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IMPROVING THE PERFORMANCES OF THE TRAFFIC NOISE MODEL USING MULTI-LINEAR REGRESSION

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Abstract: *This research aims to examine the traffic noise levels and to improve the performances of the Calculation of Road Traffic Noise model (C.R.T.N.) by applying the statistical multiple linear regression approach. Research methods included traffic noise level measurements with a noise measuring device in an urban area, using a sampling method in different periods. An evaluation of the measured data and prediction results was performed. Based on the predicted values of the C.R.T.N. model and coefficient of determination (R^2), multi-linear regression was carried out to determine statistically significant parameters. The obtained multi-linear regression equation defined a new form of C.R.T.N. model. When applying the new improved version based on the C.R.T.N. model, higher accuracy of prediction is achievable. It can be seen that by applying multi-linear regression, the obtained prediction values are acceptably equated with field measurements in the chosen research environment. So, in this way, the differences between the predicted values of the noise level and the values measured in the field were minimized. Finally it can be concluded that when applying the new improved version based on the C.R.T.N. model, higher accuracy of prediction is achievable.*

Keywords: *traffic noise prediction, multi-linear regression, noise pollution, C.R.T.N. model*

JEL classification*: C35, C52, C53*

INTRODUCTION

Traffic noise is an environmental problem and according to the World Health Organization (WHO) (Theakston, 2011), has a detrimental effect on human health. In the European Environment Agency (EEA) reports road traffic is one of the leading causes of noise pollution (European Environment Agency, 2020). It can be stated that

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traffic noise is considered one of the main causes of the decrease in the quality of life.

The noise level is mostly influenced by the number of vehicles, traffic flow, the relative share of individual and freight vehicles, their speed, types and road characteristics, whether the traffic is one-way or two-way, intersections, weather conditions, etc. *(Lindov O. , 2011)*. The construction of traffic infrastructure, the increase in the number of motor vehicles, as well as the conditions of traffic, and non-compliance with legal regulations, led to alarming levels of traffic noise *(Lindov O., 2003)*.

The increase in noise levels in the areas near the roads is caused by the increase in road traffic, which initiates the need for noise monitoring. Monitoring noise levels will help mitigate traffic noise intensity and help in urban planning. In order to do so, the first thing that needs to be done is to collect data on the current situation by measuring traffic noise. Since the measurement of the traffic noise levels is very difficult to carry out due to high costs and the consumption of a large amount of time, various models are used to predict the level of traffic noise.

By applying models for predicting the noise levels, it is possible to assess the effects of noise during the planning and development residential areas projects, when new urban roads are planned, existing ones are expanded or relocated, when the flow of motor vehicles increases, or when new intersection light signaling is introduced (*Mehanović M. 2017*). Noise level modeling also enables acoustic zoning and zoning of urban areas according to spatial use and urban planning.

Most of the models available in the literature are based on the establishment of analytical links between traffic noise levels and selected traffic flow parameters, such as the flow of light and heavy vehicles, vehicle movement regime, meteorological and environmental conditions, road design, etc (Murphy & Hannaby, 2019). The traffic noise level prediction accuracy depends on the quality of the data and used models.

Models for traffic noise levels prediction were developed on the basis of existing experimental data. In certain cases, the characteristics of the traffic flow for the given environment for which they were adopted are also taken into account (*Mehanović & Palić, 2019*). This is one of the reasons why they cannot be applied in their original form with the same precision in other environments, considering the age of the vehicles, the structure of the traffic flow and the characteristics of the vehicle fleet are different.

Several types of research have shown that despite the existence of certain correction factors when calculating noise levels, large discrepancies can occur when comparing the measured and calculated noise levels *(Guarnaccia C., et. al., 2018)*. Possible differences in the outcome of noise calculations using different national methodologies are up to 15 dB(A) (*Nijland & Van Wee, 2005*). Thus, there are also certain deviations when using the C.R.T.N. model *(Ibili, Owolabi, Ackaah, & Ballack Massaquoi, 2022)*. This necessitates the need to calibrate the models in order to achieve the most accurate predictions of traffic noise levels.

