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Short Communication

Verifying Traffic Noise Analysis Calculation Models

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Abstract

This paper concerns choosing the best software for road noise simulation. Three independent parts of roads were analysed using three calculation programmes based on three mathematical models. The results of conducted measurements and analyses proved how important the selection of the right calculation programme for each numerical traffic noise simulation is. One should also be careful when choosing a calculation programme for rare traffic situations, such as bus terminals or transport bases. Despite striving to create an ideal calculation model for traffic noise considering the large number of changeable acoustic and non-acoustic parameters, engineers should also be informed about the criteria of usefulness of a programme (model) for a certain road situation.

Keywords: noise control, traffic noise, vehicle flow, predictive models

Introduction

The safe exploitation of technical structures such as a public road is connected not only with safety of traffic but also with minimization of its negative impact on the environment. The quality of the natural environment influences the comfort of life – especially the comfort of relaxation of inhabitants of both big cities and small villages [1]. Research connected with minimizing the bad impact of transport on the environment has been conducted all over the world for years. While doing acoustic analyses we should take into account the fact that there are many factors influencing the level of traffic noise. The most essential ones are: type, condition, and quality of road surface; the number of vehicles passing in a certain period of time, and their technical state; the intensity of traffic depending on the time of day; the number of road lanes; the distance from buildings protected acoustically; the changeability of traffic connected with traffic organization; and weather conditions.

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According to many World Health Organization (WHO) recommendations [2] and to a European Union directive [3], noise is treated as any other contamination of the environment. These documents include useful instructions on how to fight traffic noise, such as obligation of monitoring, preparing acoustic maps, or assessing impact on the environment. WHO recommends that the A-equivalent sound pressure level outside a building should not exceed 55 dB during the day and 45 dB at night. At such levels outside a building it is still possible to keep the right acoustic conditions inside, with windows set ajar or temporarily opened.

The inspiration for this paper was publications [4, 5] indicating the differences in acoustic simulation results while using commercial calculation programmes. In the publication [5] we can find the acoustic analysis for one section of a road in the open area at changeable traffic intensity conducted in some calculation methods used in the world. In this case the results show the difference even up to 4 dB. It is obvious that when applying programmes built on different algorithms we should get results more or less similar. An engineer using a certain calculation programme expects that the simulation results will allow him or her to draw technical conclusions necessary for project realization. In most cases he or she does not consider whether applying a different programme would provide better results describing the reality. When applying the recommended calculation algorithm, he or she assumes that the simulation results are right. Conducting our own acoustic analyses for projects of building or modernization of roads and for numerous degree dissertations as a supervisor, the authors have noticed significant discrepancies in results – especially during calculations done for sections of roads of unusual traffic structure.

The aim of this article is not to show exceeding permissible noise levels in analysed measurement points, but instead to indicate the possibility of the wrong choice of acoustic calculation programme in certain situations.

Estimating the equivalent sound pressure level regarding an existing road requires some measurement methods, as for example in [6]. In the case of acoustic prognosis done for newly designed or modernized sections of roads we use calculation methods.

Different countries use different calculation algorithms, often adjusted to the specific climate or traffic structure typical of the country. Most often recommended are: NMPB-Routes-96 [5, 7], CoRTN [5, 8], FHWA [9], RLS 90 [5, 10], and Nord2000 [11]. However, in countries like Poland, where there is not any recommended calculation method, estimating the equivalent traffic noise level is conducted according to a short procedure described in regulation [12]. According to [12], in each calculation case it is necessary to verify the calculation model by means of real field measurements. The criterion of similarity (W descriptor) included in [12] is described by the formula:

$$W = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(L_{zm,i} - L_{obl,i}\right)^2} \leq 2.5\,dB \qquad (1)$$

...where $L_{zm,i}$ is the measured value of noise descriptor [dB], $L_{obl,i}$ is calculated under the same conditions (value of noise descriptor [dB]), and n is the number of calculations and comparative measurements.

The value 2.5 is a standard deviation of the difference of measurement results and calculations. The value has been established so as to avoid tightening the accuracy criteria and in the same way to ensure maximum possible convergence of calculations and measurements of traffic noise. It must be noted that measurement methods used are characterized by the uncertainty range 2.5-3 dB; besides, the calculation algorithms in most cases are characterized by the accuracy of ±3 dB. Also, weather conditions influencing noise sound wave propagation bring in an essential inaccuracy and during measurements there are often applied so-called "assumed values" of these parameters.

