Verification of NAISS Model for Road Traffic Noise Prediction in Urban Areas

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Abstract—**Background of mathematical model for prediction of road traffic noise called NAISS model is shown in this paper. The model has been created by extracting function relation among the equivalent noise levels and the traffic parameters collected by systematic traffic noise monitoring in urban areas of the city of Nis. Based on the analysis of three different variants of traffic noise prediction model, the model with three input parameters (the number of passenger vehicles, freight vehicles and buses) and one output (Leq) and two separate equations for two ranges of noise levels has been proposed as rather correctly for using in the urban areas of the city of Nis. In order to examine validity of formed model, it is carried out the comparative analysis of NAISS model and the other models available in literature and the verification of NAISS model based on data collected by traffic noise monitoring in urban areas of the city of Nis during the years 2008-2010. The good results obtained in the comparison with other prediction methods have been confirmed in the verification process of NAISS model. Scatter plot for model verification shown in this paper as well as the results of statistical analysis of the differences between measured and calculated data show the validity and enforceability of the NAISS model for traffic noise prediction in urban areas of the city of Nis.**

Index Terms—**Acoustics, noise measurement, predictive models, traffic noise**

I. INTRODUCTION

By nature, noise represents a composite time-varying signal. Some of its components can be controlled while others cannot [1]. Noise is one of the environmental pollutants that are encountered in everyday life. Noise pollution, even at lower frequencies, has become a major concern of communities living in urban areas, where the level of man-made noise is less dependent on the number of people living in certain areas, than the technical sophistication of local infrastructure and lifestyle [1].

With urbanization and the corresponding increase in the number of vehicles in cities, the pollution is increasing at an alarming rate. Main areas of concern are related to air and noise pollution. More than 70% of total noise in our environment is due to vehicular noise. Investigations in several countries in the past decades have shown that noise has adverse effects on human health, especially for population living in urban areas near traffic lanes [2]–[4].

Therefore, the control of road traffic has become a matter of major concern for communities trying to maintain a satisfactory living and working environment. Traffic control systems used in modern cities can solve many traffic problems such as traffic jams, traffic incidents, delays, parking, fuel consumption, noise emission, air emission, and others. One such system, among other things, must include the model for traffic flows imitation [5] and traffic noise prediction model. By using a traffic noise prediction model, one can calculate and examine the noise level in the processes of planning and designing.

A theoretical solution to the problem of road traffic noise modelling has to be a complex one, as it needs to involve a large number of model parameters and because of the fact that we have to take into consideration the complexities or shortages of analytical equations used to describe correlations between noise levels and different parameters which have an impact on noise.

Developed theoretical models include the characteristics of noise sources for the purpose of calculating noise source emission and modelling the sound wave propagation pattern from the place of emission to the place of immission, i.e. the receiver point (calculation point). Theoretical models are precise but the calculation takes a long time. There is a large number of software packages which include different models of noise level calculations, but their usage is highly complex, as one needs to go through a detailed preparation of input data related to the noise source, as well as to the digitalized terrain model, which largely influences noise propagation due to different factors a sound wave encounters on propagation path (reflexion, diffraction, terrain absorption, air absorption, refraction, etc.).

This is the reason why mathematical models based on experimental results of noise level monitoring and establishing their correlations with traffic parameters are developed. Very many authors have offered a large number

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of mathematical models (linear and non-linear, statistical, based on fuzzy logic or neural networks, etc.) which describe traffic noise with different levels of precision and which differ from each other in regard to the factors they take into consideration.

Some of available models we find in current literature are based on establishing functional relations between the parameters of noise emission and the parameters of traffic and traffic lanes [6]–[8]. Functional relations are usually acquired by means of a statistical analysis (e.g. regression analysis) and the empirical models are finally represented by equations.

Nevertheless, having in mind that nearly all mathematical models are created on the basis of experimental data, each model includes certain characteristics of the measurement spot, as well as the features and specificities of the traffic flow, so they cannot provide a precise approximation of the change trend of the equivalent noise level as dependent on a number of physical parameters defining the traffic and the traffic lanes in question. This is why one has to be cautious when applying each of these models to the conditions which govern other urban environments.

II. NAISS MODEL BACKGROUND

Using the existing models for the purpose of traffic noise prediction on the territory of the city of Nis does not provide proper results, as each of these models includes certain characteristics of the measurement spot, as well as the features and specificities of the traffic flow. This is why the NAISS model was developed – it reflected the specificities of the traffic flow and the traffic infrastructure on the territory of the city of Nis. The detailed description of the model and its creating procedure is provided in [9], [10].