This study examines the performances of the C.R.T.N. model and the possibility of improving its performances by carrying a multi-linear regression modeling approach. Regression models enable estimating and predicting the dependent variable's value based on the independent variable's value with a certain degree of reliability (*Merdić & Hodžić, 2021*). In this paper the methodology of data collection and the method of their application in the evaluation of C.R.T.N. is explained. After the calculations, empirical evidence based on collected data is shown. This chapter also contains the evaluation results of the C.R.T.N. model and explaination of the model performance improvement methodology using multi-linear regression. In the following, the model was calibrated with the aim of making the values valid for local conditions. By adopting empirical methods of road traffic noise calculation (C.R.T.N.) and the statistical multi-linear regression (MLR) modeling approach, the performance of the given traffic noise model for predicting the equivalent noise level was improved. In the conclusion, the most important findings that were reached during this research will be highlighted.

METHODOLOGY AND EMPIRICAL EVIDENCE

For the purpose of this research, roads with different traffic and infrastructural characteristics were selected, so that a large number of parameters could be examined, their influence on the noise level could be determined, and a more complete database could be provided. The measured values of the traffic noise level were obtained by traffic monitoring in the area of the City of Sarajevo and Sarajevo Canton. Noise measurement was performed at 35 locations. Traffic noise measurement was conducted during working days (Monday-Friday) for day and night traffic regime in 2021 (during the spring months). For this research, it is essential to emphasize that during the measurement period of the traffic noise level, no movement restriction orders were in force resulting from the coronavirus pandemic regulations.

The sampling method in intervals of 15 minutes was used during the traffic noise measurement at the previously mentioned locations (Maruyama, Kuno, & Sone, 2013). The device was placed at a height of 1,2 (m) from the ground surface, with a distance of 1 (m) from the researcher to the device (Kanton Sarajevo, 2016), and at a distance of 10 (m) from the central axis of the nearest traffic lane. In the case of proximity to objects the distance of at least 3 (m) from reflective surfaces was taken into account.

To measure the equivalent noise level, a Bruel&Kjaer type 2260 Investigator type 1 measuring device capable of real frequency analysis of 1/3 octave with broadband and spectral statistical distribution was used.

Figure 1: Measuring device and map of measurement locations in Sarajevo (red spots on the map)

Source: Authors

During the application of the C.R.T.N. model, data on the average annual daily traffic (AADT) was taken from publicly available publications (*Direkcija za puteve Kantona Sarajevo, 2016*), (*Direkcija za puteve Kantona Sarajevo, 2019*):

- Traffic counts on the existing primary city and regional road network under the jurisdiction of the Sarajevo Canton Road Directorate from 2015-2018. ;
- Traffic counts on the main roads of the Federation of BiH 2015-2020. in the jurisdiction of JP Roads of the Federation of Bosnia and Herzegovina;
- Traffic counts on the highways of the Federation of BiH 2015-2019. in the jurisdiction of JP Autocesta FBiH (data gathered on request).

C.R.T.N. method (Calculation of Road Traffic Noise) is a model created in Great Britain and developed by the Department of the Environment in 1975. Later, this model was perfected and improved with the cooperation of the TEEL (Transport and Road Research Laboratory) laboratory and the Ministry of Transport of Great Britain (in 1988). Today it is used to estimate the statistical level L10 [dB] of noise in road traffic on an hourly basis or in the period between 6:00 and 24:00. The L10 value per hour dB noise level is the value of the noise level exceeded only 10% of the time during a period of one hour.

The equation of C.R.T.N. model used for calculation of noise level *(Department of transport Welsh Office, 1988*) is:

Formula 1: Equation of C.R.T.N. model

$$L_{10} = 42{,}2 + 10logQ + \Delta L_V + \Delta L_S + \Delta L_P + \Delta L\alpha \ \text{[dBA]} \quad (1)$$

Source: Department of transport Welsh Office, 1988

where:
Q – motor vehicle flow [vehicles/h],
ΔL_V – correction factor for speed and percentage of heavy vehicles,
ΔL_S – correction factor for road gradient,
ΔL_P – correction factor for road surface,
ΔL_α – correction factor in the case of a line source of limited length.