In this article, the verification of a calculation programme was conducted on the basis of short-term, one-hour analyses, and also the equivalent sound pressure level was defined. Later in the article there are three examples of chosing the right calculation programme using the similarity criterion described by formula (1).

Experimental Procedures

The verification of a calculation programme was conducted on three independent sections of roads – A, B, and C – using in each case three calculation programmes: software I, II, and III. The software used in calculations was chosen freely from the many available on the market, but in the way that they meet the criteria of different calculation methods. In applied calculation programmes, the linear sound source is declared by giving average traffic intensity for a certain unit (the number of vehicles per hour and traffic structure) determining a heavy vehicles' percentage in general traffic. In software I the calculation algorithm is proposed by the author [13], in software II a French norm NMPB was implemented, and in software III CoRTN methodology is used.

Analysed sections of roads A, B, and C differ first of all in traffic structure, which is the number and type of vehicle passing there. In the case of Section C we have high-volume traffic, and in sections A and B we can describe the city traffic as low intensity. Moreover, in Section A we have additional disturbances caused by a small bus terminal. The comparative analysis of results using computer programmes was conducted by comparing the results of calculated sound pressure levels ($L_{obl,i}$) done for real (measured) one-hour traffic intensity in each measurement point with the results of field measurements of noise ($L_{zm,i}$) in these points. In both cases the referred time is one hour.

Software I and II were used to calculate the noise descriptor L_{Aeq} (equivalent sound pressure level – the steady sound level that, over a specified period of time, would produce the same energy equivalence as the fluctuating sound level actually occurring). Software III was used to calculate the descriptor L_{10} (the sound pressure level that is exceeded for 10% of the time, for which the given sound is measured). This was according to implemented norms in these programmes. It must also be mentioned that noise descriptor L_{10} gives the results, which are about 3 dB higher than descriptor L_{Aeq} [14, 15], which is valid for continuous high-volume traffic. [16] includes a linear relationship between L_{10} and L_{Aeq}: experimental points are fitted by linear equation $L_{10} = 0.92\, L_{Aeq} + 3.61$, with a correlation coefficient $R^2 = 0.965$.

Later in calculations, for software III it was assumed that $L_{obl,i} = L_{Aeq} = L_{10} - 3$ dB.

The field measurements were done identically for all sections of roads with cooperation with the accredited laboratory, in a way described below. The date of measurements was chosen so that weather conditions match exactly the meteorological parameters applied in programmes. It was determined that these are the following parameters: 10ºC, humidity 70%, pressure 1,000 hPa, and lack of wind.

The measurements were conducted by a digital SVAN 912AE portable sound analyser with wind cover, a multifunction device that is an integral meter of sound pressure level, and an octave and 1/3-octave analyser. It shows first-class accuracy, and applying digital processing of a measured signal enables simultaneous measurement of most parameters characterising the noise. Before and after measuring, the measurement track together with sound analyser was calibrated by a first-class calibrator. The whole measurement set had necessary calibration certificates. The controlling measurement points were 4.0 m above area level and at minimum 4.0 m distance from the building wall. In each measurement point there were three 10-minute noise measurements, making three samples. During measurements car traffic was registered independently for each point. Ten-second measurements of acoustic background were done when there was no traffic at all. Because of differences in measurements of background level and noise imission levels higher than 10 dB, it was assumed that the background does not influence measurement results. On the basis of conducted measurements we calculated an equivalent noise level $L_{Aeq} = L_{zm,i}$ and an extended uncertainty of evaluation of this level was determined. The extended uncertainty U_{R95} was calculated according to the procedure of accredited laboratory, taking into consideration the uncertainty of B type, which is connected with inaccuracy of measuring equipment, research procedures, and models of acoustic phenomena and uncertainty of A type, which concerns statistic scattering of measurements. It should be highlighted that field measurements were purposely conducted during the day so as to get traffic intensity of at least 300 vehicles per hour.

Results and Discussion

Road Section A

The analysed acoustic situation is connected with temporary exploitation of an old PKS bus station for local communication [17]. The location of the small terminal and controlling points is shown in Fig. 1.

