EUROREGIO
BNAM2022
Joint Acoustics Conference
9th-11th of May, Aalborg, Denmark

Statistical analysis of urban noise measurement data: case study for the city of Skopje

Maja Anachkova[1,*], Simona Domazetovska[2] , Filip Nikolovski[3], Viktor Gavriloski[4]

[1,2,3,4]Faculty of Mechanical Engineering in Skopje, North Macedonia

*maja.anachkova@mf.edu.mk

Abstract

Noise from the road transport, particularly from vehicles in urban city areas largely accounts for the general noise level and annoyance of the citizens. The numerous volumes of motor vehicles flow can be treated statistically, which can establish a deeper insight into the contribution of the road noise to the prevalent noise pollution and its' characteristics. According to ISO 362 and ISO 1996:2, the environmental noise level from traffic is highly dependent on the vehicle category regarding the factor of contribution to the overall urban noise level. The purpose of this study is to analyze the dependence between the number and types of vehicles and measured standardized parameters (L_{eq}, L_{AF} and L_{95}) for noise level assessment by implementing a statistical model analysis of the collected results. The number and the type of the vehicles is obtained from the States' traffic management and control center for a chosen road in the center of the city, whereas noise level measurements have been conducted with a Bruel&Kjaer sound level meter by using a standardized noise level measurement methodology procedure for the selected period on the given location. This study provides a detailed statistical approach of the collected noise and traffic volume data to obtain conclusions and prediction models for further management of the noise pollution problem in the city.

Keywords: road traffic noise, statistical analysis, urban noise level measurement

1 Introduction

In the past decade, the noise from high density traffic networks in urban cities including residential areas has been rapidly increasing and evidently contributes to citizens' annoyance **[1]**. Consequently, methods for evaluation and assessment of the urban road-traffic noise need to be established as a part of a general sustainable management plan for its' prediction and control. Common method to facilitate systematic management of the road traffic noise are the noise maps of cities introduced in relation to the Environmental noise directive of the European Parliament and Council (Directive 2002/49/EC). Noise maps contribute to understanding the noise situation in the city, including the location of hot spots and the specific noise level of a specific noise source to which the population is exposed. Nevertheless, when a noise map is not available for an existing city, a statistical relationship between the urban form indicators and parameters and the road-traffic noise can be practical and efficient**.**

Many researches have been conducted in order to explore the traffic and road noise impact on the noise pollution in urban cities and some of them are reviewed in this section. Khan, J. et.al. in **[2]** have presented a review paper where current methods of modelling and exposure assessment techniques for road traffic noise pollution are analyzed. In **[3]**, Akgüngör et.al. have conducted a study to explore traffic-based noise pollution in the city of Kırıkkale in Turkey whereby using a multi regression model, the effect of traffic density and composition of the traffic noise level in the city has been investigated. Pobedin et. al in **[4]** have performed a range of experimental research of the noise emissions of the passenger car individual elements by creating a mathematical model for computation of the expected noise in passenger car cabin and a method of probabilistic computational evaluation of car noise. The system discussed in paper **[5]** by Zambon et. al. has applications in terms of traffic noise prediction in large urban environments and obtains an accurate description of traffic noise by conducting measurements of road noise from monitoring stations positioned over a zone of interest. In **[6]**, the authors have provided a comparative analysis between the measured and predicted noise levels obtained by a traffic noise propagation model combined with an urban traffic noise map. Ramirez et. al. in **[7]** elaborate the development and evaluation of a stochastic dynamic traffic noise prediction model for the city of Bogotá established on noise functions for vehicle classes, their speed, and different types of vehicles. In **[8],** the same relation is investigated by means of numerical calculations for two cities, Amsterdam and Rotterdam. Researchers in **[9]** describe the roadside traffic noise assessment conducted in dense built-up urban areas in Hong Kong by using multiple regression to provide a set of empirical formulas for predicting road traffic noise level. Measurement data included statistical analysis including the number of light vehicles, the number of heavy vehicles, the total traffic flow, and the time period on the given location is presented. In Section 3, the noise mapping for the discussed area is presented. In Section 4 the results obtained are analyzed and explained, and in Section 5 the conclusions from the research are provided.

