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APPLICATION OF THE PARTICLE SWARM OPTIMIZATION FOR DEVELOPMENT OF A TRAFFIC NOISE PREDICTION MODEL

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Abstract: *Road traffic represents one of the main sources of noise pollution in urban areas. 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 particle swarm optimization in developing of simple mathematical model for prediction of equivalent A-weighted level of road traffic noise in urban areas of the city of Niš, Serbia. Predictions of the developed mathematical model are compared to experimental data collected by traffic noise measurements, as well as to predictions of commonly used traffic noise models, and the obtained results of statistical analysis of differences between measured and calculated noise levels are presented in this paper.*

INTRODUCTION

Road traffic represents the dominant source of noise pollution in urban environments. According to the latest data obtained from the strategic noise mapping for the EU agglomerations and major roads, close to 68 million people 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 significantly affects human health and productivity, causing stress, sleep disturbance, cardiovascular problems, etc. Moreover, the environmental noise pollution has a large impact on real estate prices [5].

In order to control road traffic noise it is necessary to have a suitable calculation method for noise levels prediction. The calculation method 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. Software packages for noise prediction are numerous, but their price is usually high and their usage is highly complex. This is the reason why the mathematical models for traffic noise prediction have been developed based on the experimental results of noise level. Since early 1950s many authors have offered a large number of mathematical models and most of the available models are based on linear regression analysis. Also, several publications use the so-called “soft computing” methods, such as artificial neural networks (ANN) [6-8] or genetic algorithms [9-10] for prediction of the traffic noise levels. A critical review of some of the most used models are given in [11], and one of the conclusions of this study was that each model is strongly influenced by certain characteristics of the traffic and the environment, such as pavement type, driving skills, road and vehicles maintenance, etc.

In this paper is presented a novel model for traffic noise prediction which reflects the specificities of the traffic flow for the territory of the city of Niš, Serbia. A functional relationship between the traffic flow parameters and A-weighted equivalent noise level is established using PSO (Particle Swarm Optimization) technique. The obtained results of traffic noise prediction are compared to experimental results of noise level measuring, as well as to predictions of several commonly used traffic noise models.

MODEL

Most of the available mathematical models for traffic noise prediction enable estimation of the equivalent A-weighted continuous noise level, *Leq*, which is recommended as a suitable descriptor for motor vehicle noise assessment by many national and international regulatory agencies [12]. Almost all the mathematical models found in literature are developed by establishing a functional relationship between the noise level and traffic flow parameters based on experimental results of noise level monitoring. The functional relationships are usually approximated by performing the regression analysis.

Some of the most used mathematical models for traffic noise prediction are those proposed by Burgess [13], Griffith [14] and Fagotti [15]. Burgess model has been applied for the first time in Sidney, Australia. According to Burgess, equivalent noise level can be calculated using the equation

$$Leq = 55.5 + 10.2\log(Q) + 0.3p - 19.3\log(d) \tag{1}$$

where Q is total number of vehicles per hour, p is percentage of heavy vehicles and d is the distance from the observation point to the center of the traffic lane.

Griffiths and Langdon proposed a simple mathematical model for estimation of the equivalent noise level from the percentile levels (L_{10}, L_{50} and L_{90}) according to the following equations:

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

Fagotti et al. determined functional relationship between the equivalent noise level and the number of light vehicles N_c, motorcycles N_m, heavy vehicles N_{hv} and buses N_b per hour:

$$Leq = 33.5 + 10\log(N_c + N_m + 8N_{hv} + 88N_b). \tag{3}$$

As all mathematical models have been developed by performing statistical analysis of the experimental data, each of the models is strongly influenced by the composition and peculiarities of the traffic flow and characteristics of the measurement locations. This is the reason why the application of existing models is often limited to the urban environment where the measurements were made. For that reason, for the purpose of prediction of traffic noise level in the urban area of the city of Niš is developed a simple mathematical model. As the equivalent noise level is logarithmic function of total number of motor vehicles, it was modeled by the following equation

$$Leq = L_0 + 10\cdot\log(N_c + a_{mt}\cdot N_{mt} + a_{ht}\cdot N_{ht} + a_b\cdot N_b + a_m\cdot N_m) - 10\cdot\log(d/d_0) \tag{4}$$

where L_0 represents average noise level of a light motor vehicle at distance d_0, while the coefficients a_{mt}, a_{ht}, a_b and a_m represent the number of light motor vehicles that generate the same noise level as one vehicle of the respective category (a_{mt} for medium trucks, a_{ht} for heavy trucks, a_b for buses, and a_m for motorcycles). Referent distance d_0 was adopted to be 7.5 m, while the distance of the measurement point from the road center lane is denoted by d. The third member in the sum accounts for spreading of sound.

