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APPLICATION OF ACOUSTIC MODEL TO TRAFFIC NOISE MAPPING – A CASE STUDY

Nowadays traffic noise in large urban areas became serious problem, especially for inhabitants and their life comfort. It is well founded to accurately identify the sound sources and their impact to environment. Therefore plenty of acoustic models allow to calculate the distribution and prediction of sound pressure levels. Unfortunately many of them do not have the required calculation accuracy in different conditions.

In the article is presented the comparison of the traffic noise modelling and measurement on the selected area of Poznan City (Poland). The LimA software was used to elaborate several acoustic maps, with different input parameters of model. The traffic noise measurement was performed during day time. Differences are shown and analyzed. Also one of the solution to reduce traffic noise was proposed.

Key words: road and rail noise measurement, traffic noise map

1. INTRODUCTION

Acoustic map is a graphical presentation of noise wave propagation or prediction of spreading sound pressure a different kind of noise sources by using the selected mathematical model. In accordance with EU Directive 2002/49/EC, each city over 250 thousand of people are required to possess the acoustic map of city, with a particular focus on road, rail, aircraft and industrial noise [European Parliament and Council of the European Union, 2002]. There are plenty of programs for development of acoustic maps which implement various types of mathematical models. However, not every mathematical model is mapping the real

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noise measurements with the expected accuracy. Validation of model or simulation by using real sound pressure measurements of noise sources is well founded. There are many examples of such kind of research in the literature. SoundPLAN is the first popular software for creating various types of noise maps. Good example of using SoundPLAN software to creating acoustic map of airport in Istanbul are research fellows from Turkey and USA [Sari et al. 2014]. Also scientists from Georgia in USA made a road acoustic map of Fulton county showing propagation of traffic noise [Seong et al. 2011]. CadnA software is another tool for creating acoustic maps different sound sources. Research works from Chile [Suarez, Barros 2014) and Poland [Mioduszewski et al. 2011] are great examples for using CadnaA software to do acoustic maps of traffic noise. In Brazil was mapping the area of Federal University of Parana using Predictor software [Zannin et al. 2013]. There are number of mathematical models for simulation of predicting and distributing sound pressure levels, for example in Asia [Dai et al. 2014; Tsai et al. 2009] which are based on other software. All these works have got common denominator. To draw attention on annoying and harmful factor: different kind of environmental noise.

In article is presented a comparison of the traffic noise maps on the selected area of Poznan City (Poland) with the equivalent sound pressure A level measurement that lasted for 16 hours, between 6 am and 10 pm. In this case road and tram noise are the two most annoying sound sources in daily time. The acoustic maps were developed in the Brüel & Kjær software named LimA. Validation of acoustic model by the traffic noise measurement was the main aim of research. The intermediate aim was to propose solution to reduce the traffic noise that affect to inhabitants on this area of Poznan City. The noise maps with acoustic screens were elaborated in next step.

2. METHODOLOGY OF MEASUREMENTS

The area of measurement is shown on the Fig. 1. The measurement area includes section of Hetmanska Street and residential building on the Madalinskiego Street. The closed tram depot, shopping center Greenpoint and petrol station Shell are in close proximity. The measuring point (microphone) is marked on the Fig. 1 by the MP symbol. The microphone is attached to the balcony balustrade which is shown on the Fig. 2. The balcony platform is a part of apartment in residential building on 23 Madalinskiego Street. The MP is located at a height of 8 m above the ground. The distance between microphone and the building facade equals 1 m. While the distance between the MP and the axis of Hetmanska Street is equal to 25 m.