2 Methodology

The purpose of this research is to provide a statistical analysis between actual measurements of noise levels in a chosen area in the city center and the number of vehicles circulating through the streets which limit that area. For this purpose, it is necessary to analyze the correlation of these results in order to gain a better insight into the relationship between the noise level and the number of vehicles, as well as the type of vehicles that make up the traffic in that area. The methodology for providing the results needed to conduct this analysis primarily involves realistic noise level measurements at the selected location to assess the noise level. This was done through short-term measurements at a point near an intersection in the city center which was previously determined to be one of the busiest intersections in traffic. The traffic at that intersection which is formed by two streets is two-way, on one street there are 4 traffic lanes, for each two, and the second street with which it is intersected has one traffic lane for each direction. Namely, the measurements were conducted at the same measuring point during two working weeks in the two most frequent months of the year, June and September. The acoustic measurements were carried out two times a day, at the morning and at the evening, during a 10-minute sampling interval. The 20 acoustic measurements have been conducted by using a Bruel&Kjaer 2250 Class 1 sound level meter, mounted at the point of measurement, at a height of 1.5 meters in the direction of a sound source 3.5 meters from the most exposed façade.

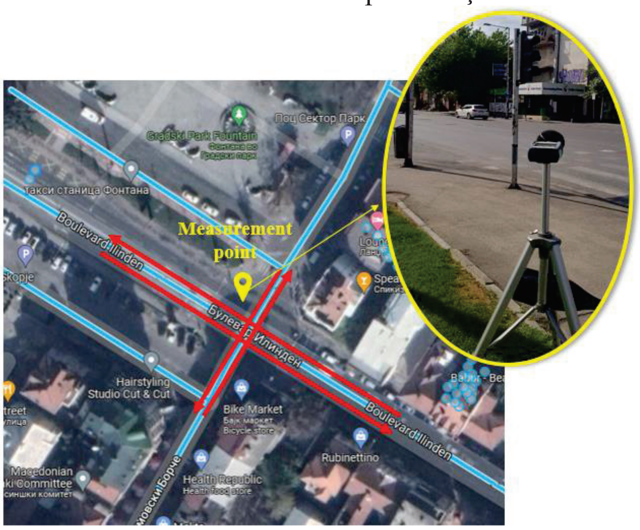

Figure 1. Measurement location (crossroad) in the city centre

At each measuring point the noise level is represented by the L_{eq}, L_{AF} and L_{95} parameter in accordance with recommendations explained in **[1].**

As the traffic jams at this intersection significantly affect the total noise level at the intersection, it was necessary to provide data on the number of vehicles passing at that intersection. For this purpose, data were obtained from the Traffic Control and Management Center, which is a state institution obliged to monitor traffic density across city roads through a network of sensors set on every crossroad in the city. The data were obtained in the form of the number of vehicles that passed on both streets in one hour, and then they were standardized to obtain the total number of vehicles that passed at the intersection for a period of 10 minutes while the measurement was performed. On the other hand, another aspect related to the overall noise level on the certain location is that different types of vehicles such as passenger cars, trucks and motorcycles contribute differently to the overall noise level and cause different noise levels **[15].** Therefore, during the 10-minute acoustic measurement, the number of heavy and medium vehicles, as well as motorcycles was manually counted and carefully noted. These numbers were used as an input parameter in the statistical analysis that was conducted to provide a correlation between the total sound level on the location and the number of vehicles, but also a relation between the types of vehicles and their contribution to the overall noise level.

3 Acoustic noise maps

The data for the number of vehicles and the type of vehicles for the 20 measurements on the crossroad were used as an input in the noise mapping software IMMI in order to create an acoustic predictive noise map for the area. This software package is used for professional and research purposes and is used for static mapping and prediction of environmental noise. For the calculations, IMMI uses the national guidelines and standards and this map was calculated according to the French National Method for Calculating Noise Indicators for Street Traffic [NMPB Routes], that classifies the equivalent noise level for the day time (from 7am-19 pm), evening time (from 19pm-23pm) and night time (from 23pm-7 am).