In order to develop a novel model for prediction of traffic noise levels, measurements of A-weighted equivalent noise levels were performed in urban areas of the city of Niš. Further, traffic noise model parameters L_0, a_{mt}, a_{ht}, a_b and a_m were determined by the experimental data fitting using particle swarm optimization (PSO) algorithm.

MEASUREMENTS

A total of 270 measurements of A-weighted equivalent noise levels were performed with Brüel&Kjær 2260 and 2250 sound level meters in 18 streets of the city of Niš, each with duration of 15 minutes. All measurements were carried out, in dry weather conditions, without snow coverage, and with wind speeds lower than 5 m/s. The measurements were performed at distances 7-15 m from the axis of the road, and at height 1.5 m above the ground. All measurement sites were at flat ground and above asphalt or concrete surface. 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 Niš. During each of the measurements, traffic density data, containing the number of light motor vehicles N_c, medium trucks N_{mt}, heavy trucks N_{ht}, buses N_b and motorcycles N_m, were collected.

PSO OPTIMIZATION

Particle swarm optimization is a population based stochastic optimization technique which is inspired by the collective behavior of a flock of birds. This technique was invented by R. Eberhart ant J. Kennedy in 1995 [16]. The advantages of PSO are its easy implementation, robustness to control parameters, and computational efficiency.

In PSO, each particle from the swarm, whose position represents a potential solution of the optimization problem, moves through the multidimensional search space according to its own experience and the experience of the whole swarm. Particles are initially placed at random positions and move in randomly selected directions. Position of each particle is evaluated by the fitness function. During each of the iterations, a particle changes direction toward best positions achieved so far by the particle itself, and the whole swarm. In an n-dimensional search space, i-th particle position and velocity are represented by vectors $X_i = (x_{i1}, x_{i2}, \ldots, x_{in})^T$ i $V_i = (v_{i1}, v_{i2}, \ldots, v_{in})^T$, respectively. In the k-th iteration of PSO algorithm, particle updates its position and velocity according to the following equations:

$$V_i^{k+1} = \omega V_i^k + c_1 r_1 \left(P_i^k - X_i^k\right) + c_2 r_2 \left(G^k - X_i^k\right), \; X_i^{k+1} = X_i^k + V_i^{k+1} \tag{5}$$

where ω is the inertia weight, c_1 and c_2 are cognitive and social scaling parameters, respectively, r_1 and r_2 are random numbers between 0 and 1, while P_i^k and G^k are best visited positions by the i-the particle and the whole swarm, respectively. The searching process repeats until the maximum number of iterations is reached or the error tolerance is met.

Table 1: PSO parameters

Number of particles	40
Inertia weight	decrease from 0.9 to 0.4 during iterations
c_1	2
c_2	2
Number of iterations	1000

The simple functional dependence between traffic noise level and traffic flow parameters (4) was optimized using PSO algorithm. The values of PSO parameters used in the optimization process are given in the Table 1. The traffic noise model parameters (L_0, a_{mt}, a_{ht}, a_b and a_m) were estimated using 170 experimental data sets, 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 2: Optimized parameters

L_0	a_{mt}	a_{ht}	a_b	a_m
43.61	3.89	6.95	5.46	1

RESULTS AND ANALYSIS

The results of traffic noise prediction of developed mathematical model are compared with experimental results of noise level measuring and the results obtained by some of the most used mathematical models for traffic noise prediction which are described in this paper. Statistical analysis was carried out for all 270 measurement data sets. The mean values of the absolute differences between measured and calculated noise levels ($\Delta\overline{L}$) and standard deviations of the differences (σ) were calculated. Furthermore, the total number of predictions with error larger than 3 dB (m) was determined for each of the applied models. In the Table 3, the results of statistical analyses are separately presented for 170 measurement data sets used in the optimization process (index "optim") and 100 data sets used for testing (index "test"). Figure 1 shows a comparative chart of measured and calculated noise levels. The results are shown for randomly selected 30 of 100 measurements used for model testing.