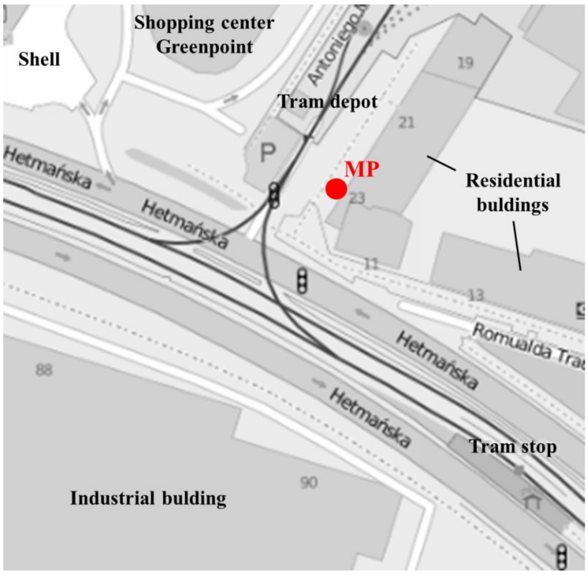


Fig. 1. The measurement area; the measuring point is marked by MP symbol, the tram network is marked by continuous lines, the arrows on the Hetmanska Street indicate the direction of the road flow (based on Google Maps)

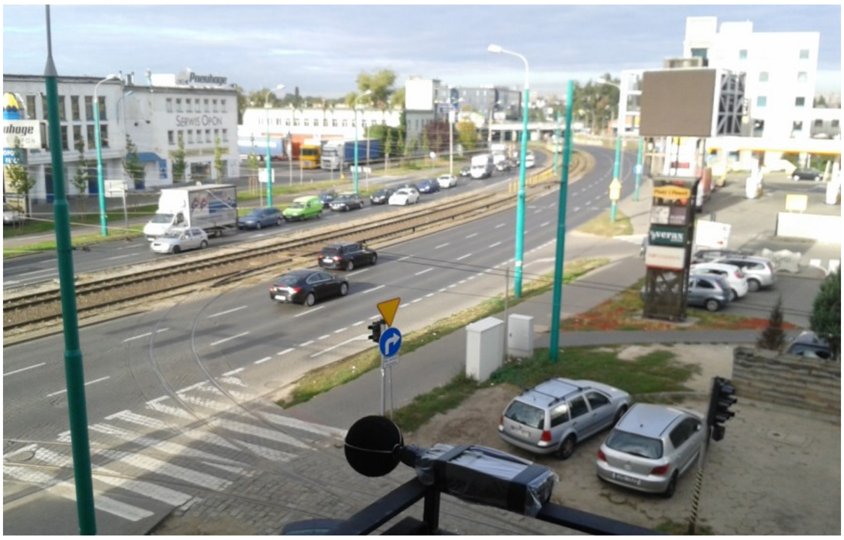


Fig. 2. The view from balcony platform; the microphone mounted on balustrade and the infrastructure of Hetmanska Street

The measurement of the equivalent sound pressure level, corrected by A frequency characteristic L_{Aeq} was conducted. The time interval T of measurement was equal to 16 hours, from 6 am to 10 pm. The L_{Aeq} value is determined in accordance with equation (1) [Polish Regulation, 2011]:

$$L_{Aeq} = 10\log\left(10^{0,1L_{Aeq0T}} - 10^{0,1L_{ATla}}\right) - 3 \quad (1)$$

where: L_{Aeq} is the equivalent sound pressure A level in dB, L_{Aeq0T} is the equivalent sound pressure A level with background noise level, determined by the continuous recording of the noise in the T = 16 hours time interval in dB and L_{ATla} is the background noise level also in dB.

The last factor equals 3 dB in equation (1), is a sound coefficient that should be used when a distance between the measuring point and the building facade is less than 2 m [Polish Regulation, 2011]. The measurement was carried out with accordance to requirements for this type of research [Polish Regulation, 2011]. Only the height of the measurement point was twice as defined in standard. However, in this case it does not matter, because developed acoustic model also allows determining the desired height of sound pressure level propagation. The measurement was conducted on Monday, 29th of September 2015. The air temperature varied between 9 °C and 18 °C throughout the daytime. Wind speed did not exceed 5 m/s, and there was no rain. The relative humidity was about 80%.

The Brüel & Kjær Sound Level Meter type 2250 was used to carry out the continuous sound pressure level A measurement (Fig. 2). The device is equipped with a first-class electro-acoustic transducer. The sample period of the acoustic signal is equal to 1 s. Furthermore, wind deflector was mounted on microphone. The sound meter was packed inside polybag and mounted on balcony balustrade. However, it did not affect on the recording signal.

