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Analysis of Urban Traffic Noise at Weekends – Case Study

RADZISZEWSKI Leszek[1, a], BĄKOWSKI Andrzej[2,b*], BURDZIK Rafał[3,c] and WARCZEK Jan[4,d]

[1,2]Kielce University of Technology, Faculty of Mechatronics and Mechanical Engineering, Al.Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland

[3,4] Silesian University of Technology, Faculty of Transport and Aviation Engineering, ul. Akademicka 2A, 44-100 Gliwice, Poland

[a]lradzisz@tu.kielce.pl, *[b]abakowski@tu.kielce.pl, [c]rafal.burdzik@polsl.pl, [d]jan.warczek@polsl.pl

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Abstract. The study carried out an analysis of the urban traffic noise parameters on Sundays and Saturdays. The results of noise simulations according to the Cnossos-EU model were compared with the sound level calculated by a permanent automatic sound and traffic volume monitoring station. The variations in results were evaluated. Analyzes carried out showed that the traffic of passenger vehicles is the main source of road noise. A very good agreement of the noise values determined according to the Cnossos-EU model and the measured ones was obtained. The maximum noise values on Sundays are only slightly smaller than on Saturdays. The shape of the noise diagram and the noise values at individual hours of the day on Saturdays are different than on Sundays. An experimental model of noise variability at weekends has been proposed. The equations describing the variability of the equivalent sound level were validated. Fit factor R^2 of the proposed equations to the experimental data ranges from 0.85 to 0.94.

Introduction

Studies of the harmful impact of urban transport means on the environment are currently presented in the literature in numerous publications [1-4] but mainly for weekdays. Some of the effects are an annoyance and sleep disturbance. Also, long-term health effects such as cardiovascular disease have also been related to traffic noise [5]. To assess urban noise, cities regularly produce noise maps. The paper [6] presents seasonal and weekday influences on noise indicators based on a noise map. For the noise mapping realized by computational methods, important are reliability and uncertainty [7]. The acoustic climate assessment for noise mapping needs the selection of acoustic hazards in the analyzed areas. Also, input noise level data are burdened with certain uncertainties. The idea of applying interval arithmetic for the assessment of acoustic models' uncertainty is formulated in the paper [8]. The problem of estimation of the long-term environmental noise hazard indicators and their uncertainty is also presented in the paper [9]. Vehicle traffic parameters such as flow, speed, and structure have a significant impact on the air and ground pollution with exhaust emissions, noise, vibrations, and other phenomena that create environmental hazards. The paper [10] presents an interesting study on the impact of tire pressure on noise generated by vehicles. An additional factor influencing the acoustic climate is the modifications to the road infrastructure, the aim of which may also be to reduce the emission of traffic noise to the environment [11]. That is while it is necessary to permanently monitor over a long period of time vehicle traffic and analyze the recorded data [12]. The variations in traffic volume and noise are of interest e.g. in dynamic traffic management systems and navigation services, assessing the environmental effects of traffic. Stationary monitoring stations or low-cost wireless sensor systems and participative citizenship initiatives measure urban noise [13]. Determining the models

describing the acoustic field caused by road noise forces the solution of many practical engineering problems. Much attention is paid to the microphone positions near intersections. In these places, conventional noise mapping methods suffer from numerical errors that often occur in large-scale city noise mapping calculations using automatically generated geographic inputs. Problems of this type are avoided, for example, by applying modifications to noise modeling methods. One of the noise mapping optimization methods is presented in [14]. Increasingly, in noise modeling, attention is paid to the variability of the frequency structure. Octave noise models are sometimes better at capturing the actual hearing experience of people in a given area. In other words, the same level does not mean the same acoustic nuisance. An example of such an approach to noise modeling is the publication [15]. Due to the complexity of the problem of noise modeling, its solution is sometimes sought with the use of artificial neural networks or by the use of genetic algorithms [16,17]. Analysis of the distribution of the traffic volume showed that in the case of interrupted traffic flows, e.g. in urban areas, it is usually non-normal. Traffic in urbanized areas can be analyzed depending on the adopted time interval and location of the road in the communication system [18,19]. Within one week, the traffic volume on weekdays differs significantly from the traffic on weekends and holidays. The period of one day can be divided into 24 hours. In each subsequent hour of the day, vehicle traffic parameters may be different. Besides the general shape of the daily flow profile, the shape of the pick periods is important for traffic management, as well.

The problem of traffic noise at weekends has been analyzed much less frequently in the literature, which is mainly due to the lower traffic intensity, especially for heavy goods vehicles. However, as the authors' research has shown, it does not cause significant changes in the sound pressure level. The goal of this research was to obtain an insight into the traffic volume profiles and to detect traffic noise patterns according to the day of the weekend and Cnossos-EU model validation. To evaluate the results, a traffic noise experimental curve model was proposed.

