University of Niš
Faculty of Occupational Safety
„Politechnica" University of Timisoara
Faculty of Mechanical Engineering

Niš, 6 - 7. 12. 2018.

26th International Conference
NOISE AND VIBRATION

APPLICATION OF GENETIC ALGORITHM IN DEVELOPING OF TRAFFIC NOISE PREDICTION MODEL

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Abstract - *In order to control noise levels it is necessary to have a suitable calculation method for traffic noise prediction. Since 1950s many mathematical models for estimation of traffic noise pollution have been developed, and most of available models found in literature are based on regression analysis. This paper presents the application of genetic algorithm in development of simple mathematical model for prediction of equivalent A-weighted level of road traffic noise in urban areas of the city of Kraljevo. Predictions of developed mathematical model are compared to experimental data collected by traffic noise measuring, as well as to predictions of commonly used traffic noise models, and obtained results of statistical analysis of differences between measured and calculated noise levels are shown in this paper.*

1. INTRODUCTION

Although technological and industrial development contributes to the progress of civilization, the development of industrial and transport capacities causes not only air, soil and water pollution, but also increase in levels of communal noise. The results of strategic noise mapping in the European Union (EU) clearly indicate that road traffic represents dominant source of noise pollution in urban environments. According to noise maps of the EU agglomerations and major roads, close to 68 million EU citizens are exposed to daytime road traffic noise levels above the excess exposure threshold, fixed by the EU at 55 dB(A) [1]. In the past decades many studies [2-4] have shown that long term noise exposure causes stress, sleep disturbance, cardiovascular problems, and therefore significantly affects human psycho-physical health and productivity of the population.

In order to manage and reduce the impact of noise pollution on human health and environment, it is necessary to have a suitable calculation method for prediction of road traffic noise levels. The calculation method represents an important tool for the process of noise mapping and noise action planning, and therefore can be of fundamental importance in the process of urban planning and designing, as well as for the traffic noise reduction through the process of traffic management. Although software packages for noise prediction are numerous, their price is high and their usage is highly complex. This is the reason why numerous mathematical models for traffic noise prediction have been developed by establishing a functional relationship between experimentally measured noise levels and selected road traffic parameters. Since early 1950s many researchers have offered a large number of mathematical models for traffic noise prediction and most of the available models are developed using linear regression analysis. Also, several publications use soft computing methods such as artificial neural networks (ANN) [5-7] or genetic algorithms [8-9] for developing or predicting traffic noise levels. The critical review of some of the most used models are given in [10], and one of the conclusions given in paper is that each model is strongly influenced by certain characteristics of the traffic flow and environment, such as pavement type, driving skills, road and vehicles maintenance, etc.

This paper presents a novel mathematical model for prediction of traffic noise levels in the territory of the city of Kraljevo. The model is developed based on experimental results of noise level measuring carried out in the city of Kraljevo and therefore reflects the specificities of the traffic flow in the areas near the city major roads. A functional relationship between A-weighted noise level and the traffic flow parameters is obtained using genetic algorithm. For the purpose of the model validation, traffic noise prediction levels obtained by developed model are compared to measurement results, as well as to predictions of several commonly used traffic noise models.

2. MODEL BACKGROUND

The most of the available mathematical models for estimation of road traffic noise levels enable prediction of the equivalent A-weighted continuous noise level, *Leq* [dBA], which is recommended as a suitable descriptor for the use in motor vehicle noise assessment by many national and international regulatory agencies [11]. Almost all mathematical models available in literature are developed based on experimental results of noise level monitoring by performing the regression analysis in approximation of functional relationship between the equivalent noise level and traffic flow and road parameters.

Some of the most used mathematical models for road traffic noise prediction are those proposed by Burgess [12], Griffith [13] and Fagotti [14]. Based on experimental data collected in the territory of Sidney, Australia, Burgess determined functional relationship between the equivalent noise level *Leq* and road traffic parameters:

$$Leq = 55.5 + 10.2\log(Q) + 0.3p - 19.3\log(d).$$

In the given equation Q represents the total number of vehicles per hour, p percentage of heavy vehicles, while the distance between the observation point and center of the traffic lane is denoted with d.

