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Evaluation Of Models For Predicting Highway Traffic Noise

Osifeko M.O.*[1] and Odufuwa B.O[2]

[1] Department of Computer and Electrical/Electronic Engineering, College of Engineering and Environmental Studies, Olabisi Onabanjo University, Nigeria.
[2] Department of Urban and Regional Planning, Olabisi Onabanjo University, Nigeria.

***Author for Correspondence:** osifeko.martins@oouagoiwoye.edu.ng

ABSTRACT

Several mathematical models have been proposed for predicting highways traffic noise on highways. Performance of these models depends on location of use, hence, the need for evaluation of existing models before adoption in any location. This study evaluates the predicting accuracy of four mathematical models towards predicting highways traffic noise in Ogun State. These models include Calculation of Road Traffic Noise (CRTN), Acoustical Society of Japan-Road Traffic Noise (ASJ RTN), Federal Highway Administration (FHWA) and Consiglio Nazionale delle Ricerche (CNR) model. Traffic noise was measured using a Sound Level Meter on four major highways. Traffic data consisting of traffic volume, type of vehicle, speed, distance and road characteristics were collected and used as input to evaluate the models. Results show that the Root Mean Square Deviation (RMSD) of the CRTN model was found to be 0.37 while the value RLS90 model was found to be 0.32. In terms of two-sample t-test, the CRTN model had a value of 2.36 while the RLS90 model had a value of 2.97. The CNR and FHWA model had a RMSD value of 0.2 and 0.31 with a t-value of 2.15 and 2.62. The result of the analysis revealed that the CNR model had the best performance when compared to the CRTN, FHWA and RLS90 models, hence the model can be used as a reliable forecast tool for planning and activities aimed at mitigating highway traffic noise in the state.

***Keywords**: Traffic Noise Models, CRTN model, FHWA model,*

INTRODUCTION

Traffic noise and its negative effects on the wellbeing of human beings and the environment at large is one of the disturbing issues in city transport management (**Anderson and Barrett, 2014;** Tomic et al, 2016; **Gozalo et al, 2016**). Urban planning is a multidisciplinary field that is concerned with creation of conducive environment for different activities of man towards having a pleasant livelihood. It is imperative to note that the need for mobility have compelled studies to emphasize that immobility perpetuates poverty (Gozalo et al, 2016). This implies that movement over space is vital for wellbeing of people and society at large. Meanwhile, highway traffic noise has been noted to relate with the volume of trips, types of vehicles, roads and fuels characteristics.

Table 1: Abbreviations and Nomenclatures

L_{eq}	Equivalent Continuous Sound Level
L_{Aeq}	A-weighted equivalent sound pressure level in dB
FHWA	Federal Highway Administration
CRTN	Calculation of Road Traffic Noise
ASJRTN	Acoustical Society of Japan Road Traffic Noise
TNM	Traffic Noise Model
NPCM	Noise Propagation Computation Method
CNR	Consiglio Nazionale delle Ricerche

Reducing implications of this transport externality requires prediction and understanding of related traffic noise predicting models. Federal Highway Administration (FHWA) (Anderson and Barrett, 2014), Calculation of Road Traffic Noise (CRTN) (Anon, 1975), Acoustical Society of Japan Road Traffic Noise (ASJ RTN) model (Sakamoto et al, 2013), RLS90, Noise Propagation Computation Method (NPCM) (Abbaléa, 2009), Road Traffic Noise - Nordic Prediction Method (Bendtsen, 1999) are notable models emphasized in literature.

De Lisle (2016) evaluated the accuracy of CRTN, TNM, ASJ RTN and NPCM using a constructed test case model. The study investigated combination of ground effect and shielding on the models. Predictions for CRTN were unrealistic because predicted noise levels for soft ground were found to be equal to hard ground in some locations. However, this was not the case in predicted noise levels from TNM, ASJ RTN and NMPB models.

