Simulation and Assessments of Urban Traffic Noise by Statistical Measurands using mPa or dB(A) Units

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Abstract. In this paper, some results of heavy vehicle traffic measurements were used to simulate noise measurands by the Cnossos-EU method for this purpose. Heavy vehicle traffic volume and velocity were recorded by a permanent automatic monitoring station. The noise was calculated in octave bands. The results were described using parameters such as the median, average peak noise, average maximum noise, first and third quartiles and relative measures of noise. The values of these parameters were expressed in mPa or dB(A). It was shown that maximum values of the acoustic pressure (mPa) occur for the frequency of f_0=500 Hz but of the acoustic pressure level (dB(A)) for f_0=1000 Hz. The dispersion of noise and type A uncertainty of the results were evaluated. Depending on the adopted noise unit, different shapes and distribution parameters were obtained.

Introduction

The ultimate scope of the Directive 2015/996/EC is to enhance the reliability and comparability of noise data in EU [1, 2]. The CNOSSOS-EU method is used for that purpose. Traffic noise and vehicle monitoring systems using permanent monitoring terminals were constructed and installed in Kielce - an example of a medium-size town (a population of approximately 200,000) located in the southern part of central Poland. The measurements results of heavy vehicle traffic flow from two vehicular lanes running towards the town and two lanes running towards Kraków were analysed. Computer simulation of the acoustic pressure in octave bands, in accordance with the CNOSSOS-EU model, were carried out.

Traffic volume and noise measurements

Traffic noise and volumes analyzed in this study were measured throughout the year by a permanent station located in Krakowska Street in Kielce [3]. The measurements from two vehicular lanes running towards the town and two lanes running towards Kraków were analyzed. The station includes a road radar box, a sound level meter and a weather station. The traffic volume and speed were measured on each lane by a WAVETRONIX digital radar with an operating frequency of 245 MHz. A microphone was positioned at a distance of 4 m from the edge of the lane at a height of 4 m. The measurements were documented in one hour intervals throughout the entire 24 hours of the day (1:00-24:00) throughout the year 2013. The traffic volume and speed data were recorded every 1 minute (buffer) and the averaged results were reported every 1 hour. Counts were used to calculate the traffic flow (understood as the sum of the number of vehicles recorded within a time interval) and average vehicle speed, split into hours. Detailed analyzes were carried out for the day sub-interval (data registered from 6.00 to 18.00) of a 24-hour period because it is the most burdensome time interval of the whole day. The results analyzed contained heavy vehicle traffic flow together with vehicle average speed measurements. In this work, analysis was based on the measurements on all working days of 2013. In this study, calculated noise parameter values are expressed in dB(A) and mPa. Advantages of the noise scale in dB(A) are widely known, but its weakness is non-linearity [4] and difficulties in performing some mathematical functions (operations), e.g. division, multiplication, analysis of variability, analysis of measurement uncertainty [5]. These problems are not there when we express the sound pressure in mPa. However, the scale of noise in mPa also has its weaknesses commonly known in the literature. Interpretative differences in the values of some road traffic noise parameters determined in dB(A) or mPa were pointed out.

CNOSSOS-EU modeling of traffic noise

In many cities, traffic measurement systems record only traffic volume and speed. To make the full use of data obtained in this way to assess environmental pollution, a noise model is still needed. In the Cnossos-EU model, the sound power level was divided into two parts – propulsion ($L_{WP,i,m}(v_m)$) and rolling ($L_{WR,i,m}(v_m)$) noise [2]. The sound power level emitted by one of the vehicle category *m* and in octave band number *i* is the following:

$$L_{W,i,m}(v_m)=10\cdot \log\left(10^{L_{WR,i,m}(v_m)/10}+10^{L_{WP,i,m}(v_m)/10}\right) \tag{1}$$