According to Griffiths and Langdon, equivalent noise level and percentile levels (L_{10}, L_{50} and L_{90}) at distance d from the center of the traffic lane can be calculated according to the following equations:

$$Leq = L_{50} + 0.018 \cdot (L_{10} - L_{90})^2,$$
$$L_{10} = 61 + 8.4\log(Q) + 0.15p - 11.5\log(d),$$
$$L_{50} = 44.8 + 10.8\log(Q) + 0.12p - 9.6\log(d),$$
$$L_{90} = 39.1 + 10.5\log(Q) + 0.06p - 9.3\log(d).$$

Fagotti et al. proposed simple mathematical model for estimation of the equivalent noise level based on the number of light motor vehicles N_c, motorcycles N_m, heavy vehicles N_{hv} and buses N_b per hour:

$$Leq = 33.5 + 10\log(N_c + N_m + 8N_{hv} + 88N_b).$$

Since the mathematical models for traffic noise prediction have been developed from experimental results of noise level measuring by performing the statistical analysis, each model is strongly influenced by the composition and characteristics of road traffic flow, as well as certain characteristics of the measurement locations. This is the reason why the application of the available models is often limited to the environment where the noise levels monitoring was conducted. Therefore, a simple mathematical model is developed for the purpose of road traffic noise prediction in the urban area of the city of Kraljevo. As the equivalent noise level represents a logarithmic function of the total number of motor vehicles, it was modeled by the following equation

$$Leq = L_0 + 10 \cdot \log(N_{lv} + a_{hv} \cdot N_{hv}) - 10\log(d / d_0)$$

where L_0 is the average A-weighted noise level of a light motor vehicle at distance d_0 from the centre of road lane, while the coefficient a_{hv} represents the equivalent number of light motor vehicles that generate approximately the same noise level as one heavy vehicle. Referent distance d_0 was adopted to be 7.5 m, while the distance between the measurement point and the road center lane is denoted by d. The third member in the sum accounts for sound spreading.

In order to develop a novel model for prediction of noise levels in the areas near the major roads of the city of Kraljevo, after measuring of A-weighted equivalent noise levels and collecting of traffic flow data in the urban areas of Kraljevo, traffic noise model parameters L_0 and a_{hv} were estimated by the experimental data fitting using genetic algorithm.

3. MEASUREMENTS

For the purpose of noise level monitoring and development of traffic noise prediction model, measurements of A-weighted equivalent noise levels were performed with Brüel&Kjær 2250 sound level meter on 28 measurement locations near the major roads of the city of Kraljevo. All measurements were carried out in dry weather conditions, without snow coverage, and with wind speeds lower than 5 m/s. Measurement positions were distant from the intersections and traffic-control lights, so it was assumed that all vehicles moved at a steady speed of 50 km/h, which is the speed limit for the territory of Kraljevo. The measuring points were far away from the airports, railway traffic, construction sites and industrial plants, so the road traffic can be considered as the only source of noise. A total of 690 measurements during the 15-minute time periods were carried out at 28 measurement locations. During each of the measurements, the numbers of light motor vehicles N_{lv} and heavy motor vehicles N_{ht} were collected.

4. GENETIC ALGORITHM

Genetic algorithm (GA) represents a powerful metaheuristic and evolutionary algorithm which is inspired by the process of biological evolution [15, 16]. Since it is capable of finding a global optimum in a space with multiple local extrema, genetic algorithm is often used in the optimization problems solving.

Genetic algorithm begins by creating a random population of the individuals. Each individual represents a candidate solution of the optimization problem. The quality of each member of the population is estimated using the fitness function. In every iteration of the algorithm, by simulating the processes of natural selection, mutation and crossover (reproduction), new generation of individuals is formed. By applying mechanism of selection, higher quality individuals survive and create new offspring. During the process of crossover new individuals are created by recombination of genetic materials between the pairs of survived individuals. The process of mutation causes a random change in the gene values. Since it introduces a new genetic material into the population, mutation represents the basic mechanism for prevention of premature convergence of the genetic algorithm. The searching process repeats until the maximum number of iterations is reached or error tolerance is met. The highest quality individual of the last generation represents an approximate solution of the given problem.

The simple functional dependence between traffic noise level and traffic flow parameters was optimized using genetic algorithm with rank based selection. According to this method of selection, after sorting the individuals based on their fitness values, the probability of an individual selection is determined according to on its rank (i.e. the position in the sorted array). If S represents the size of the population, the probability of selecting a individual with a rank i can be calculated with the following equation:

$$p_i = \frac{i}{\sum_{j=1}^{S} j}.$$

After selecting two different parental individuals, one child is formed by applying BLX-α crossover [17] of the parental genes. After offspring creation, a non-uniform gene mutation [18] (with a low mutation probability p_m=0.05) is applied. The values of GA parameters used in the optimization process are given in the Table 1. The traffic noise model parameters (L_0 and a_{hv}) were estimated using 494 experimental data sets collected at 20 measurement locations, and the result of the algorithm is a set of parameters that minimize the mean square difference between the measured and calculated noise levels. The results of the optimization are given in Table 2.