George and Okeke (2015) assessed the noise levels of ten locations in Port Harcourt metropolis of Nigeria using noise dosimeter and prediction model. Using pearson' product moment correlation (r) and single factor Analysis of Variance (ANOVA), result of the study revealed that there was strong relationship between actual and predicted equivalent noise levels (Leqs). It was concluded that the Calixto model could be satisfactorily applied for Nigerian conditions as they gave acceptable results with good “r” value. Garg et al (2015) evaluated the applications of artificial neural networks to predict the equivalent continuous sound level (LAeq) and ten Percentile exceeded sound level (L10) generated due to traffic noise for various locations in Delhi. The comparative study showed that neural networks performed better than the analytical models developed in terms of total traffic flow and equivalent traffic flow. Tomic et al (2016) proposed two mathematical models and compared their predictions compared to data collected by traffic noise monitoring in urban areas, as well as to predictions of commonly used traffic noise models. The results show that traffic noise prediction models could benefit from the application of evolutionary algorithms and neural networks. Goswami et al (2013) assessed the noise levels in twelve different squares of Rourkela city. Prediction models were used in the study to predict noise pollution level. Comparison of predicted data with that of the actual measured data revealed that the model used for the prediction could accurately predict traffic noise and yield reliable results close to that by direct measurement.

Despite their accuracy, one of the challenges encountered in using these models, is that the peculiarities of the measurement location usually affect their performance (Tomic et al, 2016), Hence, the need for assessment of these models before adoption in other locations. This study aims at evaluating models for predicting traffic noise with measured data from four major highways in Ogun Sate, Nigeria.

MATERIALS AND METHODS

Based on literature, four models for predicting traffic noise were identified and selected for use in this study.

CRTN Model

This model estimates the basic noise level L_{10} on two reference time of 1h and 18h. The original model (Anon, 1975), was modified and presented in Quartieri (2009). According to the model, the noise level is obtained at 10m from the nearest carriageway edge of a highway using equations 1 and 2 below.

$$L_{10}(1h) = 42.2 + 10\,Log\,(q)\ \ (dbA) \qquad (1)$$

the basic noise level in terms of total 18-hour flow is:

$$L_{10}(18h) = 29.1 + 10\,Log\,(Q)\ \ (dbA) \qquad (2)$$

Where, q = hourly traffic flow (vehicles/hour) & Q = 18-hour flow (vehicles/hour),

Equations 1 and 2 are valid for the following conditions;

velocity (v) = 75 km/h, percentage of heavy vehicles (P) = 0 and road gradient (G) = 0%.

The Equations can be modified to accommodate for a change in the mean traffic speed, percentage of heavy vehicles and gradient

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Despite their accuracy, one of the challenges encountered in using these models, is that the peculiarities of the measurement location usually affect their performance (Tomic et al, 2016), Hence, the need for assessment of these models before adoption in other locations. This study aims at evaluating models for predicting traffic noise with measured data from four major highways in Ogun Sate, Nigeria.

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Equations 1 and 2 are valid for the following conditions;

velocity (v) = 75 km/h, percentage of heavy vehicles (P) = 0 and road gradient (G) = 0%.

The Equations can be modified to accommodate for a change in the mean traffic speed, percentage of heavy vehicles and gradient contribute using equation 3.

$$\Delta_{pv} = 33\text{Log}\left(v + 40 + \frac{500}{v}\right) + 10\text{Log}\left(1 + \frac{5p}{v}\right) - 68.8\ (\text{dbA}) \quad (3)$$

Where v = mean speed.

The percentage of heavy vehicles (P) is then given by equation 4:

$$P = \frac{100f}{v} = \frac{100F}{v} \quad (4)$$

Where, f and F are the hourly and 18- hour flows of heavy vehicles respectively.

The value of v to be used in equation (3) depends on the road gradient.