The acoustic climate of an analysed section of road is shaped by car traffic, where vehicles are moving on nearby roads and on arrivals and departures stands, and also on the manoeuvring square of the terminal. The measurements were conducted for the section of the road opposite bus stops, where there are multiple dwellings most exposed to noise, concerning traffic at bus stops.

The locations of three controlling points were chosen as follows: point P1, near the edge of the road; points P2 and P3 near multiple dwellings that are closest and most exposed to noise. On the analysed section of road the traffic intensity was on average 350 vehicles per hour with 8% heavy vehicles and at the same time on average 80 vehicles per hour with 65% of heavy vehicles moving through the bus terminal. The measurements were done during the day between 10.00 and 12.30. Table 1 presents measurement results $L_{zm,i}$ and noise calculations $L_{obl,i}$ in measurement points.

On the basis of Table 2 it can be assumed that the calculation results done by software II do not meet the similarity criterion defined by formula (1). We got the correct calculation results using software I and III.

Table 1. Results of measurements and calculations.

Point No.	Measurement results $L_{zm,i}$	Extended uncertainty of measuring U_{R95}	Calculation results $L_{obl,i}$		
			I	II	III
	[dB]		[dB]		
P1	60.7	±1.6	60.2	66.2	63.7
P2	57.7	±1.4	57.4	58.3	57.3
P3	59.8	±1.8	58.6	63.4	59.8

Table 2. Specification of calculation of W descriptor.

Software	Criterion of similarity "W"	Notes
I	0.94	Criterion met
II	4.67	Criterion not met
III	2.14	Criterion met

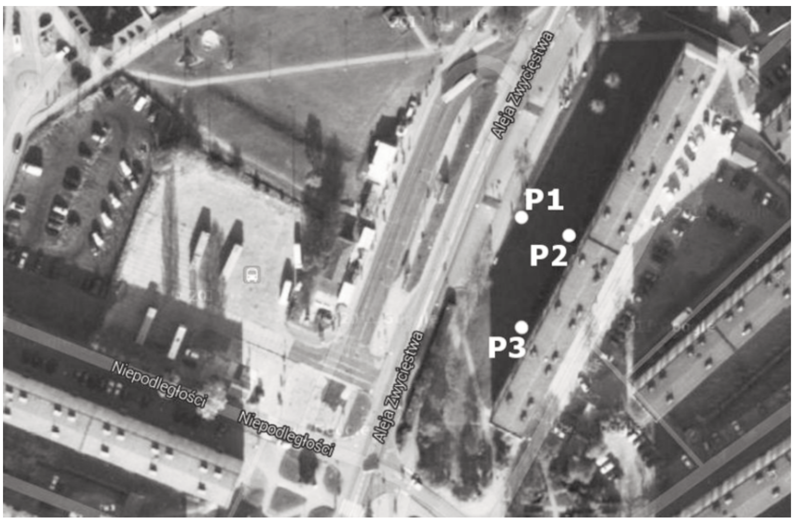

Fig. 1. Approximate map of the analysed area A.

Table 3. Results of measurements and calculations.

Point No.	Measurement results $L_{zm,i}$	Extended uncertainty of measuring U_{R95}	Calculation results $L_{obl,i}$		
			I	II	III
	[dB]		[dB]		
P1	66.1	±1.4	66.4	67.2	63.7
P2	64.7	±1.3	64.3	66.3	61.2
P3	65.3	±1.5	64.8	66.1	62.4

Table 4. Specification of calculation of W descriptor.

Software	Criterion of similarity "W"	Notes
I	0.50	Criterion met
II	1.48	Criterion met
III	3.63	Criterion not met

Table 5. Results of measurements and calculations.

Point No.	Measurement results $L_{zm,i}$	Extended uncertainty of measuring U_{R95}	Calculation results $L_{obl,i}$		
			I	II	III
	[dB]		[dB]		
P1	67.8	±1.4	66.9	70.2	64.3
P2	62.7	±1.3	62.3	63.6	61.3
P3	68.2	±1.4	67.8	71.7	65.1

Table 6. Specification of calculation of W descriptor.

Software	Criterion of similarity "W"	Notes
I	0.75	Criterion met
II	3.06	Criterion not met
III	3.45	Criterion not met

Road Section B

The subject of analysis was an existing section of local county road assigned for modernization. The location of this section and controlling points are shown in Fig. 2.