Measurements and Calculations Results

The traffic volumes and noise analyzed in this study were measured [12] by the permanent station recording traffic volume, velocity, and sound pressure levels located in Popieluszka Av. in Kielce. The analysis was determined in accordance with the procedure presented in [13], with the difference that the noise was recorded every 1 hour. The box plots of vehicle speed on Saturdays and Sundays in 2016, are shown in Figure 1.

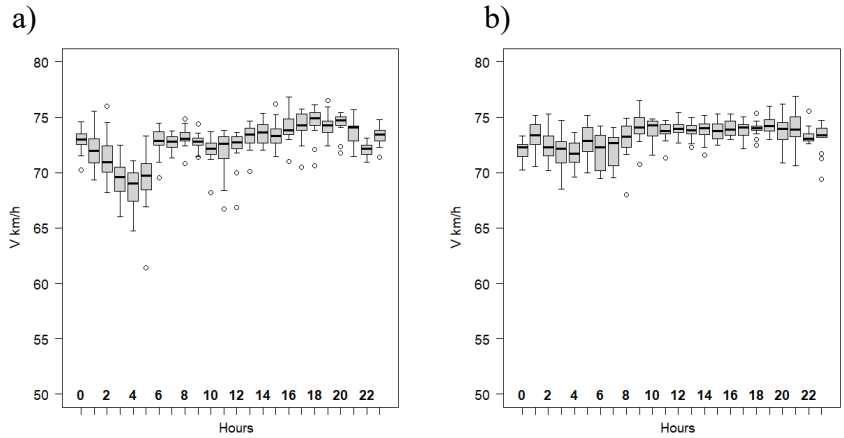

Fig. 1. *Box plots for weekends of the relation between the hourly traffic speed and time for 24 h period a) on Saturdays, b) on Sundays.*

It is worth noting that the speed charts on Saturdays and Sundays have different courses. On Saturdays from midnight, the median speed decreases to its minimum value at 4 AM and then increases to 7 AM. Then, in the subsequent hours, its value changes slightly and the highest occurs at 6 PM. Compared to Saturdays on Sundays, both the shape of the speed chart and the speed values at individual hours of the day are different. The analysis of the share of individual groups of vehicles in the traffic structure [12] showed that the dominant group is passenger vehicles, for which the share in the traffic flow was on Sundays 84%. The next group was medium-heavy vehicles, for which the share in the analyzed period amounted on Sundays to 11%. The share of heavy vehicles mounted on Sundays to 2%. For this reason, in the further part of the work, the traffic of passenger vehicles will be analyzed. Figure 2 presents traffic volume box plots for individual hours of the day for passenger vehicles on weekends [12]. On Saturdays (Fig. 2 a), it can be seen that the number of vehicles increases from 5 AM and stabilizes between noon at 12 AM and 14 PM to around 1000 per hour. From 15 PM the number of vehicles is gradually decreasing. On Sundays, the number of vehicles only increases from 6 AM to 3 PM and gradually declines from 4 PM. One can also notice a certain symmetry in the graph of changes in the number of vehicles in the range from 8 AM to 11 PM (Fig. 2 b).

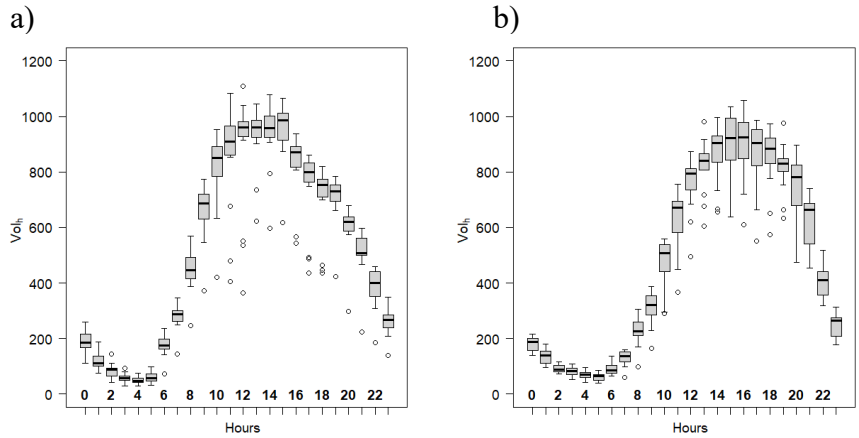

Fig. 2. *Volume of passenger vehicle traffic for individual hours of the day: a) on Saturdays, b) on Sundays.*

The differences in the number and speed of vehicles on Saturdays and Sundays have an impact on the chart shape and time distribution of noise values. Smaller numbers of vehicles on Sundays contribute to reducing the noise level, especially in the evening and at night, which can be seen in Fig. 3. On the other hand, during the day, on Sundays, passenger vehicles and medium-heavy vehicles drive at higher speeds and more dynamically than on Saturdays, which means that the maximum noise values are only slightly reduced. These conclusions are confirmed by the results of simulations made in accordance with the Cnossos-EU model.