For roads with gradient, traffic speed is decreased by ΔV which is presented in equation 5

$$\Delta V = \left[0.73 + \left(2.3 - \frac{1.15p}{100}\right)\left(\frac{p}{100}\right)\right] * G \ \text{km/h} \quad (5)$$

RLS 90 model

RLS90 is a popular traffic noise prediction model commonly used in Germany. According to this model, the traffic noise on a road is obtained using equation 6 (RLS, 1990; Quartieri et al, 2009)

$$L_{mE}^{(25)} = 37.3 + 10\text{Log}\left[W + (1 + 0.082P)\right] \quad (6)$$

Where, Q is the number of vehicles per hour, P is the percentage of heavy trucks (weight > 2.8 tons), assuming a speed of 100 km/h and a road gradient below 5%. Equation 7 is used when the conditions are different from those equation 6.

$$L_m = L_{mE}^{(25)} + R_{SL} + R_{RS} + R_{RF} + R_E + R_{DA} + R_{GA} + R_{TB} \quad (7)$$

Where, R_{SL} is a correction for the speed limit, R_{RS} is a correction for road surfaces with values that ranges from 0 to 6 dB.

$$R_{RS} = 0.6|g| - 3 \quad \text{for } |g| > 5\%$$

$$R_{RS} = 0 \quad \text{for } |g| \leq 5\%$$

R_{RF} is a correction for rises and falls along the roads, R_E is a correction for the absorption characteristics of building surfaces, R_{DA} is the attenuation coefficient that accounts for the distance from the receiver and the air absorption. R_{GA} is the attenuation coefficient due to ground and atmospheric conditions while R_{TB} is the attenuation coefficient due to topography and buildings dimensions.

$$R_{SL} = L_{pkw} - 37.3 + 10\text{Log}\left(\frac{100 + (10^{0.1D} - 1)P}{100 + 8.23P}\right) \quad (8)$$

$$\text{Where, } L_{pkw} = 27.7 + 10\text{Log}\left[1 + (0.02v_{pkw})^3\right] \quad (9)$$

$$L_{lkw} = 23.1 + 12.5\text{Log}(v_{lkw}) \quad (10)$$

$$D = L_{lkw} - l_{pkw} \quad (11)$$

where v_{pkw} is the speed limit in the range of 30 to 130 km/h for light vehicles and v_{lkw} is the speed limit in the range of 30 to 80 km/h for heavy vehicles.

CNR Model

This model is an adaptation of the RLS 90 model. According to this model, the predicted traffic noise level in dBA is given by Quartieri et al. (2009), Canelli et al, (2016).

$$L_{aeq} = \alpha + 10\text{Log}(Q_L + \beta Q_p) - 10\text{Log}\left(\frac{d}{d_0}\right) + \Delta L_V + \Delta L_F + \Delta L_B + \Delta L_S + \Delta L_G + \Delta L_B \quad (12)$$

where Q_l and Q_p are the traffic flow in one hour that relates to light and heavy class of vehicles respectively, d_0 is a reference distance of 25 meter and d the distance between the lane centre and observation point on the road's edge. Then ΔL_V is the correction due to mean flux, ΔL_F and ΔL_B are the correction for the presence of reflective façade near the observation point with a default value of +2.5 dBA and +1.5 dBA when in opposite direction; ΔL_S is the correction for the road's pavement, ΔL_G is the correction for a road's gradient greater than 5% . The correction value is +0.6 dBA for each % gradient over 5%. ΔL_B is a coefficient that considers the presence of traffic lights (+1.0 dBA) or slow traffic (-1.5 dBA).

FHWA Model

This model was proposed by the Federal Highway Administration agency, US. According to the model, traffic noise can be predicted based on individual vehicle noise levels, vehicle volume and speed, observer distance and other correlations. Traffic noise can be predicted using

Equation 13 (Cocchi, et al, 1991; Anderson and Barrett, 2014) .

$$L_{eq} = L_o + \Delta L_i \quad (13)$$

Δl_i - adjustment applied.

$$L_{eq}(h)_i = (l_o)E_i + 10\text{Log}\left(\frac{N_i d_o}{S_i}\right) + 10\text{Log}\left(\frac{D_o}{R_n} - \frac{D_o}{R_f}\right) - 30 \quad (14)$$

$L_{eq}(h)_I$ is the reference energy mean emission level of i_{th} class of vehicle N_i is the no of vehicles in the ith class passing a specified point during some specified time. D_o is the reference distance at which the emission levels are measured. In FHWA model, D_o is 15 meters. Si is the average speed of ith class vehicle and is measured in kilometres/hour. T = is the period over which the equivalent sound level computed and Rn is the distance in meters between the centreline of the near end of the roadway segment and the observer. R_f = is the distance in meters between the centreline of the far end of the roadway segment and the observer.