Table 3: Comparison of different models for noise prediction

Model	$\Delta\overline{L}$	$\Delta\overline{L}_{train}$	$\Delta\overline{L}_{test}$	σ	σ_{train}	σ_{test}	m	m_{train}	m_{test}
PSO	1,37	1,33	1,43	0,92	0,94	0,88	12	7	5
Burgess	2,00	1,83	2,30	1,37	1,40	1,28	59	32	27
Griffith	4,90	4,76	5,13	1,62	1,63	1,59	229	139	90
Fagotti	2,97	2,95	3,00	1,88	1,86	1,94	123	78	45

The results of comparative analysis clearly show that the application of the developed mathematical model for traffic noise prediction presented in this paper leads to more accurate predictions of noise pollution for the territory of the city of Niš. It is important to notice that the number of predictions with an error larger than 3 dB is significantly reduced.

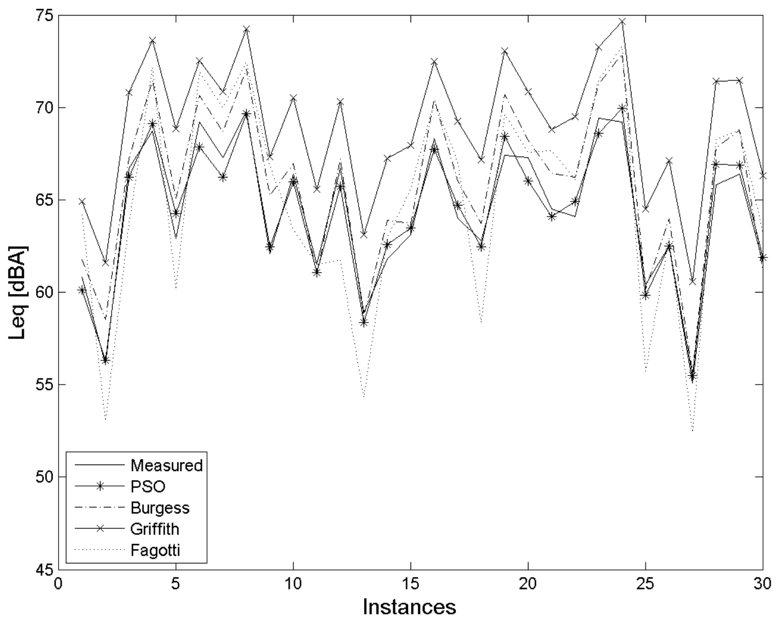

Figure 1: Comparative chart of measured and predicted noise levels

The reason for the superior performance of presented model is that it is developed on the basis of experimental results of noise monitoring in the urban areas of the city of Niš, and, therefore, tuned to the characteristics of the road traffic in this city.

CONCLUSION

Since the application of the extensively used mathematical models for traffic noise prediction did not provide satisfying results for the territory of the city of Niš, a total of 270 noise level measurements were performed in 18 streets of this city in order to develop a more accurate model.

Traffic noise levels were estimated made using a known model that accounts for influences of different types of vehicles that are met in urban areas, and the contribution of individual types of vehicles to the overall traffic noise level was calculated using the evolutionary algorithm PSO.

The results show that such model significantly improved the estimation of the noise emission levels in the city of Niš. The proposed model may be important in engineering practice because it enables a simple prediction of the traffic noise level on the basis of traffic composition data, which opens door for traffic noise management on the basis of re-direction of traffic of certain types of vehicles.

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ПРИЛОЖЕНИЕ НА ОПТИМИЗАЦИЯТА НА РОГОВИТЕ ЧАСТИЦИ ПРИ МОДЕЛА ЗА ПРОГНОЗИРАНЕ НА ШУМОЗАМЪРСЯВАНЕТО

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СЪРБИЯ

Ключови думи: *шумозамърсяване, прогнозиране на шума, оптимизация на роговите частици.*

Резюме: *Автомобилният транспорт е един от основните шумозамърсители в градска среда. За да се прогнозират правилно нивата на шумозамърсяване, е необходимо да се използват подходящи методи. От 1950 г. насам за прогнозиране на шумозамърсяването се използват и развиват основно математически модели, като в научната литература предимно се срещат модели, базирани на регресионни анализи. В настоящия доклад се прилага оптимизацията на роговите частици за усъвършенстване на прост математически модел за прогнозиране на нивото на шумозамърсяване на територията на град Ниш, Сърбия. Прогнозните данни от модела се сравняват с хипотетични данни, събирани при измерване на шумозамърсяването, както и при използването на често срещани модели за прогнозиране на шумозамърсяването. Освен това са представени и резултатите, получени при сравнението на данните от статистическия анализ и изчислените нива на шума.*