Evaluation Of Models For Predicting Highway Traffic Noise

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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

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{eq}$</td>
<td>Equivalent Continuous Sound Level</td>
</tr>
<tr>
<td>$L_{Aeq}$</td>
<td>A-weighted equivalent sound pressure level in dB</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
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<tr>
<td>CRTN</td>
<td>Calculation of Road Traffic Noise</td>
</tr>
<tr>
<td>ASJRTN</td>
<td>Acoustical Society of Japan Road Traffic Noise</td>
</tr>
<tr>
<td>TNM</td>
<td>Traffic Noise Model</td>
</tr>
<tr>
<td>NPCM</td>
<td>Noise Propagation Computation Method</td>
</tr>
<tr>
<td>CNR</td>
<td>Consiglio Nazionale delle Ricerche</td>
</tr>
</tbody>
</table>

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 State, 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.

\[
L_{10}(1h) = 42.2 + 10 \log (q) \ (dbA) \quad (1)
\]

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

\[
L_{10}(18h) = 29.1 + 10 \log (Q) \ (dbA) \quad (2)
\]

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

\[ L = L_o + \Delta L \quad (13) \]

\[ \Delta L = \text{adjustment applied.} \]

\[ L_{eq}(h)_i = (L_o)E_i + 10 \log \left( \frac{S_i}{R_n} \right) + 10 \log \left( \frac{D}{R_n} \right) - 30 \quad (14) \]

\( L_{eq}(h)_i \) is the reference energy mean emission level of class of vehicle \( N_i \) is the number of vehicles in the \( i \)th class passing a specified point during some specified time. \( D \) is the reference distance at which the emission levels are measured. In FHWA model, \( D \) is 15 meters. \( S_i \) is the average speed of \( i \)th class vehicle and is measured in kilometres/hour. \( T \) is the period over which the equivalent sound level computed and \( R_n \) is the distance in meters between the centreline of the near end of the roadway segment and the observer. \( R_o \) 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 dB(A) with an accuracy of ±1.5 db.

**Figure 1.** Benetech GM1352 digital sound level meter

Measurements were taken three times a day for five consecutive days between the hours of 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 different 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):

\[ \text{MSD} = \frac{1}{n} \sum_{k=1}^{n} \left( \frac{\gamma_k - \chi_k}{\chi_k} \right)^2 \quad (15) \]

\[ \gamma_k = \text{kth predicted value,} \]

\[ \chi_k = \text{kth measured value} \]

\[ n = \text{total number of observations} \]

and

\[ t = \frac{x_o - x_i}{s_p \sqrt{2/n}} \quad (16) \]

where \( s_p = \sqrt{\frac{s_x^2 + s_x^2}{2}} \)

\( s_p \) is the pooled standard deviation for \( x_i \) and
n=n1=n2 and $S_1^2$, $S_2^2$, and $S_3^2$, $S_4^2$ 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

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

**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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>CRTN</th>
<th>RLS 90</th>
<th>CNR</th>
<th>FHWA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road 1 _m</td>
<td>62</td>
<td>67</td>
<td>62</td>
<td>68</td>
</tr>
<tr>
<td>Road 1 _d</td>
<td>63</td>
<td>66</td>
<td>63</td>
<td>68</td>
</tr>
<tr>
<td>Road 1 _e</td>
<td>66</td>
<td>65</td>
<td>66</td>
<td>69</td>
</tr>
<tr>
<td>Road 2 _m</td>
<td>66</td>
<td>71</td>
<td>66</td>
<td>69</td>
</tr>
<tr>
<td>Road 2 _d</td>
<td>67</td>
<td>72</td>
<td>67</td>
<td>70</td>
</tr>
<tr>
<td>Road 2 _e</td>
<td>66</td>
<td>71</td>
<td>66</td>
<td>69</td>
</tr>
<tr>
<td>Road 3 _m</td>
<td>68</td>
<td>72</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>Road 3 _d</td>
<td>64</td>
<td>68</td>
<td>64</td>
<td>69</td>
</tr>
<tr>
<td>Road 3 _e</td>
<td>61</td>
<td>65</td>
<td>61</td>
<td>65</td>
</tr>
<tr>
<td>Road 4 _m</td>
<td>63</td>
<td>66</td>
<td>63</td>
<td>65</td>
</tr>
<tr>
<td>Road 4 _d</td>
<td>62</td>
<td>65</td>
<td>62</td>
<td>66</td>
</tr>
<tr>
<td>Road 4 _e</td>
<td>61</td>
<td>64</td>
<td>61</td>
<td>66</td>
</tr>
</tbody>
</table>

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 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

\[
\text{Average value} = \frac{\sum_{i=1}^{12} i_{1...12}}{n}
\]

Where \( i_{1...12} \) = 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.

**REFERENCES**