3. THEORETICAL ASPECTS

Propagation or transmission of acoustic waves can be described by Green's function, implemented in accordance with Helmholtz-Huygens principle. Firstly, Green function describes the spatial paths propagation from point r_0 to point r. The Green function $g(r|r_0)$ in free space for the point source is equal to (2) [Mechel 2009; Skudrzyk 1971; Vorlander 2008]:

$$g(r|r_0) = \frac{e^{-jk|r-r_0|}}{4\pi|r-r_0|} \quad (2)$$

where: r_0 is the sound source position, r is the the sound receiver position, k is the wave number and j is the imaginary value.

Secondly, the basic Helmholtz wave equation of acoustic radiation is (3) [Skudrzyk 1971; Vorlander 2008]:

$$\Delta p(r) + k^2 p(r) = -jkZ_0 q(r_0) \quad (3)$$

where: Δ is the Laplace operator, p is the sound pressure, Z_0 is the acoustic impedance and q is the harmonic volume source excitation.

Finally, the implementation of equation (2) and (3) to the Helmholtz-Huygens principle leads to integral equation (4) [Skudrzyk 1971; Vorlander 2008]:

$$p(r) = \iiint jkZ_0 q(r_0) g(r \mid r_0) dV_0 + \iint \left(g(r \mid r_0) \frac{\partial p(r_0)}{\partial n} - p(r_0) \frac{\partial g(r \mid r_0)}{\partial n} \right) dS_0 \quad (4)$$

where: dV_0 is the differential of source volume, dS_0 is the differential of source surface and n is the orthogonal vectors to source surface.

With this equation, the resulting sound power pressure of various kind of source distribution in a space and any kind of reflection from boundaries on a surface surrounding the sources can be calculated [Skudrzyk 1971]. First part of the (3) equation refers to the sound power (acoustic energy) of the source. Second part, is related to surface of wave radiation from the source to space.

4. THE ACOUSTIC MODEL

Development of a comprehensive acoustic model could be divided into two stages. Firstly the acoustic model of road noise was determined. In accordance with EU Directive 2002/49/EC, each country without their own mathematical model to determination the sound pressure level of road noise, should use the French model named NMPB 2008 „Road noise prediction" [Sétra 2009; Sétra 2011]. It is possible to estimate the equivalent sound pressure level L_{Aeq} of road noise in daily time, between 6 am and 10 pm, by using proper mathematical model [Sétra 2009; Sétra 2011]. It can be carried out a noise prediction or propagation.

The main assumption of the model is to estimate the daily sound power level L_w per meter of the road [Sétra 2009; Sétra 2011]. Based on L_w factor is evaluated the distribution of sound pressure level depending on the distance from road noise and including zoning area. Parameters describing the road flow and road infrastructure have to be specified to estimate the sound power level L_w [Sétra 2011], which are:

- average number of vehicles driving through the cross section of the road within an hour during the daytime – QVD = 2000/hour,
- average number of heavy vehicles driving through the cross section of the road within an hour during the daytime – QPD = 200/hour,
- the permissible maximum speed of vehicles on the selected section of the road – V = 50 km/h,
- classification of the road – urban road,
- type of surface road – standard surface; sleek tarmac or concrete,
- gradient of the road – horizontal gradient,

– indicate the flow direction and characterize the traffic flow – periodically stop and go traffic flow (approximately for one minute).