Each of the C.R.T.N. model parameters is defined mathematically below.

Corrections for speed and percentage of heavy vehicles are:

Formula 2: Corrections for speed and percentage of heavy vehicles

$$\Delta L_V = 33log\left(v + 40 + \frac{500}{v}\right) + 10log\left(1 + \frac{5p}{v}\right) - 68{,}8\ [dB] \quad (2)$$

Source: Ibid.

where:
v – speed of motor vehicles [km/h],
p – share of heavy vehicles in the traffic flow [%], where:

Formula 3: Share of heavy vehicles in the traffic flow

$$p = \frac{100f}{Q} \quad (3)$$

Source: Ibid.

where:
f – flow of heavy vehicles during one hour
The road gradient correction is calculated using the following equation:

Formula 4: Road gradient correction

$$\Delta L_S = 0{,}3 \cdot g\ [dB] \tag{4}$$

Source: Ibid.

where:
g – road gradient [%].

If the speed of motor vehicles is less than 75 km/h, and the road surface is covered with asphalt, it is necessary to reduce the predicted noise level by 1 dBA. However, at speeds greater than 75 km/h, it is necessary to apply formula (5) to calculate the impact of the road surface on the traffic noise level:

Formula 5: Road gradient correction

$$\Delta L_P = \begin{cases} 10log(90 \cdot TD + 30) - 20 & \text{in the case of a concrete surface} \\ 10log(20 \cdot TD + 60) - 20 & \text{in the case of an asphalt surface} \end{cases} \tag{5}$$

Source: Ibid.

where:
TD – depth of pavement surface texture [mm].

If part of the roadway from the reception location point is seen at an angle α [°], then:

Formula 6: Correction factor in the case of a line source of limited length

$$\Delta L_\alpha = 10log\left(\frac{\alpha}{180°}\right)\ [dB] \tag{6}$$

Source: Ibid.

The following table shows measured and predicted noise values for different types and categories of roadways:

Table 1: Measured and predicted noise values for different types and categories of roadways

MOTORWAY		
WORKING DAYS (MON-FRI)		
Mark of the measuring place	NOISE LEVEL VALUES BASED ON MEASUREMENTS L_{eq} (dB)	NOISE LEVEL VALUES ACCORDING TO C.R.T.N. MODEL L_{eq} (dB)
AC1	72,2	73,37
AC2	66,1	69,5
AC3	68,7	68,93
AC6	71,4	73,12
AC7	73,4	73,83

HIGHWAY		
BC1	72,2	70,11
BC2	72,6	72,51
BC3	72,6	72,18
BC4	71,9	72,31
FIRST RANK CITY ARTERY		
GAPR1	67,9	70,77
GAPR2	68,0	69,59
GAPR3	70,7	69,30
GAPR4	70,4	68,09
GAPR9	69,3	69,73
GAPR11	67,0	69,77
FIRST RANGE CITY ROADWAY		
GAPR1	67,9	70,77
GAPR2	68,0	69,59
GAPR3	70,7	69,30
GAPR4	70,4	68,09
GAPR9	69,3	69,73
GAPR11	67,0	69,77
SECOND RANGE CITY ROADWAY		
GSDR1	67,5	64,88
GSDR2	64,5	63,41
GSDR3	64,7	65,78
CONECTION ROADS		
SU1	65,7	68,07
SU2	63,8	63,23
SU3	64,8	66,58
SU4	64,3	65,01
SU5	63,2	65,75
SU6	63,1	64,29
SU7	59,4	62,85
SUBURBAN ROAD		
PC1	63,3	63,01
PC2	60,6	61,64
PC3	67,0	64,75
PC4	63,2	64,06

Source: Authors

Performance evaluation of the C.R.T.N. model

In this chapter, a statistical and correlational analysis will be done, as well as an evaluation of the performance of C.R.T.N. model based on measured and predicted noise levels. During the evaluation, the following methods will be used: correlation coefficient (*r*), determination coefficient (R^2), mean value of the absolute deviation of the measured and predicted noise level (ΔL), (*Šimundić, 2008)* variance (expected mean square errorσ^2, MSE), standard deviation (*σ, RMSE*) and accuracy (*Acc*) (*Singh Rana & Singh, 2018*).