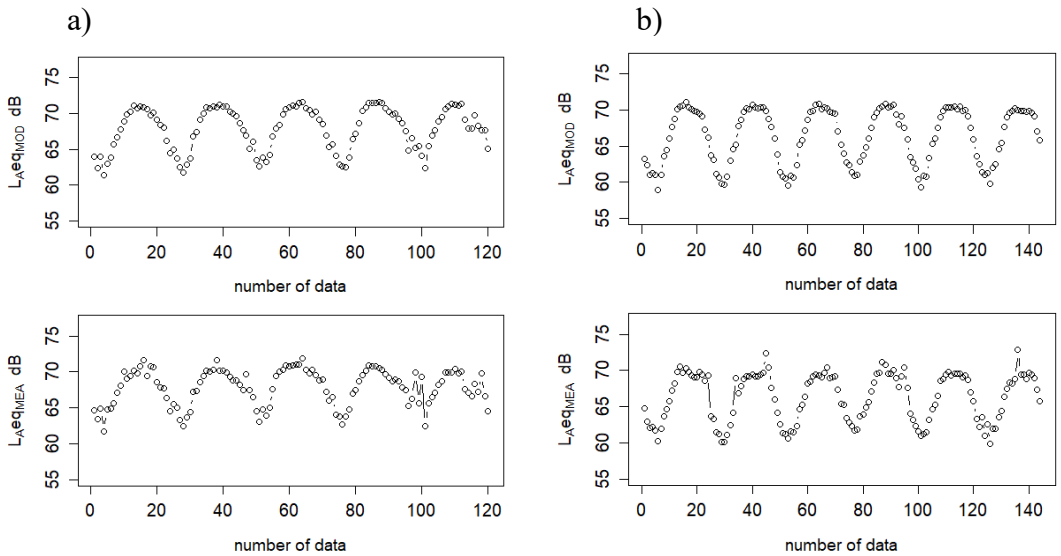

Fig. 3. *Simulated and measured values of equivalent sound level for all vehicles in 2016 for a) 5 Saturdays and b) 6 Sundays.*

The comparison of the median results of the simulations carried out according to the Cnossos-EU [13] model and the experimental ones are shown in Fig. 4. The relationships, shown in Figures 4a and 4b, indicate both some similarities and differences in traffic noise on weekends. Noise values on Saturdays and Sundays are similar, but their time distributions are varied. One can also notice a certain symmetry in the graph of changes in noise in the range: for Saturdays from 5 AM to 11 PM (Fig. 4a) and for Sundays from 9 AM to 11 PM (Fig. 4b).

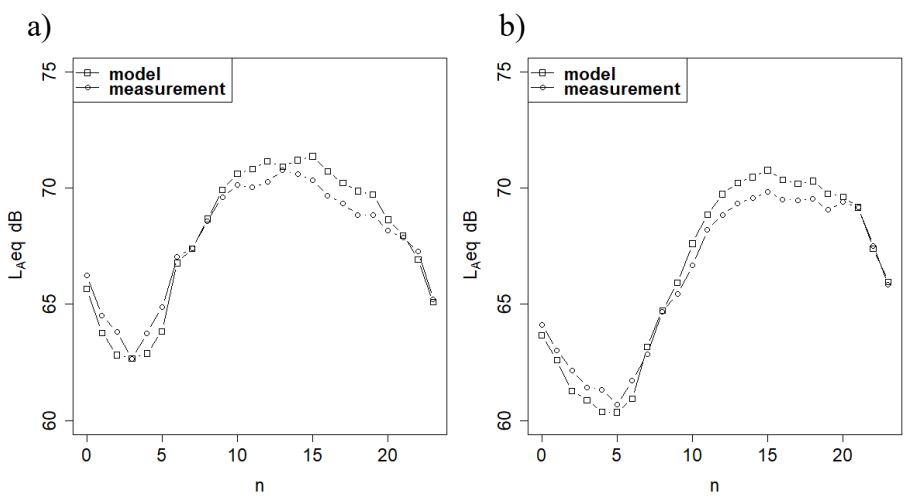

Fig. 4. *Median of equivalent sound level for all vehicles in 2016 for a) Saturdays, b) Sundays.*

One can notice a very good agreement of the obtained results in these figures. This compliance is confirmed by the value of the RMSE parameter, which for Saturdays is 0.68 dB(A) and for Sundays, it is 0.66 dB(A).