Determination of the rail acoustic model is the second stage of development the comprehensive acoustic model. Similar as in the first step, the sound power level L_w per meter of rail track have to be estimated [Baranovskii 2011; RMVR 1996]. The proper mathematical model describing the rail noise has to be chosen. Poland does not have their own tram noise model to prediction or simulation a sound pressure levels. In accordance with EU Directive 2002/49/EC, each country without their own mathematical model to determination the sound pressure level of rail noise, where the sound source is noise from rail or tram vehicles, ought to use the Dutch model named RMR 1996 „Reken en Meetvoorschrift Railkverkeerslawaai" [RMVR 1996]. However, should be noted that RMR model is concerned only railway traffic noise. The main assumptions of the RMR model were used in study, referring them to the tram traffic noise in the selected area. In LimA software the RMR model is named RLM2ISO and it is in accordance with ISO 9613 standard. Similar as in NMPB model, the sound power level L_w is determined by description of type of rail vehicles and track [Szwarc et al. 2011]:

– average number of trams driving through the cross section of the rail track during daytime – ND = 200,

– type of rail vehicles – Passenger train with brake blocks and disc (the one type of tram is assumed in model),

– the permissible maximum speed of vehicles on the selected section of the road – V = 50 km/h,

– type of rail track: standard tram line situated in the horizontal gradient, with jointless connections and concrete sleepers.

It was important to perform a sound wave simulation at the same height as the measuring point location; 8 m above the ground. Logarithmic addition of simulation mathematical model results, road and rail noise wave spreading, was the final step of study. In simulation was provided proper weather condition parameters, similar to those in which were made the measurement. Also the area in simulation was mapped as in reality. Thereby, the simulation and model conditions elaborated in LimA software were as possible similar to real conditions.

5. THE RESULTS OF RESEARCH

The results of the traffic noise measurement are equal to:

– L_{Aeq0T} – the equivalent sound pressure A level with background noise level, determined by the continuous recording of the noise between 6 am and 10 pm, equals 72,2 dB. In the Fig. 3 is shown the L_{Aeq0T} in time function (only selected part of measurement with the highest value of noise). Distribution of the L_{Aeq0T} is dependent on the traffic lights. It can be observed a decrease the sound pressure level below 60 dB during stop vehicles at red light. When vehicles start driving, noise is increased to over 78 dB. Based on the all measurement and decreases of sound pressure level was estimated the background noise level L_{ATla}.

– L_{ATla} – the average background noise level was equal to 57 dB.

Based on the measurement and the (1) equation can be calculated the equivalent sound pressure A level L_{Aeq} including the reflection coefficient, which equals 69 dB.

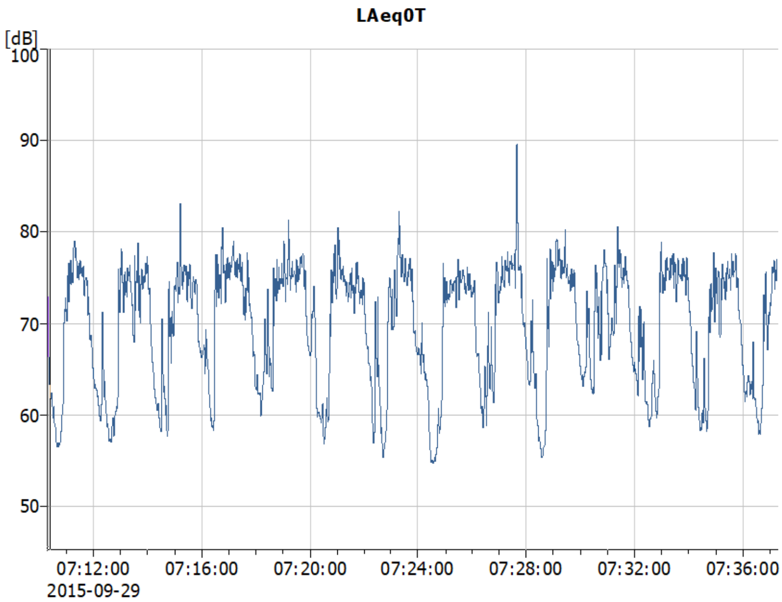


Fig. 3. The equivalent sound pressure A level with background noise level L_{Aeq0T} in time function (selected part)

In Fig. 4 is shown an acoustic map made by using LimA software. It can be notice; the equivalent sound pressure A level L_{Aeq} at the measuring point MP is similar to the real measurement results. The MP is located in the noise range of 68–70 dB (Fig. 4). The value of L_{Aeq} above the road equals only 78 dB. The cause is the height of the model simulation, which is equal to 8 m over the ground.