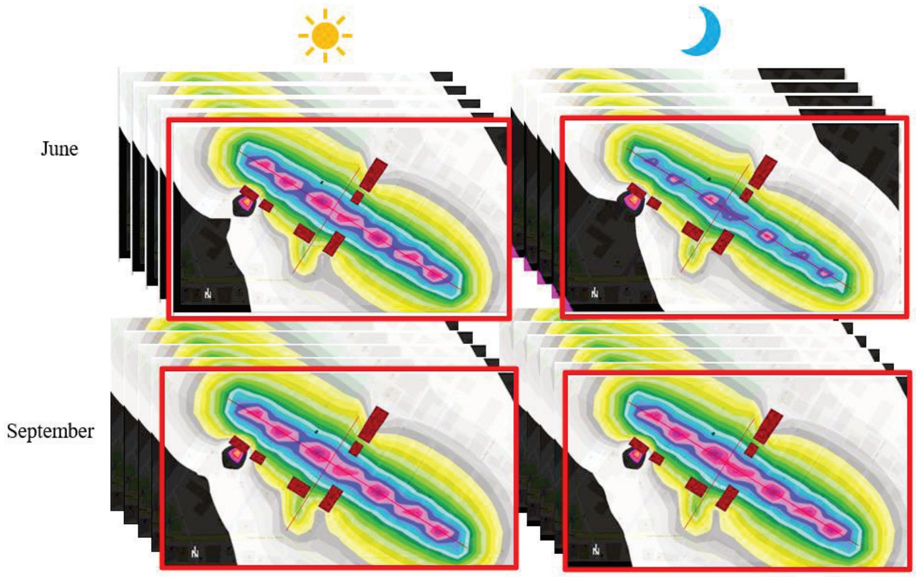

Figure 2. Four representative noise level dispersion maps for morning and evening period of two days during the measurement week

The correct input of the sound sources such as the total traffic flow (number of vehicles) and the types of vehicles for the specific streets and periods of the day is an important aspect in the process of creating the maps. In this case, additional interventions before inserting the traffic noise sources should be made in terms of defining the height of the objects as a part of the infrastructure around the area. Namely, for proper calculation of the sound propagation, the heights of the buildings are manually inserted into the model after conducting previous calculations of the individual objects heights in the area. The number of vehicles, average speed and types of vehicles characterizes the urban traffic noise and are required to be input in the software model. In this map, the number of vehicles for the two streets forming the crossroad, differing the types of vehuicles as heavy, medium and motorcycles over the two periods of the day (day and evening) The average traffic speed on the boulevards is 50 km/h. Having these parameters, the program calculates the noise maps dispersion models and the obtained results for the equivalent noise level L_{eq} for the day and evening scenarios expressed in L_d and L_e are presented in Fig.2. The calculation is visualized using the vehicle flow on the two streets modeled in the software as line sources of noise.

4 Results from the statistical analysis and discussion

In order to obtain conclusions about the impact of the traffic volume and different types of vehicles on the total noise level at the selected location, the linear correlation statistical method was performed on the obtained data. It was noticed that data for the number of medium and heavy vehicles contain matching extremes (Fig.3, left), but the same data are not extremes for the number of motorcycles. Therefore, the data analysis approach was decided to be looked at from three aspects: with extremes, without extremes and ordinally (considering only the ranking of values, not the measured / enumerated values). The correlation between the number of vehicles by type (medium, heavy, motorcycles), the number of vehicles on both streets and the total number of vehicles with the variables that emit noise levels (L_{eq}, L_{AF}, L_{A95}) was compared. The aim was to determine how the noise level depends on the number and type of vehicles.