Traffic Noise Forecasting on Saturdays and Sundays

The division of the day into three-time intervals, i.e. day, evening, and night, is justified for physiological and normative reasons related to the harmful influence of transport on humans. On the other hand, it is complicated by the mathematical description of the variability of the values of vehicle motion parameters as a function of time, which was presented in [12].

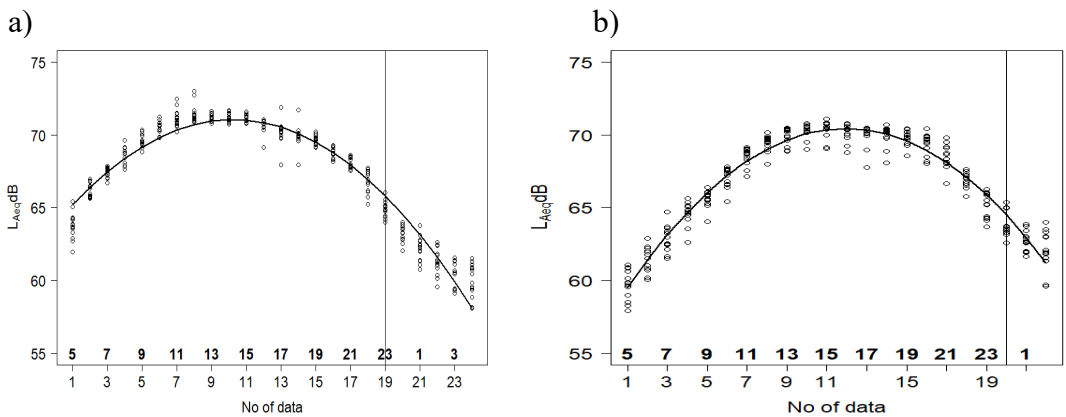

Fig. 5. Dependence of L_{Aeq} on hours of the day for all vehicles a) from 5 AM on Saturdays until 4 AM on Sundays b) from 5 AM on Sundays until 2 AM in Mondays.

For this reason, the authors decided to develop an experimental model of noise variability on weekends in 2016 and conduct an analysis in the time interval from 5 AM on Saturdays to 4 AM on Sundays and from 5 AM on Sundays until 2 AM in Mondays. Such a transformation in the time domain does not affect the value of the sound intensity level but facilitates its mathematical description of the variability.

Changes in the sound intensity level can be described by the equation:

– for the time interval from 5 AM on Saturdays to 4 AM on Sunday

$$L_{Aeq} = 63.84 + 1.40 \cdot \mathrm{h} - 0.07 \cdot \mathrm{h}^2 \quad (1)$$

– for the time interval from 5 AM on Sundays until 2 AM on Mondays

$$L_{Aeq} = 57.41 + 2.18 \cdot \mathrm{h} - 0.09 \cdot \mathrm{h}^2 \quad (2)$$

where h – number of data.

The coefficients of fitting model curves to the experimental data are approximately R^2= 0.94. The validation of the experimental model was carried out on the set of measurement data from 2011 (noise was calculated according to the Cnossos-EU model). The determined values of the RMSE parameter for Saturdays are 1.39 dB(A) and for Sundays 1.26 dB(A), which confirms the possibility of practical use of the proposed model for noise forecasting. The analysis of the measured sound level values on Sundays showed that from 11 AM to 9 PM the value of 68 dB(A) was exceeded. For this reason, simulations of the impact of limiting vehicle speed to 50 km/h on noise values were carried out. Calculations have shown that the noise values are reduced by about 3 dB(A) and that the level of 68 dB(A) is not exceeded.

Conclusions

1. The noise level exceeds the permissible values both on Saturdays and Sundays, which is mainly due to the number and speed of passenger vehicles.
2. Compared to Saturdays on Sundays, both the shape of the noise diagram and the noise values at individual hours of the day are different
3. Time distributions of noise values at the weekend can be described by a second-order polynomial and the RMSE parameter values are in the range from 0.70 dB(A) to 1.40 dB(A)
4. The simulations of the impact of the vehicle speed limit to 50 km/h on the median noise values (according to the Cnossos-EU model) showed that the noise values were reduced by about 3 dB(A) and that the 68 dB(A) level was not exceeded.

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