Table 1 *GA parameters*

Number of individuals	40
Selection method	rank based selection
Crossover method	BLX-α (α=0.5)
Method of mutation	non-uniform mutation
Mutation probability	0.05
Number of iterations	500

Table 2 *Optimized parameters*

L_0	a_{hv}
42.6	13

4. RESULTS

Traffic noise prediction results of developed mathematical model are compared with experimental results of noise level monitoring and prediction results obtained applying Burgess, Griffith and Fagotti mathematical models for estimation of traffic noise levels. Statistical analysis of differences between measured and calculated noise levels was carried out for all 690 measurement data sets. The mean values of the absolute differences between measured and calculated noise levels (ΔL), standard deviations of the differences (σ) and correlation coefficient (r) were calculated and shown in the Table 3. The obtained results of statistical analyses are separately presented for 494 measurement data sets used in the optimization process (index "optim") and 196 testing data sets collected at 8 remaining measurement locations which were not used in the process of optimization (index "test"). Furthermore, for each of the applied models, the total number of predictions m with error larger than 3 dB and the largest value of prediction errors ($\Delta L_{\max}$) are given in the Table 4. Figure 1 shows a comparative chart of measured and calculated noise levels. The results are shown for randomly selected 50 of 196 measurements used for model testing.

The results of the statistical analysis clearly show that the application of novel mathematical model for prediction of road traffic noise levels presented in this paper leads to more accurate estimation of noise pollution in the urban areas of the city of Kraljevo. It is important to notice that the number of predictions with an error larger than 3 dB is significantly reduced. The reason for superior performance of presented model is that it is developed on the basis of experimental results of noise monitoring in the city of Kraljevo, and, therefore, it is tuned to the characteristics of the road traffic in this city.

Table 3 *Comparison of different models for traffic noise prediction*

Model	ΔL	ΔL_{optim}	ΔL_{test}	σ	σoptim	σtest	r	r_{optim}	r_{test}
Novel model	1.32	1.26	1.47	0.88	0.86	0.93	0.89	0.9	0.87
Burgess	1.66	1.56	1.90	1.31	1.22	1.50	0.86	0.87	0.84
Griffith	4.38	4.39	4.35	1.67	1.67	1.68	0.87	0.88	0.86
Fagotti	3.75	3.74	3.76	1.62	1.61	1.67	0.88	0.89	0.86

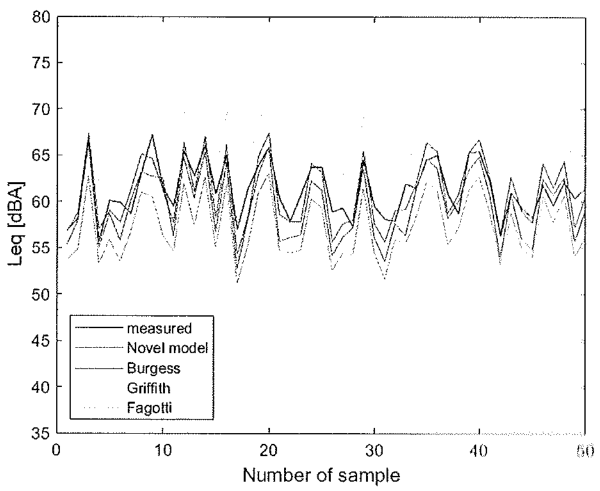

Fig. 1 *Comparative chart of noise levels*

Table 4 *Prediction error statistic*

Model	m	m_{optim}	m_{test}	$\Delta L_{\max}$	$\Delta L_{\max}^{optim}$	$\Delta L_{\max}^{test}$
Novel model	36	19	17	4.01	3.65	4.01
Burgess	126	77	49	6.19	5.37	6.19
Griffith	528	377	151	7.75	7.75	7.61
Fagotti	431	310	121	7.23	7.20	7.23

5. CONCLUSIONS

Noise levels predicted by extensively used mathematical models for traffic noise prediction deviate significantly from the experimental results of noise level monitoring in the territory of the city of Kraljevo, which indicates the need for development of a new model for equivalent noise level prediction. In order to develop more precise model, a total of 690 noise level measurements were performed during the 15-minute time periods at 28 measurement locations near the city major roads. Functional relationship between equivalent A-weighted noise level and traffic flow parameters was established using genetic algorithm.

The validation of developed mathematical model was performed by statistical analysis of the deviations between predicted and measured noise levels, as well as the correlation analysis of these levels. Results of statistical and correlation analysis show good agreement between measured and calculated values. A comparative analysis of the results obtained by proposed models and some of frequently used models for road traffic noise prediction has shown that the application of proposed models enables not only more precise prediction of traffic noise levels, but also significantly lower number of predictions with error larger than 3 dB.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Serbian Ministry of Education and Science for support through project TR37020.

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