where: *i* – number of octave bands, from *i*=2 for f_0=125 Hz up to *i*=7 for f_0=4000 Hz, *m* – vehicle categories (*m*=1-light motor vehicles, *m*=2-medium heavy vehicles, *m*=3-heavy vehicles, *m*=4-powered two-wheelers), v_m –rolling speed of vehicle category *m*. If a steady traffic flow of vehicles of category *m* per hour is assumed with an average speed v_m the directional sound power level per 1 m per frequency band *i* of the source line determined by the vehicle flow is defined by:

$$L_{Weq,i,m}=L_{W,i,m}(v_m)+10\cdot \log\left(\frac{Q_m}{1000\cdot v_m}\right) \tag{2}$$

where: Q_m – traffic flow of vehicles of category *m* per hour with an average speed v_m. The acoustic pressure to the second power, measured by microphone, generated by vehicles category *m* in octave band *i* we can calculate according to the following formula:

$${p_{i,m}}^2=\sum_{j=1}^{Q_t} p_0^2 \cdot 10^{\left(L_{Weq,i,m}+10\cdot \log\left(\frac{l_S}{Q_t}\right)-20\log(R_j)-8\right)\cdot 0,1} \tag{3}$$

where: l_S - length of a source line with homogeneous traffic, Q_t – amount of source line segments, p_0- reference sound pressure equal to $2\cdot 10^{-5}$ Pa, *j* – index of source line segments, R_j – distance of the center of the *j* source line segments from the measuring microphone. The correction coefficients for deviations from reference conditions were not taken into account in the paper.

The tests [4] for the components contained in the acoustic signals were based on the following percentiles: C_{10}, C_{25}, C_{50}, C_{75}, C_{90}, and C_{99} defined as the values of noise exceeded by the signal, respectively in 90% (average background noise level), 75%, 50% (median), 25 %, 10% (av. peak level) or 1% (av. maximum noise) of the measurement period. Standard uncertainty of the acoustic pressure, determined in the Type A evaluation, can be calculated from the following relationship:

$$u_A = \sqrt{\frac{1}{n(n-1)}\sum_1^n (p_i-\bar{p}_i)^2} \tag{4}$$

where *n* is the amount of data.

The authors analyzed acoustic pressure values p_i expressed in units of mPa to be able to easily compare the fixed components (median) and variable components of the acoustic pressure signals. The tests for the variable components contained in the signals were based on the following measures: coefficient of variation [7], quartile deviation (Q_{31}), quartile variation coefficient (V_q). The average quartile deviation is the measure of dispersion of the variable:

$$Q_{31} = 0.5 \cdot \left[C_{75}(p_i) - C_{25}(p_i) \right] \tag{5}$$

By relating it to the median, the positional coefficient of variation is calculated from (6):

$$V_q = \frac{Q_{31}}{Med} \cdot 100\% \tag{6}$$

The positional coefficient of variation and the quartile coefficient of dispersion are positional measures of the data between the first and third quartiles.

It was assumed in this paper that the acoustic source are the following: entry traffic on two lanes that leads from Kraków towards Kielce and exit traffic on two lanes that leads from Kielce towards Kraków. It was assumed that the linear acoustic source is located along the symmetry axis of the respective lanes. Thus, the work analyzed the results of computer simulations of acoustic pressure in the place where the measuring microphone is located, i.e. at a distance of 4 m from lanes and at a height of 4 m for two incoherent acoustic sources using measurements of relevant parameters of road vehicles. The acoustic pressures generated by these sources were also added up, which allowed for the assessment of total noise generated by the examined road section. In [3], the values of the equivalent sound level (for all vehicles category) experimentally measured and calculated according to the Cnossos-EU method, were compared by calculating the RMSE parameter. The calculated value of this parameter is about 1 dB.