Correlation represents a mutual connection between different phenomena represented by the values of two sets of variables. If the values of the measured and predicted noise levels were equal, the predicted values would be in perfect correlation with the measured values, ie the correlation coefficient (*r*) would be equal to one ($r = 1$). he coefficient of determination R^2 xpresses the strength of the linear relationship, and it is calculated by squaring the correlation coefficient *r.* The more representative the model is if the coefficient of determination is closer to one (*Hankard, Cerjan, & Leasure, 2006*). When analyzing the mean absolute deviation, the model is more representative the closer the mean value of the absolute deviation is to zero *(Singh Rana & Singh, 2018)*. The mean error of an individual measurement is a measure of the deviation of the predicted values from the measured values. It is never below zero, and the closer the values are to zero, the more reliable the model (Guarnaccia, Lenza, Mastorakis, & Quartieri, 2011). The standard deviation is a measure of the quality of the estimator. It is never below zero, and the closer the values are to zero, the more reliable the model. When reading the results, it is necessary to rely on the empirical rule of 2-sigma (±) in the case of normal data distribution.[1] The normal distribution (Gaussian distribution) is symmetrical, bell-shaped, continuous and regular. One standard deviation or one sigma includes 68% of all data points, while two sigma includes 95% of all data points. Accuracy (Acc) is defined as the percentage difference between predicted and measured values of the dependent variable, with an acceptable error/deviation ranging from ± 1,5 dBA to ± 2,5 dBA (*Singh Rana & Singh, 2018*). Table 2 shows the performance evaluation results of C.R.T.N. model.

Table 2: Results of the model performance evaluation for prediction of the level of traffic noise

Model	r	R^2	ΔL	σ2 (MSE)	*σ* (RMSE)	Acc (%)		
						±1,5	± 2	±2,5
C.R.T.N.	0,90	0,82	1,30	2,58	1,58	65,63%	68,75%	84,38%

Source: Authors

Based on the Chadock scale *(Banjanin M. , Stojčić, Drajić, Milanović, Ćurguz, & Stjepanović, 2021.*), looking at the coefficient of correlation and determination, a strong relationship between the measured and predicted values of the noise level was

[1] The normal distribution or Gaussian distribution (Gaussian curve), in probability theory, is one of the most common continuous distributions - a function that expresses the probability that any observation will be found between any two real limits or real numbers, because the curve, on both sides, tends to zero.

established. The mean absolute deviation value is 1,30 dBA, close to zero, which is within satisfactory range. The standard deviation is 1,58, which means that by applying the model in the prediction of road traffic noise emission levels, deviations of 1,30 dBA in the ±1,58 dB range are obtained in 68% of cases, and in 95% of cases of 1,30 dBA in the range ±3,16 dBA. It is also important to read that by applying the C.R.T.N. model in predicting traffic noise levels one can expect 65,63% accuracy with deviations in the range of ±1,5 dBA, then 68.75% accuracy with deviations of ±2 dBA, and 84,38% accuracy in deviation range of ±2,5 dBA.

Improvement of the C.R.T.N. model performances using multi-linear regression

By adopting empirical methods of calculating road traffic noise (C.R.T.N.) and the statistical multi-linear regression (MLR) modeling approach, the given traffic noise model was calibrated.