The NAISS model was created by extracting a functional relation between the equivalent noise level and the traffic parameters, using polynomial functions described in [11]. The polynomial coefficients were calculated by experimental data fitting by Nelder - Mead method using the computer program written in MATLAB® environment. Nelder-Mead method was applied in the optimization process to find the minimum of the function, which is formed as the difference between the measured and the predicted equivalent noise level.

The experimental data related to the traffic flow and the measured equivalent noise levels gathered in 1995 were used to create this model. In order to facilitate the estimation of the impact which the traffic flow had on the equivalent noise level, the total number of vehicles was divided into the number of passenger vehicles, freight vehicles and buses, which meant having three input parameters for the model: the number of passenger vehicles (N_c), the number of freight vehicles (N_{hv}) and the number of buses (N_b). This resulted in the model which had three inputs (the traffic flow data) and one output (the equivalent noise level). The block scheme is presented in [9], [10].

The different variants of model were created. First, the fitting based on the experimental data for all grouped measurement spots and one equation for described road traffic noise was carried out. In this case, a scatter plot of the measured and the calculated values of noise levels shown in the Fig. 1 points out to two level ranges with grouped data and a good correlation between the measured and the calculated values in these ranges.

Based on the analysis of all variants of traffic noise prediction model [9], [10], one can notice that the road traffic noise prediction done by separate equations for two ranges of noise level is rather correct. The equivalent noise level, *Leq*, can be calculated with satisfactory precision with the following equations [9], [10]:

$$Leq = 10\log(N_c + 3.7N_{hv} + 1.9N_b) + 38.2, \quad 55dB(A) < Leq \le 65dB(A), \tag{1}$$

$$Leq = 10\log(N_c + 11.7N_{hv} + 3.1N_b) + 44.3, \quad 65dB(A) < Leq < 75dB(A). \tag{2}$$

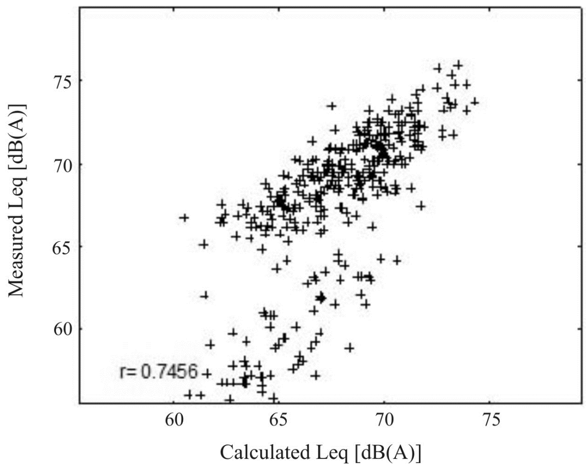

Fig. 1. The measured Leq against the calculated Leq by NAISS model with one equation for all measurement points.

The equivalent noise level of road traffic at a distance of 7.5 m from a traffic lane is determined by the NAISS model on the basis of the number of passenger vehicles, freight vehicles and buses during one hour. Based on the traffic flow, the equivalent noise level is calculated using (2). If the calculated level is below or equal to 65 dB(A), a recalculation of the noise level is done using (1).

In order to test the NAISS model, the results of road traffic noise level calculations were compared to the results of the calculations of road traffic noise levels done by means of a number of empirical methods of noise level prediction available in literature [6]–[8]. The comparison of noise level calculations acquired using different models was done on the basis of the database encompassing the measured road traffic noise levels and the road traffic flow on the territory of the city of Nis during 1995. The same data were used to create the NAISS model.

The created NAISS model has been used in practice in various municipal institutions to calculate road traffic noise levels during drafting spatial and general city plans, detailed city plans and projects, regulation studies and action plans in those aspects related to the environmental noise.

Also, the NAISS model has been successfully used in other cities, e.g. in Bukit Mertajam (Malaysia), Erbil City (Iraq) and Novi Sad (Serbia) [12], [13].

The advantages of the NAISS model over other empirical methods available in [6]–[8] are shown in [9], [10], [11], [13]. The comparative analysis of the NAISS model and other empirical methods show that the NAISS model provides the best results in the process of road traffic noise calculation near traffic lanes [9], [10], [11], [13].

III. NAISS MODEL VERIFICATION

The measured data were collected near the main city traffic arteries with typical properties of commercial, residential, industrial and hospital areas, five times during daytime period for all locations. All measurements were done on working days during the years 2008-2010, excluding all atypical conditions. Every measurement spot was determined from an acoustic point of view by the equivalent noise level. In addition, data related to the urban planning circumstances of each spot were taken into account as well as the measurement of traffic density, according to the number of each type of vehicle per hour (the number of light vehicles, heavy vehicles and buses). The standard apparatus based on the sound level meters, model Brüel&Kjær 2260 and 2250, was used to determine the equivalent noise levels. Some of the measurement spots were different in relation to the measurement spots used in the optimization process of NAISS model.