Data Collection

The location of study is Ogun State located in the South-West geopolitical zone of Nigeria with a coordinate of 7°00'N 3°35'E. The study was conducted in the Gateway State of Nigeria (Ogun State). Based on the high volume of traffic and location, four (4) major roads (Sango – Papa Expressway; Papa – Abeokuta Expressway; Abeokuta - Sagamu Expressway; Sagamu - Ijebu Ode Expressway) were selected. The Benetech GM1352 Sound Level Meter was used to measure traffic in selected roads. The A-Weighting Meter has a measuring range of 30 – 130 dbA with an accuracy of ±1.5db.

el meter

Measurements were taken three times a day for five consecutive days between the hours of affic 7:00am to 8:00am, 12:00pm to 1:00pm and 5:00pm to 6:00pm. Also, traffic count was conducted, consisting of traffic volume, type of vehicle, speed, distance and the road characteristics (e.g surface type, terrain, gradient). Vehicles were grouped into light motor, medium trucks, heavy trucks, buses, and motorcycles. It is noteworthy that the traffic count was carried out simultaneously with the traffic noise measurements. The data from the field was used to predict traffic noise using four traffic noise prediction models. The result from the models were compared with the noise level measured with Sound Level Meter used in the study.

Data Analysis

To predict the noise levels and to ease computations, four models were represented using MATLAB. Data obtained from the traffic study were used as parameters into the represented models. The outputs from the models are recorded for further analysis. The measured hourly noise level L_{eq} was used to compare values predicted by the CRTN, FHWA, CNR and RLS90 model. The model evaluation was carried out using two statistical methods. Root-Mean-Square Deviation (RMSD) and Student's t-test. The RMSD measures the differences between values predicted by a model and the measured or observed values. The value of MSD is always positive, representing zero in the ideal case. On the other hand, the t-test can be used, for example, to determine if two sets of data are significantly different from each other. The RMSD and t-test may be computed by using equation (15) and (16):

$$MSD = \sqrt{\frac{1}{n}\sum_{k=1}^{n}\left(\frac{y_k - x_k}{x_k}\right)^2} \quad (15)$$

γy_k = kth predicted value,

χ_κ = kth measured value

n = total number of observations

and

$$t = \frac{\bar{x}_1 - \bar{x}_2}{s_p\sqrt{2/n}} \quad (16)$$

where $s_p = \sqrt{\frac{s^1 x_1 + s^2 x_2}{2}}$

Sp = is the pooled standard deviation for x_2 and n=n1=n2 and S^2 x_2 and S^2 x_2 are the unbiased estimators of the variances of the two samples. The denominator of t is the standard error of the difference between two means.

RESULTS AND DISCUSSION

To reduce complexity in computation and analysis, we compare the predicted and actual noise for the four roads simultaneously i.e. the performance of each model was evaluated across the four roads instead of doing same per road. This is because there are no major differences in the environment the roads are situated. Thus, the performance of the models is expected to be consistent across each of the roads.

Table 2. Model Parameters obtained during the traffic study

Parameters	Road 1	Road 2	Road 3	Road 4
Hourly traffic flow	250, 278, 215	232, 247, 290	257, 275, 232	274, 257,289
Velocity	70km/h	100km/h	110km/h	110km/h
Hourly traffic flow of heavy vehicles	74, 78, 66	65, 61, 57	61, 64, 66	66, 59, 56
Road gradient	*0%*	*0%*	*0%*	*0%*
Speed limit V_{pkw}	100km/h	100kmh	100km/h	100km/h
Width of Road	6m	7m	8m	8m
Distance of measurement	10, 25, 15m	10, 25, 15m	10, 25, 15m	10, 25, 15m