In Fig. 5 is presented the second acoustic map. In this case the sound wave propagation is simulated at the height of 4 m above the ground, in accordance with the standards [Sétra 2011; RMVR 1996]. The noise level above the road increased by 4 dB and equals over 82 dB. While the sound pressure level at the MP also increased and is approximately 71 dB. Furthermore, the shopping center Greenpoint and the industrial buildings marked grey color on the map are visible. The height of these buildings is between 4–8 m. Based on the noise map analysis, it can be concluded the sound pressure level emitted by road vehicles is higher than the tram noise.

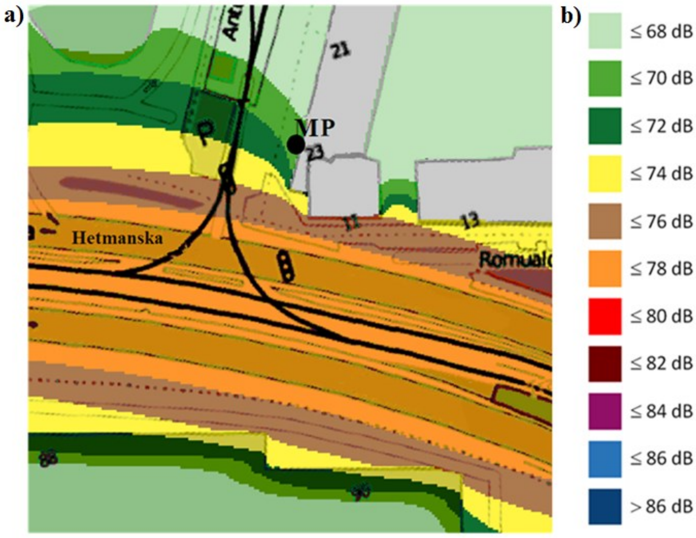


Fig. 4. a) The first acoustic map representing the traffic noise levels around the measuring point MP at the height of 8 m over the ground, b) Range of colors assigned along with the equivalent sound pressure A levels L_{Aeq}

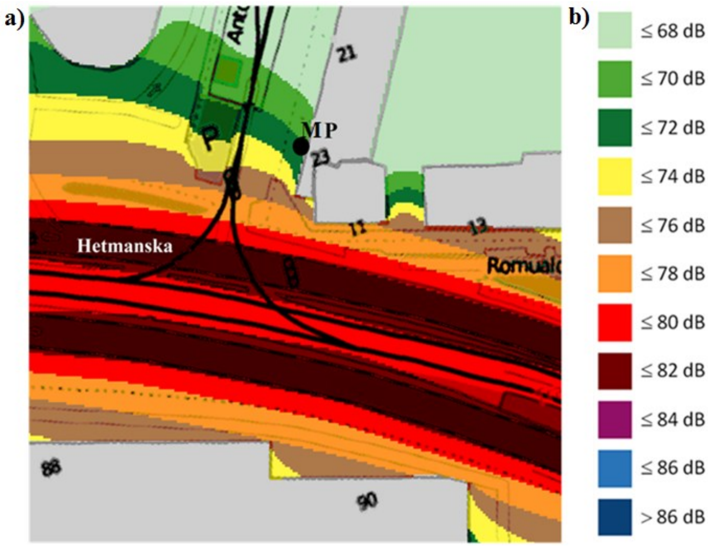
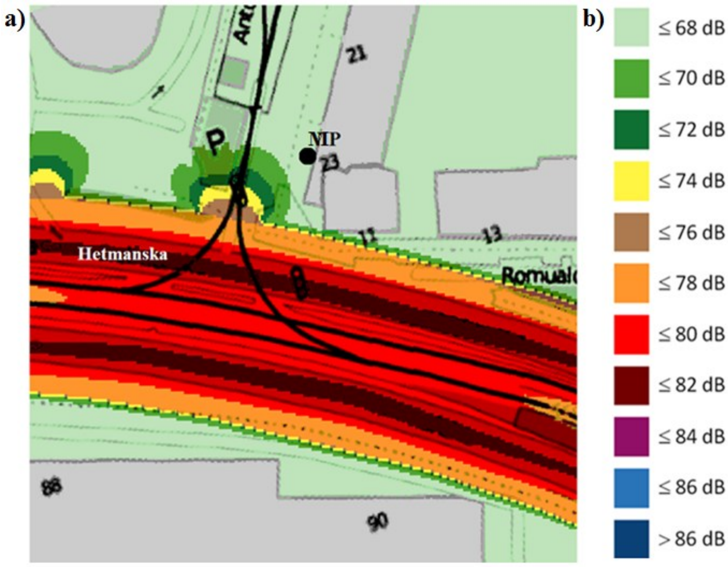


