relationship of light vehicles – obtained on the basis of noise measurements and medium heavy vehicles from the CNOSSOS method. Therefore, it should be concluded that the values of the sound power level of medium heavy vehicles correlate better with the values of the sound power level of light vehicles in Poland. It should be underlined, however, that – despite a large number of noise measurements carried out for light vehicles – the data come from only one measurement scenario. Therefore, in order to unequivocally confirm the above conclusion, the noise measurements should also be conducted in other measurement scenarios (close to the other roads). Nevertheless, it is worth trying already at this stage to find out why there are such large differences between the sound power level of light vehicles and light motor vehicles (CNOSSOS method). Most likely, the differences are caused primarily by the poorer technical condition of motor vehicles on Polish roads and the poorer technical condition of the road surface (to a lesser degree). This conclusion is supported by the fact that the greatest differences occur for low vehicle velocity, for which propulsion noise dominates. For higher vehicle velocities – for which rolling noise becomes the dominant noise source – the differences in sound power level values are smaller.

A comparison of the sound power level values determined from the noise measurements of heavy vehicles with the sound power level determined from the CNOSSOS method shows that the differences range from 3.3 dB – for a vehicle velocity of 30 km/h – to approximately 1 dB – for a vehicle velocity of 100 km/h. The explanation for these differences in sound power level values is similar to that for light vehicles.

In order to validate the CNOSSOS noise prediction method, the short-term equivalent sound level, $L_{Ae,T}$ (T = 15 min.), was measured. During the measurements, 101 values of $L_{Ae,T}$ were measured. In addition, the average traffic speed was measured during each $L_{Ae,T}$ measurement.

The measured $L_{Ae,T}$ values were then compared with the values that were calculated using the CNOSSOS method and the measured traffic intensity (the number of light and heavy vehicles) and average traffic speed. In the first step, the measured $L_{Ae,T}$ values were compared with the calculated values, with the measured number of light vehicles assigned to the medium heavy vehicle category. In the second step, the measured $L_{Ae,T}$ values were compared with the calculated values. The measured number of light vehicles was assigned to the medium-heavy vehicle category, with corrections applied based on vehicle type and traffic speed, as determined in this study. After taking the correction into account, the average difference between the measured and calculated sound power level values is 1.6 dB, thereby improving the accuracy of the calculation by 3.5 dB.

8. References

Attenborough, K., Li, K. M., & Horoshenkov, K. (2007). *Predicting Outdoor Sound*.

Commission Directive (EU) 2015/996 of 19 may 2015. (2015). *Commission Directive (EU) 2015/996 of 19 may 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council*.

Directive 2002/46/EC of the European Parliament and of the Council of 10 June 2002. (2002). *Directive 2002/46/EC of the European Parliament and of the Council of 10 June 2002 on the approximation of the laws of the Member States relating to food supplements*.

Dutilleux, G., Defrance, J., Gauvreau, B., & Besnard, F. (2008). The revision of the French method for road traffic noise prediction. *Proceedings - European Conference on Noise Control*, 875–880. https://doi.org/10.1121/1.2933163

ECAC.CEAC Doc 29 4th Edition. (2016). *ECAC.CEAC Doc 29 4th Edition Report on Standard Method of Computing Noise Contours around Civil Airports Volume 3, Part 1 - Reference Cases and Verification Framework*.

Gołębiewski, R. (2007). Simple methods for determination of the acoustical properties of ground surfaces. *Archives of Acoustics*, *32*(4).

Gołębiewski, R., & Makarewicz, R. (2002). Engineering formulas for ground effects on broad-band noise. *Applied Acoustics*, *63*(9), 993–1001. https://doi.org/10.1016/S0003-682X(02)00007-5

Hamet, J. F., Besnard, F., Doisy, S., Lelong, J., & Le Duc, E. (2010). New vehicle noise emission for French traffic noise prediction. *Applied Acoustics*, *71*(9), 861–869. https://doi.org/10.1016/j.apacoust.2010.05.003

Hammer, E., Egger, S., Saurer, T., & Bühlmann, E. (2016). *Road traffic noise emission modelling at lower speeds TRAFFIC NOISE EMISSION MODELLING AT LOWER SPEEDS*. https://www.researchgate.net/publication/305000128

Heutschi, K. (2004). SonRoad: New Swiss Road Traffic Noise Model. In *ACTA ACUSTICA UNITED WITH ACUSTICA* (Vol. 90).