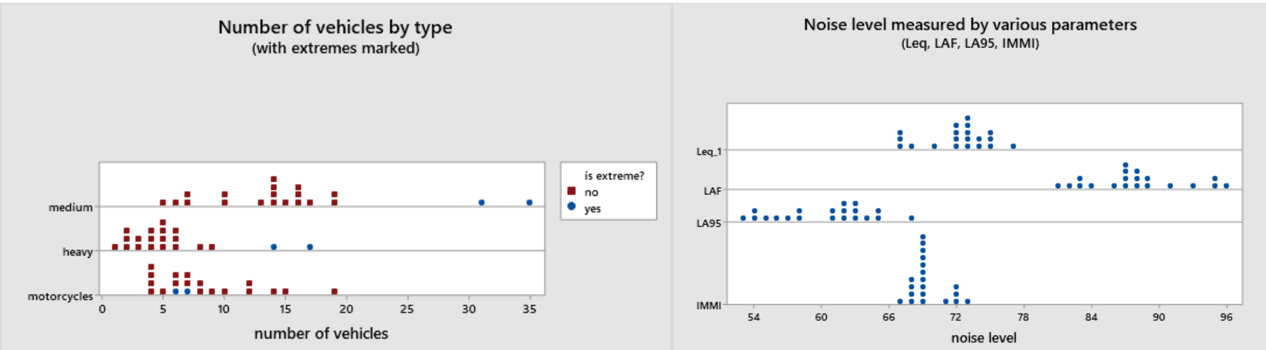

Figure 3. Review of number of vehicles by type (left) and values for the measured noise parameters (right)

After the initial overview of the data, three scatter plots were created. Each of them shows the number of vehicles on the x-axis and the corresponding noise measure (L_{eq}, L_{AF}, L_{95}) on the y-axis. Additionally, the vehicle type (with a different symbol and color for each type) was marked and added a simple linear model for each type to see the trend (trendline). This approach and these elements were chosen because it is easy to see the trend of the noise measure according to the number of vehicles.

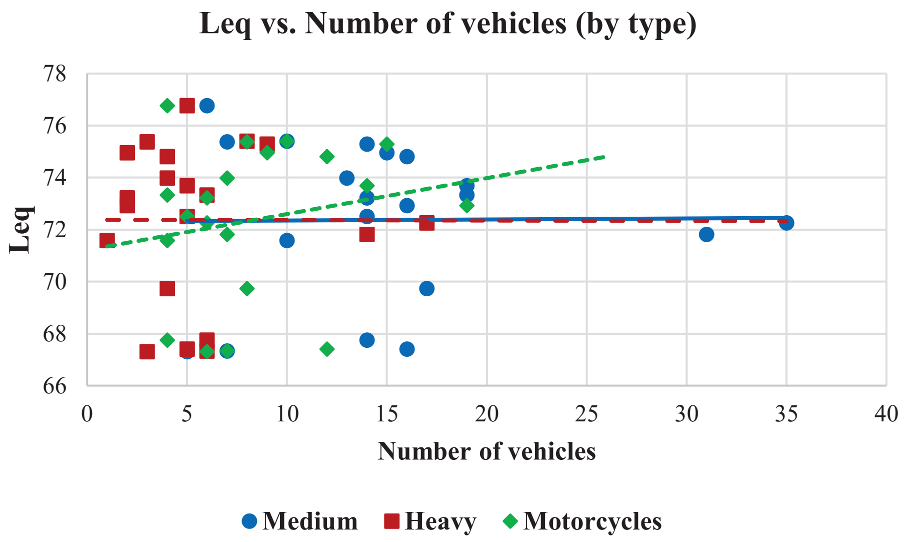

Figure 4. Correlation between the number of all three types of vehicles and L_{eq} parameter

From the initial analysis, it is obvious that the more vehicles were included in the traffic, the higher noise level was measured (positive correlation). The dependence is moderate in all cases. The volume of traffic on the main boulevard Ilinden is most influential when it comes to noise level, and the impact of the intersecting street is smaller. On the other hand, medium and heavy vehicles are weakly correlated with the noise level, except when considering the normal (ordinal) values for heavy vehicles. In this case the correlation is negative and moderate, which means that in the days ranked as days with higher volume of heavy vehicles are in relation to days ranked as days with lower noise levels (Fig. 4).