Results

Shapiro-Wilk and Jarque-Bera tests showed that the acoustic pressure distributions generated by heavy vehicles are not compatible with the normal distribution. Histograms of acoustic pressure distributions for heavy vehicles confirmed deviations from the normal distribution. Examples of histograms in the octave band f_0 = 500 Hz are shown in Figure 1. Values of selected data distribution parameters are the following: for figure 3a: skewness is 2.06 and kurtosis is 13.33, for figure 3b: skewness is -0.68 and kurtosis is 10.86. Note the diverse forms of these distributions.

Table 1 compiles the analysis results for acoustic pressure parameters in selected octave bands, on working days for the day sub-interval, generated by heavy vehicles calculated by the Cnossos-EU method. The calculations show that maximum values of median as well as percentiles C_{10} and C_{90} were obtained in an octave band with a central frequency of f_0 = 500 Hz. But for the percentile C_{99} the maximum value is in the octave band of f_0=125 Hz. The minimum values of these parameters were obtained in the octave with a frequency of f_0 = 4000 Hz. The values of the parameter C_{99} in relation to the value of C_{90} are as follows: in the octave with a frequency of f_0 = 125 Hz they are higher by about 138% and for the frequency of f_0=500 Hz, f_0=1000 Hz or 2000 Hz by about 80%. Values of positional coefficients of variation are about 8% and uncertainty u_A is less than 0.10 mPa. Statistical analysis of the acoustic pressure values shows that the values of Q_{31} for heavy vehicles fall within the range of 0.4 mPa to 1.6 mPa.

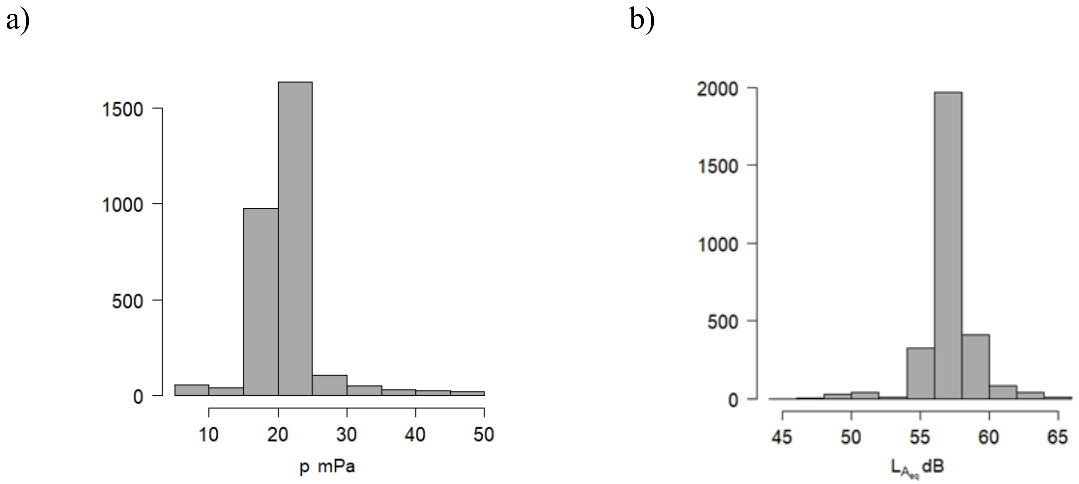

Fig. 1 Histograms of noise distributions in octave band f_0=500 Hz for heavy vehicles on working days of 2013: a) acoustic pressure in mPa, b) acoustic pressure level in dB(A).

Table 1. The values of sound pressure in units mPa calculated by the Cnossos-EU method, for heavy vehicles on working days for the day sub-interval

Central frequency band f_0 [Hz]	*Med.* [mPa]	Q_{31} [mPa]	*Vq* [%]	u_A [mPa]	C_{10} [mPa]	C_{90} [mPa]	C_{99} [mPa]
125	16.73	1.33	7.97	0.10	14.24	20.04	47.67
250	18.58	1.45	7.80	0.10	15.80	22.02	46.96
500	20.75	1.58	7.62	0.09	17.71	24.36	43.52
1000	19.04	1.44	7.54	0.08	16.23	22.16	39.09
2000	10.51	0.80	7.63	0.05	8.96	12.32	23.60
4000	5.78	0.44	7.68	0.03	4.92	6.81	13.76