IEC 61672-1. (2013). *IEC 61672-1:2013, Electroacoustics - Sound level meters - Part 1: Specifications*.

ISO 9613-2:2024. (2024). *ISO 9613-2:2024 Acoustics — Attenuation of sound during propagation outdoors Part 2: Engineering method for the prediction of sound pressure levels outdoors*.

Kephalopoulos, S., Paviotti, M., & Anfosso-Lédée, F. (2012). *Common noise Assessment Methods in Europe (CNOSSOS-EU)*. https://doi.org/10.2788/31776

Khan, J., Ketzel, M., Jensen, S. S., Gulliver, J., Thysell, E., & Hertel, O. (2021). Comparison of Road Traffic Noise prediction models: CNOSSOS-EU, Nord2000 and TRANEX. *Environmental Pollution*, *270*. https://doi.org/10.1016/j.envpol.2020.116240

Kokkonen, J., Kontkanen, O., & Maijala, P. (2016). *CNOSSOS-EU Noise Model Implementation in Finland* (Conference paper, Ed.). https://www.researchgate.net/publication/307907554

Kragh, J., Thysell, E., Finne, P., Pedersen, F., Michelsen, L., & Fryd, J. (2023). The Nord2000 prediction method for road traffic noise–outline and validation, and application in environmental noise mapping. *The Journal of the Acoustical Society of America*, *154*(1), 547–555. https://doi.org/10.1121/10.0020275

Makarewicz, R., & Gołębiewski, R. (2006). Estimation of the A-weighted long term average sound level. *Acta Acustica United with Acustica*, *92*(4), 116–120. https://doi.org/10.1016/j.apacoust.2016.04.016

Makarewicz, R., & Gołębiewski, R. (2016). The impact of multi-lane traffic flow distribution on road noise variability. *Noise Control Engineering Journal*, *64*(3), 354–362. https://doi.org/10.3397/1/376385

Makarewicz, R., & Gołębiewski, R. (2016). The uncertainty of noise composed of separate sound events. *Archives of Acoustics*, *41*(1). https://doi.org/10.1515/aoa-2016-0013

Makarewicz, R., & Kokowski, P. (1997). Simplified model of the ground effect. *The Journal of the Acoustical Society of America*, *101*(1), 372–376. https://doi.org/10.1121/1.417982

Ministry of Housing, S. P., & the Environment (VROM). (2001). *Calculation and Measurement Guidelines for Railway Traffic Noise (Reken- en Meetvoorschrift Railverkeerslawaai)*. https://wetten.overheid.nl/BWBR0004171

Nijland, H. A., & Van Wee, G. P. (2005). Traffic Noise in Europe: A Comparison of Calculation Methods, Noise Indices and Noise Standards for Road and Railroad Traffic in Europe. *Transport Reviews*, *25*(5), 591–612. https://doi.org/10.1080/01441640500115850

Pallas, M.-A., Le Bellec, A., Ecotiere, D., Litou, G., Dunez, P., & Pot, G. (2024, August). CNOSSOS-FR: are current road traffic noise emission coefficients still representative of today's vehicle fleet and roads? *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*. https://doi.org/https://doi.org/10.3397/IN_2024_3927[ince.publi...onnect.com],[ince.publi...onnect.com]

Peeters, B., & van Blokland, G. (2018). Correcting the CNOSSOS-EU road noise emission values. *Proceedings of Euronoise 2018*, 1245–1251.

Peeters, B., & v.Blokland, G. (2007). *IMAGINE Improved Methods for the Assessment of the Generic Impact of Noise in the Environment The Noise Emission Model For European Road Traffic*. www.imagine-project.org

Regulation of the Minister of the Environment of 16 June 2011. (2011). Regulation of the Minister of the Environment of 16 June 2011 . In *Regulation of the Minister of the Environment of 16 June 2011 (Journal of Laws No 140, item 824)* (Vol. 824).

Sandberg, U., & Ejsmont, J. A. (2002). *Tyre/road noise reference book*. Informex.

Wilson, D. K., Andreas, E. L., Weatherly, J. W., & Pettit, C. L. (2006, December). INTER-NOISE 2006 Uncertainty in outdoor sound propagation predictions as determined from high-resolution atmospheric simulations. *Proceedings of INTER-NOISE 2006*.