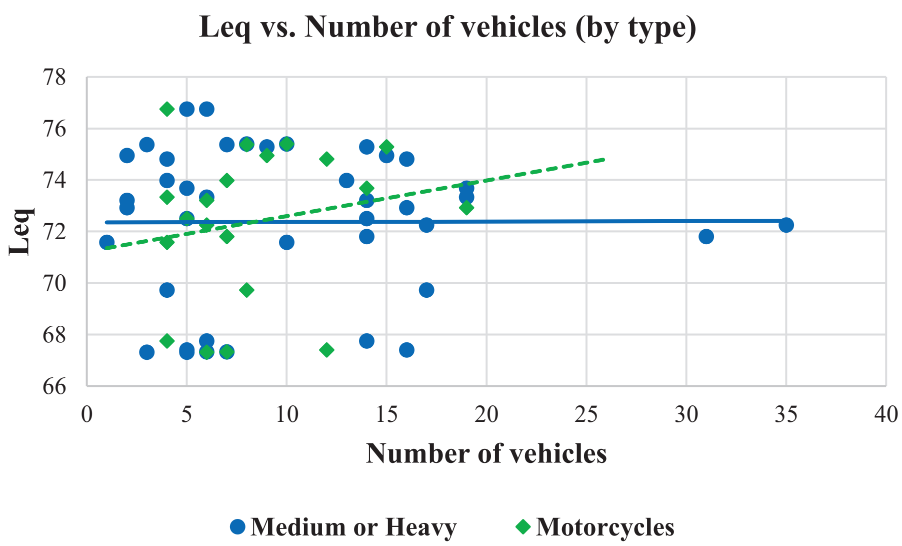

Figure 5. Correlation between the number of medium and heavy vehicles and motorcycles on L_{eq} parameter

For data with extremes, there is a moderate positive correlation between the number of vehicles by type and noise level. This is an indication that there is a dependence between noise level and vehicle type, but this dependence is moderate. By rejecting the extremes or looking at the ranked data, the correlation between medium and heavy vehicles on the one hand and the noise level on the other is significantly reduced. It is interesting that there is a reverse trend in motorcycles where the correlation is increasing (Fig.5). The number of motorcycles is a stable indicator of the noise level (there is a moderate positive correlation with the level in all cases). The volume of traffic on Ilinden and the total volume of traffic are a good indicator of the noise level (positive, fairly strong correlation). According to the type of vehicles, a modest correlation with the noise level can be noted.

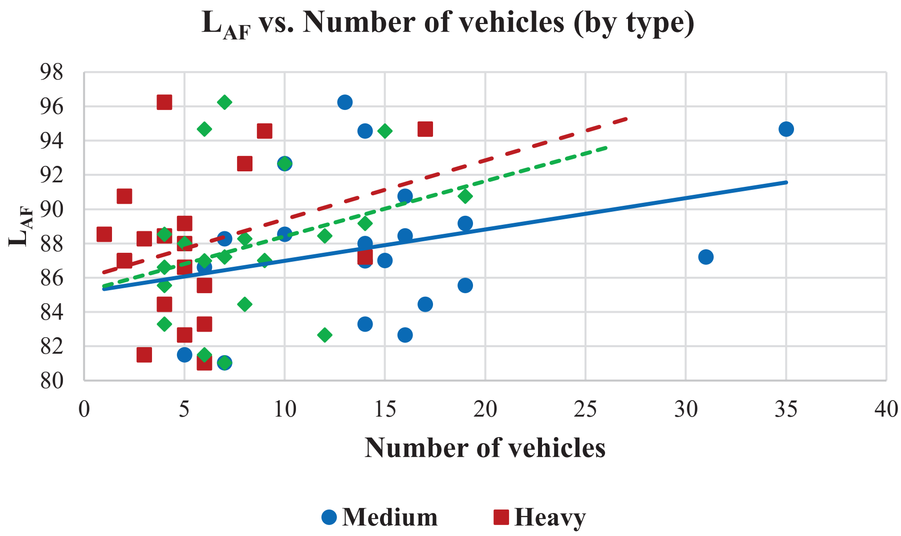

Figure 6. Correlation between the number of medium and heavy vehicles and motorcycles on L_{AF} parameter