Fig. 5. a) The acoustic map representing the traffic noise levels around the measuring point MP at the height of 4 m over the ground, b) Range of colors assigned along with the equivalent sound pressure A levels L_{Aeq}

The final step of noise modeling was to test, how will change the sound pressure levels when placed a noise barriers along both sides of Hetmanska Street. An example of the noise map with acoustic screens is presented in Fig. 6. All model assumptions are the same as on the map shown in Fig. 5. The height of acoustic screens is 4 m. There are two gaps, where authors do not place the noise barrier, because of the entry to shopping center and tram depot (Fig. 6). Around these places is increased a noise level. What is important, the equivalent sound pressure level on the MP is lower and equals less than 68 dB.



Rys. 6. a) The acoustic map representing the traffic noise levels around the measuring point MP at the height of 4 m over the ground, with noise barriers along Hetmanska Street b) Range of colors assigned along with the equivalent sound pressure A levels L_{Aeq}

Presented acoustic model with noise barriers conception is only one of many examples of traffic noise reduction. Thanks to the possibilities of modeling and simulation in LimA software, can be performed plenty of scenarios related to the sound waves distribution.

6. SUMMARY AND CONCLUSIONS

The traffic noise measurement, which lasted between 6 am and 10 pm, was performed. Based the measurement the equivalent sound pressure A level was calculated and it is equal to 69 dB. The estimated value exceeds the equivalent sound pressure A level in day period for urban zone which is 68 dB according to Polish standard [Polish Regulation, 2012].

Based on the traffic flow observations and using mathematical assumptions of the LimA software, the acoustic maps were elaborated. The noise model was validated using acoustic measurement. In the measuring point the equivalent sound pressure A level is between 68–70 dB, which means that an elaborated noise model is consistent with the real conditions.

Furthermore, two next acoustic maps were elaborated, in accordance with standards [Sétra 2011, RMVR 1996]. The main aim of acoustic modelling was to compare the sound levels and to propose the concept of noise reduction on the selected area. The impact of acoustic screens allows decreasing the sound pressure level from 72 dB to less than 68 dB.

Research shows that LimA software is appropriate tool for road noise modelling in Polish conditions. However the tram noise propagation and prediction cannot be clearly modelled by LimA software. In this case there are no appropriate math models describing tram noise in Polish conditions.

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APLIKACJA MODELI AKUSTYCZNYCH DO OPRACOWANIA MAP HAŁASU TRANSPORTU MIEJSKIEGO – STUDIUM PRZYPADKU

Streszczenie

W artykule przedstawiono porównanie opracowanego modelu propagacji hałasu generowanego przez miejski transport drogowy oraz szynowy na wybranym obszarze śródmiejskim z rzeczywistym ciągłym pomiarem równoważnego poziomu dźwięku skorygowanego na podstawie charakterystyki częstotliwościowej A w porze dziennej, tj. w godzinach 6.00–22.00. Mapy akustyczne opracowano za pośrednictwem programu Lima firmy Brüel & Kjær. Celem badań była walidacja modelu akustycznego w określonym miejscu. Ponadto opracowano kolejne modele akustyczne w celu zaproponowania obniżenia poziomu hałasu na wskazanym obszarze przez umieszczenie wzdłuż drogi ekranów akustycznych.

Słowa kluczowe: pomiary hałasu środków transportu drogowego i szynowego, mapy akustyczne