The multi-linear regression model is derived from the predicted values of the C.R.T.N. model and parameter values using the coefficient of determination (R^2). After obtaining the prediction results, it is necessary to first perform a multi-regression with the appropriate parameters. If the parameters correspond to the adopted intervals, the reliability of the model is compared with the measured noise values. The multi-linear regression equation looks like this:

Formula 7: Multi-linear regression equation

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_k X_k \tag{7}$$

Source: (Nagahara, 1999)

where:
Y – traffic noise levels,
β_0 – model constant representing that portion of the value of the dependent variable not explained by the independent variables,
$\beta_1 - \beta_k$ – regression coefficients associated with traffic composition, traffic volume, vehicles speed, share of freight vehicles and number of freight vehicles.

RESULTS AND DISCUSSION

Considering previous studies of noise modeling in road traffic, light vehicles, heavy/freight vehicles and speed were the basic input parameters in the development of the noise models *(Palić & Lindov, 2022*). Other variables, such as the proximity of the road to buildings or barriers, the surface of the pavement/road, road gradient are included in the initial equation of the C.R.T.N. model.

In this case, the parameters taken into account are the current average vehicle speed, motor vehicle flow, and the number of heavy vehicles. In Table 3 is an overview of the results of the multi-regression analysis.

Table 3: Overview of the results of the multi-regression analysis (with the freight vehicles share)

Results of multi-regression analysis	**r**	**R^2**	**R^2 (adj.)**	**SE**
	0,96	0,93	0,92	0,97
Parameters	**Coefficients**	**SE**	**T-value**	**p-value**
Constant	58,94	0,51	114,81	0,000
Current average vehicle speed (v)	0,0653	0,008	8,01	0,000
Traffic volume (Q)	0,0003	0,00002	13,19	0,000
Heavy vehicles share (p)	0,1143	0,081	1,42	0,167

Source: Authors

From table 3 it can be seen that, for the parameter **heavy vehicles share,** the ***p*- value** result from the correlation of 0,167 is **higher than the significance level of 0,05**. These results show that the correlation between the model-predicted values and the freight vehicle share is **statistically insignificant.** For this reason, this parameter will be replaced with the number of freight vehicles, and the multi-regression analysis will be performed again.

Table 4. Overview of the results of the multi-regression analysis (with the number of heavy vehicles)

Results of multi-regression analysis	**r**	**R^2**	**R^2 (adj.)**	**SE**
	0,97	0,94	0,94	0,88
Parameters	**Coefficients**	**SE**	**T-value**	**p- value**
Konstanta	59,15	0,46	129,36	0,000
Current average vehicle speed (v)	0,0708	0,006	12,02	0,000
Traffic volume (Q)	0,0002	0,00002	8,85	0,000
Number of heavy vehicles (HV)	0,0213	0,006	3,32	0,0025

Source: Authors

As can be seen from Table 4, the ***p*- value** for the correlation results is now **less than the significance level of 0,05 for all parameters**. These results show that the correlation between the model-predicted values and the specific input parameters is **statistically significant**. Now the calibration C.R.T.N model can be defined on the basis of the Formula 7 and parameters from Table 4.:

Formula 8: Multi-linear regression equation

$$Y = 59{,}15 + 0{,}0002 \cdot Q + 0{,}071 \cdot v + 0{,}0213 \cdot HV \quad (8)$$

Source: Formula 7 and Table 4.

where:
Q – traffic volume,
v – current average vehicle speed (km/h),
HV – number of heavy vehicles.

After the calculated values and the evaluation with the new prediction results, a comparison was made in table 5.