What is interesting, even unexpected is the negative dependence in some cases: a larger number of vehicles are associated with a lower noise level. In heavy and medium vehicles, huge changes occur in the results based on the approach of analysis. The volume of traffic on Ilinden and the total volume of traffic are a good indicator of the noise level (positive, fairly strong correlation). The dependence between vehicle type and noise level is quite modest, even weak (except for medium vehicles where the correlation is moderate and negative).

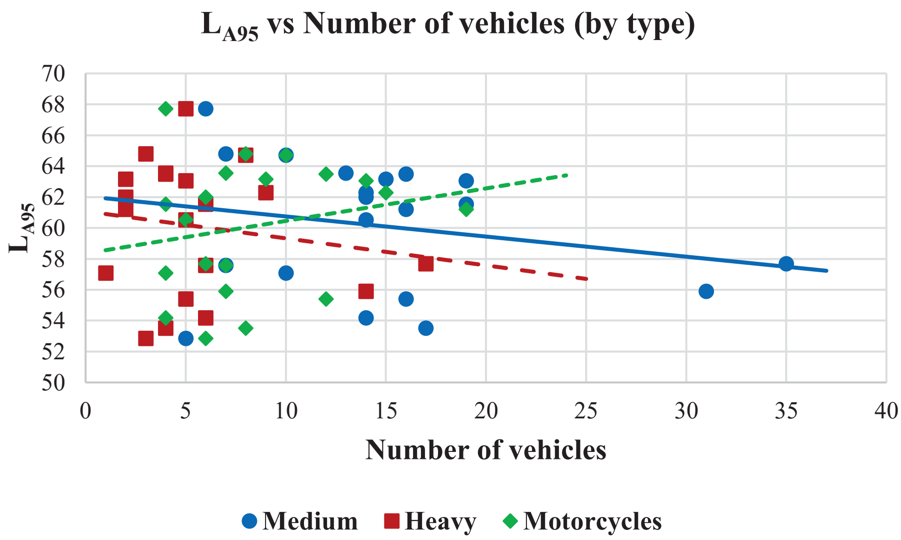

Figure 7. Correlation between the number of medium and heavy vehicles and motorcycles on L_{A95} parameter

From the statistical analysis can be concluded that the number of motorcycles is the most stable indicator of the noise level which has been noticed in all combination analyzes. On the other hand, it was concluded that it is preferable to work with L_{AF} (Fig. 6) or L_{A95} (Fig. 7) indicators for noise level. In some cases, there is a negative correlation between the number of vehicles of a certain type and the noise level (for example medium vehicles and L_{A95} as shown in Fig.7). This is an indication that on average a larger number of medium vehicles means less noise, meaning the dominant noise is caused by another type of vehicle.

5 Conclusions

This paper presents the results from a conducted statistical analysis approach of the impact of traffic density, as well as the type of vehicles that make up the traffic on the overall noise level measured through three parameters (L_{eq}, L_{AF}, L_{A95}) at a selected crossroad in the center of Skopje. To obtain the input parameters for the noise level, 20 short 10-minute noise measurements were made at the selected location, and afterwards, data for the number of vehicles that passed through the intersection in those periods, as well as the type of vehicles that contributed to the traffic was obtained.

From the exposed detailed analysis, can be concluded that the heavy traffic at the selected location has a large, dominant impact on the noise level at that location. At the same time, it can be concluded that the different types of vehicles that were considered in this study have different contributions to the overall noise level. It was noticed that the most stable indicator of increased noise level are the motorcycles, and the parameters L_{AF} and L_{A95} are the most stable parameters of increased noise level, because in general they have shown a positive correlation with the total number of vehicles.