More than 300 measured samples (noise data and traffic data) collected during 2008 - 2010 were included in the verification process. Also, measured and calculated equivalent noise level by NAISS model was compared. Fig. 2 shows the measured and calculated road traffic noise level values for the year 2008.

Also, scatter plots of measured and calculated values that were used for model verification are shown in Fig. 3–Fig. 5, for the years 2008 - 2010. In the same figures the regression line of 45° slope is shown.

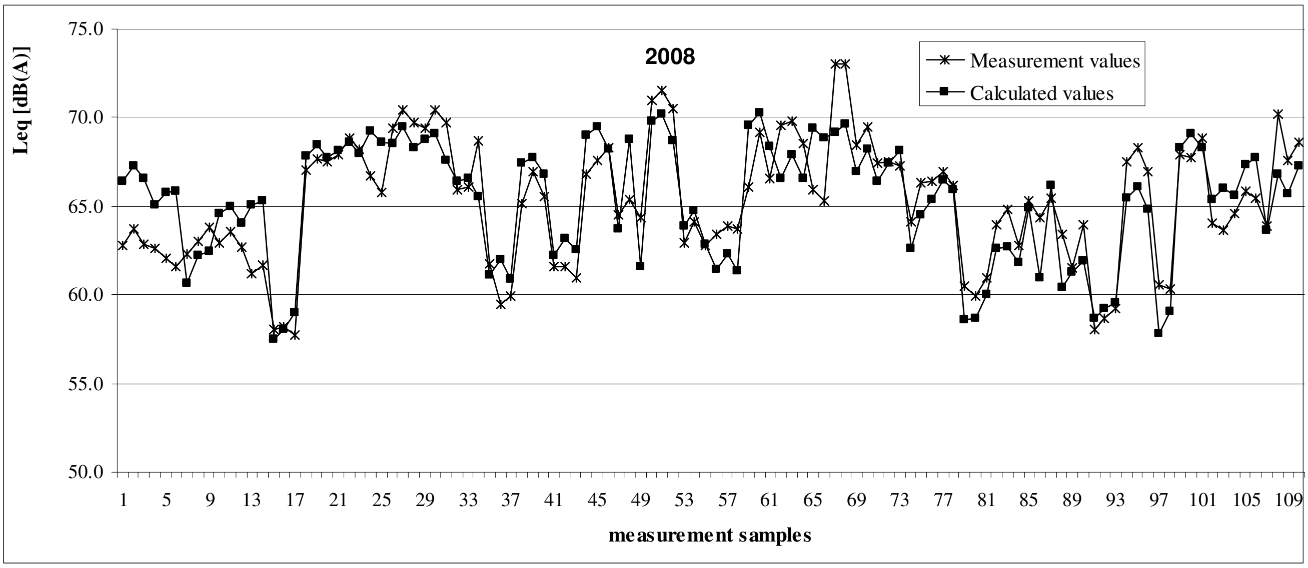

Fig. 2. Measured *Leq* values and calculated values *Leq* by NAISS model for year 2008.

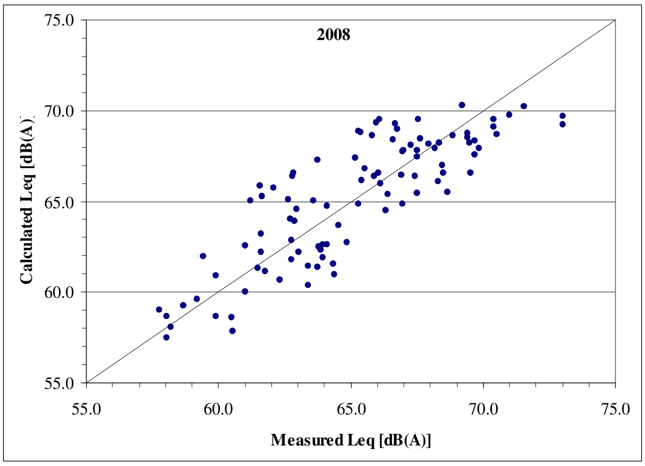

Fig. 3. Scatter plot of measured values *Leq* and calculated values *Leq* by NAISS model for year 2008.

In order to examine validity of NAISS model, statistical analysis of differences of measured and calculated equivalent noise levels according to the model equations, the flow and composition of the road traffic was carried out.

The average values of absolute differences of the calculated and the measured equivalent noise levels ($\overline{\Delta L}$) and standard deviations of differences (σ) have been calculated. The parameters of statistical analysis are given in Table I, where *N* is number of measured samples.

TABLE I. THE RESULTS OF STATISTICAL ANALYSIS OF DIFFERENCES OF THE CALCULATED AND THE MEASURED DATA.