**Road 1 (Sango – Papa Expressway), Road 2 (Papa – Abeokuta Expressway), Road 3 (Abeokuta - Sagamu Expressway), Road 4 (Sagamu - Ijebu Ode Expressway)

Table 3. Summary of Measured and Predicted noise levels in dB

	CRTN		RLS 90		CNR		FHWA	
	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.
Road 1_m	62	67	62	68	56	58	60	59
Road 1_d	63	66	63	68	55	57	61	58
Road 1_e	66	65	66	69	62	63	65	64
Road 2_m	66	71	66	69	61	63	64	64
Road 2_d	67	72	67	70	62	62	64	62
Road 2_e	66	71	66	69	61	59	63	61
Road 3_m	68	72	68	70	63	61	65	62
Road 3_d	64	68	64	69	61	63	63	62
Road 3_e	61	65	61	65	58	59	60	58
Road 4_m	63	66	63	65	57	59	61	60
Road 4_d	62	65	62	66	59	58	60	59
Road 4_e	61	64	61	66	57	59	58	57

Meas. = Measured and Pred. = Predicted, _m = morning, _d = day, _e = evening

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Figure 2 shows the comparison between the CRTN and RLS 90 model. A direct comparison was carried out for the two models because they both had a measuring distance of 10m. The measuring distance for the CNR model is 25m while that of FHWA model is 15m.

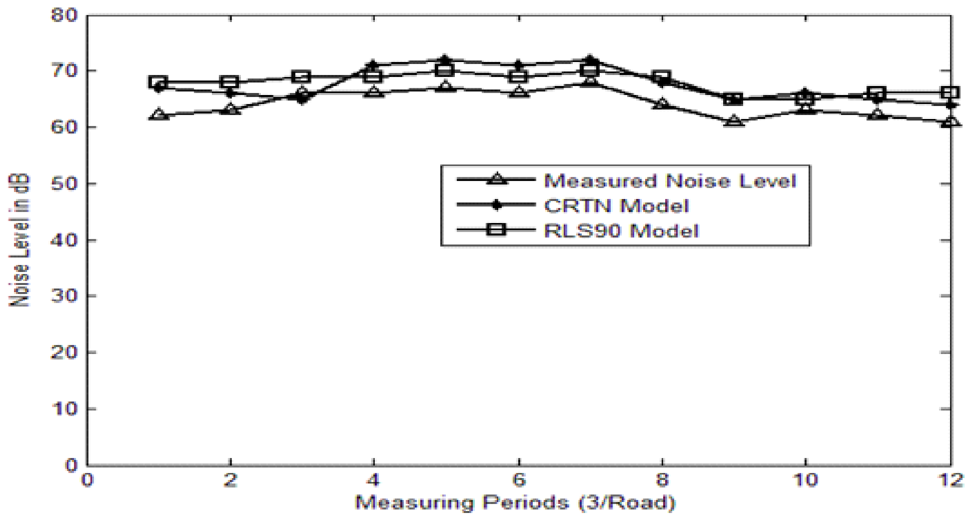

Figure 2: The CRTN Model and RLS90 model in Comparison with the measured noise level