Table 2. The values of sound pressure level in units dB(A), calculated by the Cnossos-EU method for heavy vehicles on working days for the day sub-interval

Central frequency band f_0 [Hz]	*Med.* [dB(A)]	Q_{31} [dB(A)]	*Vq* [%]	u_A [dB(A)]	C_{10} [dB(A)]	C_{90} [dB(A)]	C_{99} [dB(A)]
125	42.35	0.69	1.63	0.04	40.95	43.92	51.44
250	50.76	0.68	1.33	0.04	49.35	52.24	58.81
500	57.12	0.66	1.16	0.03	55.74	58.51	63.55
1000	59.57	0.66	1.10	0.03	58.19	60.89	65.82
2000	55.61	0.66	1.19	0.04	54.23	56.99	62.64
4000	50.22	0.67	1.33	0.04	48.83	51.65	57.75

Table 2 summarizes the results of the data analysis for the values of acoustic pressure level parameters in selected octave bands, on working days for the day sub-interval, generated by heavy vehicles calculated by the Cnossos-EU method. Maximum values of median as well as percentiles C_{10} and C_{90} or C_{99} were obtained in the octave band with a central frequency of f_0=1000 Hz. The minimum values of these parameters were obtained in the octave band with a frequency of f_0=125 Hz.

The values in octave bands of median and percentile C_{99} of noise for heavy vehicles on working days for the day sub-interval are presented in Figure 2.

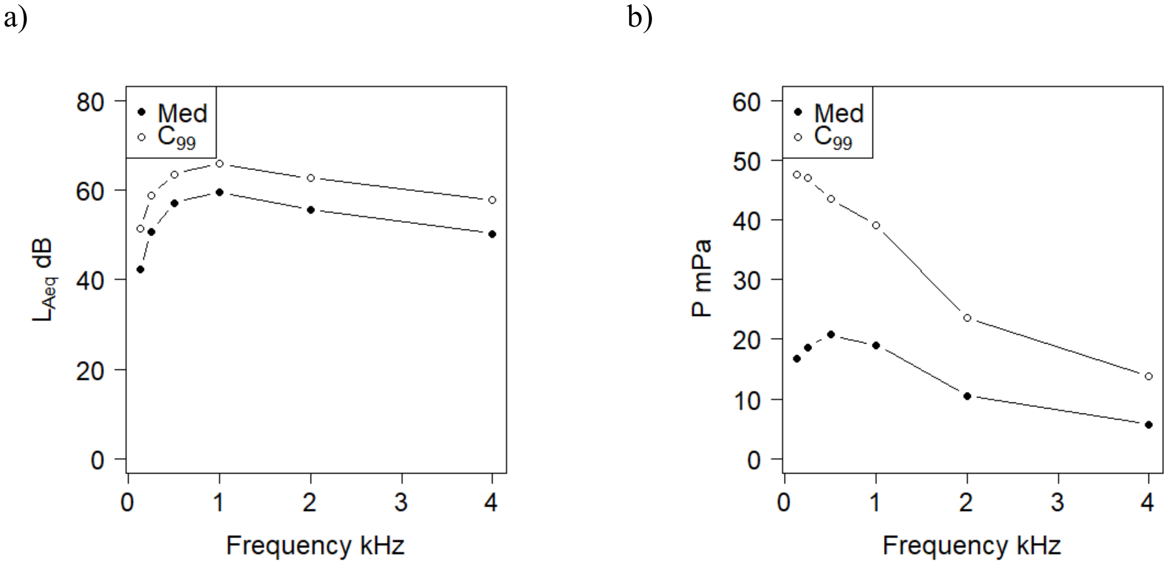

Fig. 2 The values in octave bands of median and percentile C_{99} of noise calculated by the Cnossos-EU method for heavy vehicles on working days for the day sub-interval: a) acoustic sound pressure level in dB(A) units, b) acoustic sound pressure in mPa units.