	2008	2009	2010
$\overline{\Delta L}$ [dB(A)]	1.63	1.66	1.52
σ [dB(A)]	1.08	1.10	0.95
N	110	97	98

The maximum among average values of differences between calculated and measured *Leq* obtained for the year 2009 is shown in Table I. and stands for 1.66 dB(A). The maximum among stadard deviation values stands for 1.10 dB(A). Therefore it can be expected that the calculated values of *Leq* for confidence level of 95% will be in the confidence interval which equals measured *Leq* ± 2.20 dB(A). The obtained values of the confidence intervals correspond to the expanded uncertainty of measured values.

The scatter plots (Fig. 3–Fig. 5) show comparability between calculated and measured values of equivalent noise level. The identity lines (1:1 lines) are drawn on the scatter plots. The concentration of the scatters points in the vicinity of the identity line shows that the calculated values are comparable with measured values.

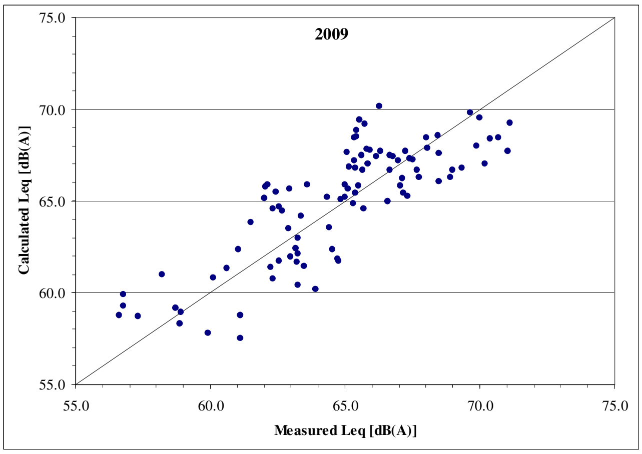

Fig. 4. Scatter plot of measured *Leq* and calculated values *Leq* by NAISS model for year 2009.

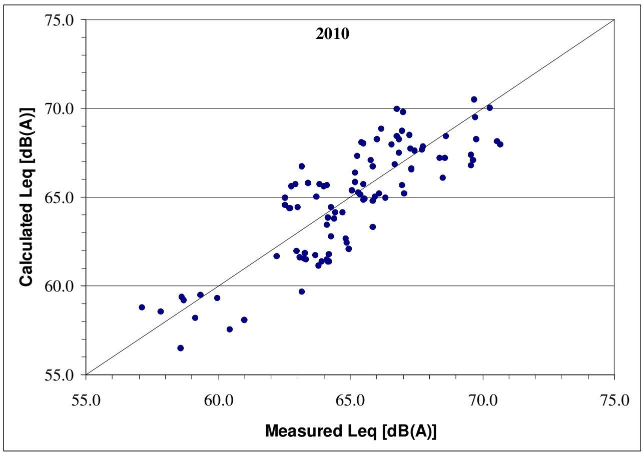

Fig. 5. Scatter plot of measured *Leq* and calculated values *Leq* by NAISS model for year 2010.

The graphs of the calculated and measured values of equivalent noise level shown in the Fig. 3 coincide for the majority of measurement samples. The larger deviations for individual samples appear due to the occurrence of the sound events such as for example a car horn or a faulty exhaust system which cannot be foreseen by NAISS model.

IV. CONCLUSIONS

The NAISS model is a mathematical model with three input parameters (the number of light vehicles, heavy vehicles and buses), one output (equivalent noise level) and two separate equations for two ranges of noise levels.

The results of the comparative analysis clearly show that the NAISS model allows better prediction of traffic noise pollution of motor vehicles in urban areas of the city of Nis than any other empirical relationship.

The good results obtained in the comparison with classical prediction methods available in literature have been confirmed in the verification process of the NAISS model. More than 300 measured samples (noise data and traffic data) collected during the years 2008 - 2010 are compared with the calculated values by NAISS model for the same group of traffic data.

Average values of absolute differences of calculated and measured equivalent noise levels and standard deviations of differences that were obtained show the validity and enforceability of the NAISS model for traffic noise prediction in urban areas of the city of Nis.

The NAISS model for road traffic noise prediction can be used in urban areas to predict road traffic noise level at a distance of 7.5 m from traffic lane on the basis of traffic flow (the number of passenger vehicles, the number of freight vehicles and the number of buses). Starting from the traffic noise level calculated by the model, it is possible to estimate the effects of noise in the process of developing urban and development projects of housing settlements, planning new city traffic lanes or widening or moving the existing lanes, increasing the flux of motor vehicles, installing new traffic lights or planning new measures for noise level reduction. Also, traffic noise level modeling and prediction by means of the NAISS model can be used for acoustic zoning process.

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