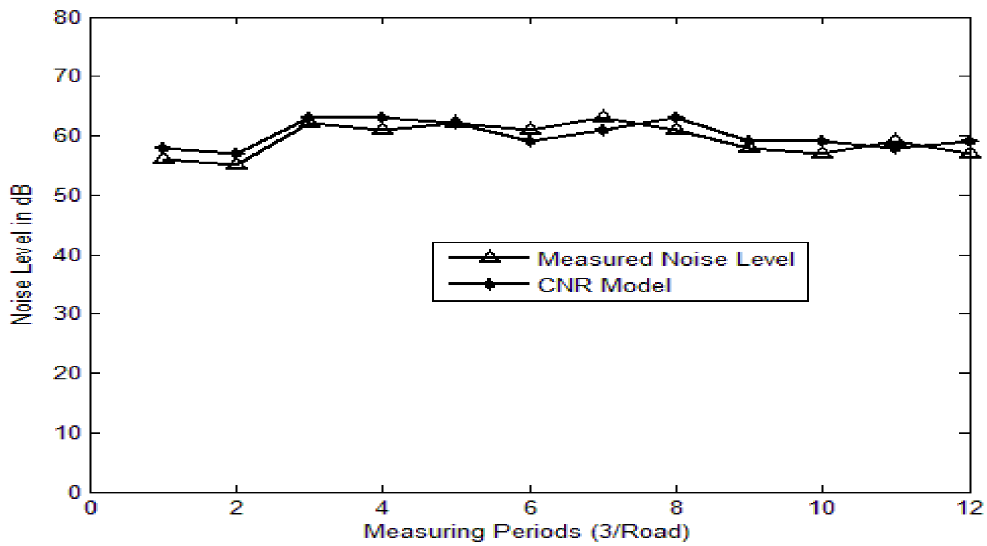

Figure 3: The CNR in Comparison with the measured noise level

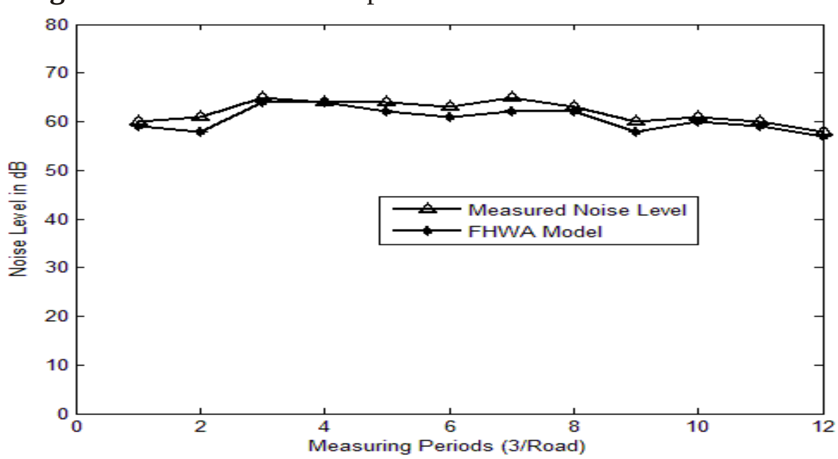

Figure 4: The FHWA in Comparison with the measured noise level

Figure 3 shows the comparison between the CNR and the measured noise level at 25m. It could be observed from the figure that the CNR model performed relatively well at the measuring distance as compared to the performance of the CRTN and RLS90 models at 10m. Figure 4 shows the comparison between the FHWA and the measured noise level at 15m. It could also be observed that this model performed better than the CRTN and RLS90 models that were measured at 10m. An interesting trend observed in these set of results, is that the performance of the models is inversely proportional to the measuring distance i.e. the farther the measuring distance, the better the performance of the model. Also, the maximum measured traffic noise for the CRTN and RLS90 models is 68dB while the max predicted values were 72dB and 70dB respectively. The CNR model has the same maximum measured and predicted value of 63dB. For the FHWA model, the maximum measured and predicted values were found to be 65dB and 64dB respectively.

To determine the performance of each model over the entire measuring period, we evaluate the average value of each model for the two statistical tools used. The average value is obtained using the equation below

$$\text{Average value} = \sum \frac{i_{1\ldots12}}{n} \qquad (17)$$

Where $i_{1\ldots12}$ = statistical tool value for each measurement period
n = total number of period = 12.

CONCLUSION

In this paper, an evaluation of four mathematical models for predicting traffic noise in Ogun State was carried out. The four models evaluated include CRTN, RLS90, CNR and FHWA. Noise levels measured from four major highways across the state were compared with noise levels predicted by the four models using two statistical methods of RMSD and two-sample t-test. Results obtained in this study reveals that the best model for predicting highway traffic noise in Ogun State is the CNR model based on its lowest RMSD value of 0.2 and a t-value of 2.15, hence the model can be used as a reliable forecast tool for planning and activities aimed at mitigating highway traffic noise in the state.

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