In order to provide more detailed results from the application of this statistical method for assessing the impact of traffic noise on the total noise level, it is desirable to provide additional more frequent and longer measurements at the selected location to be able to draw stronger conclusions in future. It is also necessary to take into account additional factors of influence such as the age of the vehicles, the type of engine and the speed and also, incidental short-term vehicle noises, such as whistling or siren, should also be considered. All this will add input to the models for statistical analysis and will deepen the analysis, as well as the conclusions from it.

For future work, it is proposed and planned to provide more detailed data through conducting more frequent and longer measurements and considering additional parameters for the traffic contents. Furthemore, creation of more detailed maps for noise level dispersion to provide a predictive method and monitor the level of road traffic noise in the city should not be mistreated.

References

[1] EU Directive. Directive 2002/49/EC of the European parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise. Off. J. Eur. Commun. 2002, 12, L189.

[2] Khan, J., Ketzel, M., Kakosimos, K., Sørensen, M. and Jensen, S.S., 2018. Road traffic air and noise pollution exposure assessment–A review of tools and techniques. *Science of The Total Environment*, *634*, pp.661-676.

[3] Akgüngör P.A. & Demirel, A. (2008) Investigating urban traffic based noise pollution in the city of Kirikkale, Turkey, Transport, 23:3, 273-278, DOI: 10.3846/1648-4142.2008.23.273-278

[4] Pobedin, A.V., Shekhovtsov, V.V. and Dolotov, A.A., 2017. Computational probabilistic evaluation of passenger cars noise level. *Procedia Engineering*, *206*, pp.1558-1563.

[5] Zambon, G., Roman, H.E., Smiraglia, M. and Benocci, R., 2018. Monitoring and prediction of traffic noise in large urban areas. *Applied Sciences*, *8*(2), p.251.

[6] Di, H., Liu, X., Zhang, J., Tong, Z., Ji, M., Li, F., Feng, T. and Ma, Q., 2018. Estimation of the quality of an urban acoustic environment based on traffic noise evaluation models. *Applied Acoustics*, *141*, pp.115-124.

[7] Ramírez, A. and Domínguez, E., 2013. Modeling urban traffic noise with stochastic and deterministic traffic models. *Applied Acoustics*, *74*(4), pp.614-621.

[8] Salomons, E.M. and Pont, M.B., 2012. Urban traffic noise and the relation to urban density, form, and traffic elasticity. *Landscape and Urban Planning*, *108*(1), pp.2-16.

[9] To, W.M., Ip, R.C., Lam, G.C. and Yau, C.T., 2002. A multiple regression model for urban traffic noise in Hong Kong. *The Journal of the Acoustical Society of America*, *112*(2), pp.551-556.

[10] Ryu, H., Park, I.K., Chun, B.S. and Chang, S.I., 2017. Spatial statistical analysis of the effects of urban form indicators on road-traffic noise exposure of a city in South Korea. *Applied acoustics*, *115*, pp.93-100.

[11] Seong, J.C., Park, T.H., Ko, J.H., Chang, S.I., Kim, M., Holt, J.B. and Mehdi, M.R., 2011. Modeling of road traffic noise and estimated human exposure in Fulton County, Georgia, USA. *Environment international*, *37*(8), pp.1336-1341.

[12] Say, N., Okten. O., Aysu, A., Yalcinkaya, M.N., 2017. Seasonal Change and Spatial Distribution of Traffic Noise in Seferihisar, Turkey. ARCHIVES OF ACOUSTICS Vol. 42, No. 4, pp. 631–642.

[13] Gaja, E., Gimenez, A., Sancho, S., Reig, A., 2002. Sampling techniques for the estimation of the annual equivalent noise level under urban traffic conditions. Applied Acoustics 64 (2003) 43–53

[14] Przysucha, B., Szeląg, A., Rosa, W. and Kania, K., 2021. Representativeness of the measurement sample in the determination of the long-term noise indicators of traffic noise. *Measurement*, *180*, p.109550.

[15] Garcia, A. and Faus, L.J., 1991. Statistical analysis of noise levels in urban areas. *Applied Acoustics*, *34*(4), pp.227-247.