The acoustic climate of the analysed section is shaped by typical car traffic of a main road leading out of a city. The measurements were conducted in three controlling points: P1, closest and mostly exposed to noise from multiple dwellings; P2 in an open area; and P3 in a building area not protected acoustically. On the analysed section of road the traffic intensity was, on average, 310 vehicles per hour with 10% heavy vehicles. Field measurements were done during the day from 10.30 to 13.00. The results of measurements $L_{zm,i}$ and noise calculations $L_{obl,i}$ in the controlling points are shown in Table 3.

On the basis of Table 4 it can be assumed that the calculation results done by software III do not meet the similarity criterion defined by formula (1). The right calculation results we get by software I and II.

Road Section C

The subject of analysis was an existing section of local county road assigned for modernization. The location of this section and controlling points are shown in Fig. 3.

The acoustic climate of the analysed section is shaped by typical car traffic on a city bypass. The measurements were conducted in three controlling points: P1, closest and mostly exposed to noise from multiple dwellings; and P2 and P3 in open areas not protected acoustically. On the analysed section of road the traffic intensity was on average

Fig. 2. Approximate map of the analysed area B.

Fig. 3. Approximate map of the analysed area C.

900 vehicles per hour with 8% heavy vehicles. Field measurements were done during the day from 13.30 to 15.00. The results of measurements $L_{zm,i}$ and noise calculations $L_{obl,i}$ in the controlling points are shown in Table 5.

On the basis of Table 6 it can be assumed that the calculation results done by software II and III do not meet the similarity criterion defined by formula (1). We got our simulation results using software I.

In each of the three analyzed examples the values presented in Tables 1, 3, and 5 form – in rows – individual pairs of measured and calculated values for the same parameters of traffic intensity.

Conclusions

The results of conducted measurements and analyses showed the importance of each stage of numeric simulation of road traffic noise and how this influences the reliability of the prognosis of impact on the environment as the right choice of a calculation programme. For example, [14] includes many calculation methods that are recommended depending on the specificity of a road project. This article proves that there is no universal calculation programme for traffic noise simulation. It should be noted that the results for road noise emmisions in software II are always higher those measured in the area. This will result in applying more expensive technical solutions (for example higher or longer screens), but at the same time better protecting the environment.

Software I in all three cases met the criterion defined by formula (1), but we should not draw conclusions that this is the universal and most effective calculation programme.

Modelling acoustic parameters of traffic noise sources may be done on the basis of the data obtained from measurements [18]. However, noise modelling is more often done on non-acoustic data, such as intensity and structure of traffic on the road. An equally essential element of each acoustic simulation is the geometrical model of the analysed area influencing directly the correctness of calculation of sound propagation in the environment. The geometrical model should reflect as precisely as possible the real location of nose sources, other architectural objects, the topography of the area, and ground structure in road surroundings [19, 20]. It seems that modelling heavy vehicles is really essential, where the engine, wheels, and exhaust system are at some distance. Modelling of such heavy vehicles would be justified so as to treat it as two or three sources of different noise emission levels and of different heights. But commonly accessible professional calculation programmes do not have such a function. Another problem seems to be the statistics base applied for validation of calculation programmes, which is also highlighted by the authors of [5, 21]. Probably it does not fully cover the real randomness of traffic.

Each verification of a calculation programme suggested by the criterion defined in formula (1) seems to be a good solution, ensuring reliability of prognosis of sound propagation in the environment. This verification is possible for every rebuilt and modernized section of road. Unfortunately, when analysing a section of newly designed road that did not previously exist, while choosing of the right calculation programme one can only draw upon earlier experience gained on the basis of analyses, assuming that a proper validation of a calculation programme is done by the software producer. One should also be careful when choosing a calculation programme for rare traffic situations, such as bus terminals or transport bases. Despite all the efforts surrounding data preparation, the user has only a small influence on the realization of simulation by a chosen calculation programme. Professional calculation programmes (CadnaA, SoundPlan, H_drog, Traffic Noise Model, and others) are based on a closed calculation algorithm [13, 19].

In summary, we can say that despite striving to create an ideal calculation model of traffic noise considering the big number of changeable acoustic and non-acoustic parameters, engineers should also be informed about the criteria of usefulness of a programme for a certain road situation. The presented formula (1) is maybe not ideal, but may be an impulse for further searching for the right criterion of similarity of measurement results with calculations done obligatorily for each traffic noise simulation.

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