Table 5. Comparison of the results with the new improved C.R.T.N. model version

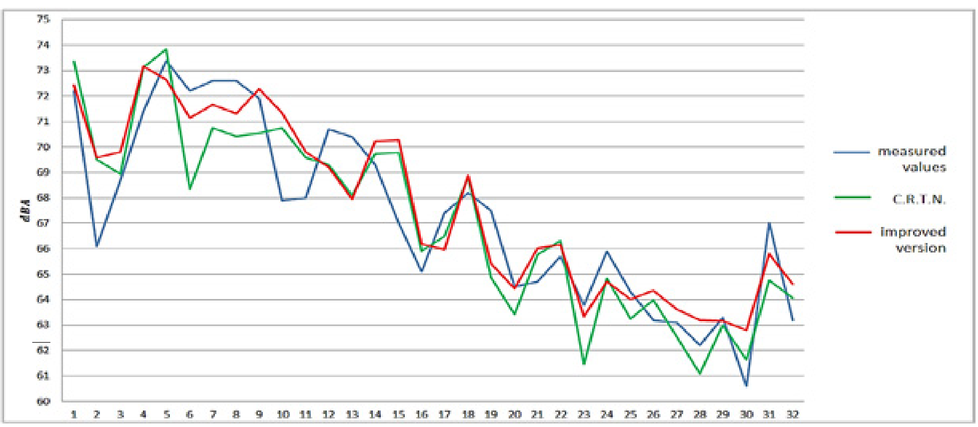
Model	r	R^2	ΔL	σ^2 (MSE)	σ (RMSE)	Acc (%)		
						±1,5	± 2	± 2,5
C.R.T.N.	0,90	0,82	1,30	2,58	1,58	65,63%	68,75%	84,38%
Improved version	0,90	0,81	1,28	2,53	1,57	75,00%	81,25%	90,63%

Source: Authors

Based on the Chadock, looking at the coefficient of correlation and determination for the improved C.R.T.N. model, a strong relationship between the measured and predicted values of the noise level was established. The mean absolute deviation value is 1,28 dBA, close to zero, which is within satisfactory range. The standard deviation is 1,57, which means that by applying the model in the prediction of road traffic noise emission levels, deviations of 1,28 dBA in the ±1,57 dB range are obtained in 68% of cases, and in 95% of cases of 1,28 dBA in the range ±3,14 dBA. It is also important to read that by applying the improved C.R.T.N. model in predicting traffic noise levels one can expect 75,00% accuracy with deviations in the range of ±1,5 dBA, then 81,25% accuracy with deviations of ±2 dBA, and 90,63% accuracy in deviation range of ±2,5 dBA.

The relation between the measured, predicted and calibrated values are shown on the graph, where you can see the results of the improvement of the prediction after the calibration of the C.R.T.N. model. When we look at Chart 1 the improved version of the C.R.T.N. model more matches the measurement values than the basic version of the C.R.T.N. model.

Chart 1: Display of the relation between measured, predicted and calibrated values for C.R.T.N. model



Source: Table 5.

CONCLUSION

This paper presents the improvement of the performances of the traffic noise model using multi-linear regression. After the evaluation, an actual state of the C.R.T.N. model behavior was obtained. The models allow critical parameters to be set with the goal that the values are valid for local conditions. The analysis determined which parameters of the model can be applied for this purpose and are statistically relevant. Such procedure applied in this paper based on multi-linear regression calibrated the model, whereby better results were obtained compared to the values obtained by the standard C.R.T.N. model equation.

The following conclusions can be drawn from the analysis of the obtained data. From the aspect of the connection strength between the measured and predicted values from table 5, it can be read that there have been no major changes, i.e. there is still a strong connection. When we compare the mean values of the absolute deviation of the measured and predicted noise levels, it can be concluded that after calibration this data is now lower by 0,01. It should be kept in mind that the model is more representative if ΔL is closer to zero. The first improvement is already visible at this point. The biggest indicator of the improvement of the prediction performances after the calibration can be read from the aspect of accuracy *Acc* (%). An accuracy of 75,00% can now be expected to be obtained using the calibrated CRTN model when the deviation is in the range of ±1.5 dBA, 81,25% for a range of ±1,5-2 dBA, and finnaly 90,63% accuracy in case of deviation of ±2,50 dBA.

It can be seen that by applying multi-linear regression, the obtained prediction values are acceptably equated with field measurements in the chosen research environment. So, in this way, the differences between the predicted values of the noise level and the values measured in the field were minimized. Finally it can be concluded that when applying the new improved version based on the C.R.T.N. model, higher accuracy of prediction is achievable.

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