It should be noted that the maximum median value is in the octave band of f_0=500 Hz or f_0=1000 Hz depending on the adopted scale of units. For the C_{99} percentile expressed in the units of dB(A), the maximum value is for f_0=1000 Hz. However, when it is expressed in the units of mPa, its value decreases systematically in each subsequent frequency band. The plots of the C_{99} parameter expressed in dB(A) and mPa units have a slightly different character. In the first case, this waveform has a local extreme for 1 kHz, in the second case there is no such extreme.

Conclusions

Statistical tests and histograms confirmed deviations from the normal distribution. The values of selected data distribution parameters depend on the units used. For heavy vehicles, the maximum values in mPa for median, percentiles C_{10} and C_{90} were obtained in the octave band with a center frequency of f_0=500 Hz. The minimum values of these parameters were obtained in the octave band with a center frequency f_0=4000 Hz. The values of the parameter C_{99} in relation to the value of C_{90} are as follows: in the octave band with a frequency f_0=125 Hz they are higher by about 138% and for the frequency of f_0=500 Hz or f_0=1000 Hz by about 80%. The values of the coefficients of variation V_q are similar in all octave bands but depend on the value of central frequency. For the same parameters but in dB(A) units, the maximum values were obtained in the octave band with a center frequency of f_0=1000 Hz and the minimum in the octave band of f_0=125

Hz. For the C_{99} percentile expressed in the units of dB(A), the maximum value is for f_0=1000 Hz. However, when it is expressed in the units of mPa, its maximum value is in the octave band of f_0=125 Hz and decreases systematically in each subsequent frequency band. The research showed that the physical and metrological aspects of noise are more convenient to analyze using mPa but its environmental impact is better described by the dB(A) scale.

References

[1] G. Dutilleuks, B. Soldano, Matching directive 2015/996/EC (Cnossos-EU) and the French emission model for road pavements, Euronoise 2018 Conf. Proc., 2018, 1213-1218.

[2] S. Kephalopoulos, M. Paviotti, F. Anfosso-Lédée, D. Van Maercke, S. Shilton, N. Jones, Advances in the development of common noise assessment methods in Europe: The CNOSSOS-EU framework for strategic environmental noise mapping, Sci. Total Environ. 482-483 (2014) 400-410. https://doi.org/10.1016/j.scitotenv.2014.02.031

[3] A. Bąkowski, V. Dekýš, L. Radziszewski, Z. Skrobacki, Validation of Traffic Noise Models, AIP Conf. Proc. 2077 (2019) art. 020005. https://doi.org/10.1063/1.5091866

[4] W. Batko, B. Stępień, Type A Standard Uncertainty of Long-Term Noise Indicators, Archives of Acoustics 39 (1) (2014) 25–36. https://doi.org/10.2478/aoa-2014-0004

[5] J. Pietraszek, A. Szczotok, M. Kolomycki, N. Radek, E. Kozien, Non-parametric assessment of the uncertainty in the analysis of the airfoil blade traces, Metal 2017 26th Int. Conf. on Metallurgy and Materials, Ostrava, Tanger, 2017, 1412-1418.

[6] J. Pietraszek, N. Radek, K. Bartkowiak, Advanced statistical refinement of surface layer's discretization in the case of electro-spark deposited carbide-ceramic coatings modified by a laser beam, Solid State Phenom. 197 (2013) 198-202. https://doi.org/10.4028/www.scientific.net/SSP.197.198

[7] A. Bąkowski, L. Radziszewski, M. Žmindak, Analysis of the coefficient of variation for injection pressure in a compression ignition engine, Procedia Engineering 177 (2017) 297-302. https://doi.org/10.1016/j.proeng.2017.02.228