Replication of Calculation of Road Traffic Noise Model for Traffic Noise Prediction at The Central Business District of Ondo Town, Nigeria

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Abstract
Traffic noise prediction models are required as aids in the design of roads and sometimes in the assessment of existing, or envisaged changes in, traffic noise conditions. In this research, traffic noise and other key parameters (traffic composition, traffic volume and speed) critical to traffic noise at the Central Business District of Ondo town were investigated. Data on traffic composition, traffic volume, speed and traffic noise levels were obtained and fitted into the Calculation of Road Traffic Noise (CoRTN) model which is a standard traffic noise prediction model. Data collected showed that the measured noise levels in equivalent noise level (Leq) for the study locations ranged between 68 dB(A) and 76 dB(A); these traffic noise levels exceed World Health Organization (WHO) and Federal Highway Administration (FHWA) permissible limit of 55 dB(A) and 60 dB(A) respectively. Results revealed that the (CoRTN) model showed efficient predictive capability when compared to measured noise levels with an acceptable coefficient of determination (R²) value of 0.943.

Keywords: CoRTN; Central Business District; Traffic noise; Ondo town.

1. Introduction
Urban traffic noise is one of the most critical types of noise and normally considered more interfering than other types of noises [1]. Many cities have faced problems of increasing use of motor vehicles [2]. Traffic noise will continue to increase in magnitude and severity because of population growth, urbanization, and the associated growth in the use of automobiles. One of the most important types of pollution encountered as a result of the evolution of different transportation systems during the past decade is noise pollution [3]. Traffic noise is the sum of the total noise generated by all moving vehicles on the highway. Therefore, the main components are the

The CBD of Ondo town can be easily identified from features such as most accessible location, expensive land values, high density of roads and buildings, cultural/historical buildings, business sector, transport centres and high traffic at peak hours. However, all these are contributing factors leading to increase in traffic noise in the CBD of the study area and cause health disorder to individuals. It should be noted that, until now, no study on traffic noise prediction has been carried out in Ondo town.

The aim of this research is to replicate a traffic noise prediction model for Central Business District (CBD) of Ondo town, Nigeria. The specific objectives to achieve the aforementioned aim are to collect data on key factors that have been identified based on literature as contributing to traffic noise at the CBD of Ondo town, develop a mathematical model based on CoRTN model and validate the model obtained with another set of data collected for validating the model.

The paper contains data of traffic composition, traffic volume, speed and traffic noise levels collected for the study. The calibration of the model was done by fitting the data collected into the CoRTN model, the model was validated by collecting data at the study locations to generate a new set of predicted traffic noise in which is later converted to equivalent traffic noise (Leq). The measured and predicted traffic noise levels were compared to determine the coefficient of determination (R²) of the model.

2. Literature Review
A number of models have been created to predict noise levels in urban areas. For instance, Federal Highway Administration Standard (FHWA) Model [4], Calculation of Road Traffic Noise (CoRTN) model [5]. The CoRTN model has been used worldwide and has been adjudged very accurate for traffic noise prediction [6].

noise generated by an individual vehicle, depending on the type of vehicle and mode of operation, the nature of the vehicle flow and
the relative proportions of the types of vehicle included in the flow. Therefore, knowledge of these factors is necessary to define the characteristics of highway noise and to subsequently predict the appropriate noise level in the surrounding area.

The (CoRTN) model is among the first systematic schemes developed to predict noise level due to road traffic. It has been widely used in the United Kingdom, Australia, New Zealand, and Hong Kong [7]. Particularly in the United Kingdom and Hong Kong, it is the sole instrument for the assessment of road traffic environmental impacts by local authorities [8].

Some researchers have studied the reliability of traffic noise prediction using the CoRTN model. In Asia city, the accuracy of the CoRTN model in predicting traffic noise with over half of motor vehicles being motorcycles was examined; the performance of the model in predicting both roadside and vertical distributions of traffic noise levels was assessed and results showed that the performance of the model is satisfactory in predicting roadside traffic noise levels, with an $R^2$ of value 0.832 and a mean difference of 0.52 dB(A) between the measured and predicted values [6].

Furthermore, a study carried out in Hong Kong showed that the accuracy of the CoRTN model was satisfactory and the predicted results using the model correlated well with the measured results with $R^2$ values ranging from 0.7742 to 0.9331 and a mean difference of $+0.4$ dB(A) to $+2.0$ dB(A). [9-12].

It is therefore imperative to use CoRTN standard model to formulate a traffic noise model for a developing city like Ondo town, Nigeria.

3. Methodology

3.1. Data collection

Data were collected during morning period (7-8am), afternoon period (11-12pm) and evening period (3-4 pm) for seven (7) days at three locations.

Fig. 1. Represents the map of Nigeria showing Ondo state.

The three study locations of data collection are indicated in Fig. 2 are:

i. Akure Garage
ii. Ile Garage
iii. Oka Roundabout

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![Map of Nigeria showing Ondo State](image-url)
The locations selected were critical to the study because they had the following CBD features; the most accessible location, characterised with expensive land values, high density of roads and buildings, cultural/historical buildings, business sector, transport centres and high traffic at peak hours which are culminating in the generation of high traffic noise in the study area. Data collected are traffic composition, traffic volume, speed of vehicle and traffic noise levels.

3.1.1. Traffic Composition Data

Traffic flow data were collected with a digital video recording camera, which was positioned adjacent to the road to record the flow of traffic; vehicles were classified into two categories as Light Vehicles (LV) which includes private cars, taxis and motorcycles, minibuses and vans carrying heavy cargos and Heavy Vehicles (HV) which are trucks and trailers. Traffic volume data were extracted from the digital video camera recording. Percentage of HV is one of the key parameters considered in CoRTN model.

3.1.2. Speed measurement

Data on speed were collected by observing the time taken for a vehicle to cover a distance of 100 m; identified by two enumerators with the aid of stop watch.

3.1.3. Traffic noise level data

Data on traffic noise levels were measured in decibels using a digital IEC Type II Sound Level Meter which responds to sound in approximately same way as the human ear. The instrument was mounted on the tripod stand at the spot where there were no obstructions such as trees, high-rise buildings, parked vehicles, etc.

The meter was set in fast mode with the microphone pointing at the road at a height of 1.5 m above the ground level and 5 m away from the centre of the road. The measured hourly noise levels were recorded manually every 30 s for a period of 1 hour at each location.

3.2. Model calibration

The data collected from the field survey were fitted into CoRTN model to obtain a predicted data set. The CoRTN traffic noise prediction model is:

$$L_{10}=L_0+Δf+Δp+Δg+Δd+Δs+Δa+Δr$$  \hspace{1cm} (1)

where $L_0$ is the basic hourly noise level, $Δf$ is correction for traffic speed and percentage of heavy vehicle, $Δp$ is road surface correction, $Δg$ is adjustment for the gradient of a road section, $Δd$ is slant distance between the road(source) and receptor, $Δs$ is correction for shielding (barriers) between the road(source) and receptor, $Δa$ is correction from the angle view of the road and $Δr$ is the correction for reflections from buildings on the opposite side of the building. Each of the CoRTN model parameters are defined mathematically below:

$$L_0=42.2+10\log q \text{ dB}(A)$$  \hspace{1cm} (2)

Where q is the hourly traffic flow

$$Δf=33\log(v+40+(500/v)) + 10 \log (1+5p/v)-68.8$$  \hspace{1cm} (3)

Where v is the traffic speed,

$$p=100f/q$$  \hspace{1cm} (4)
Where \( p \) is the percentage of heavy vehicles

\[
\Delta g = 0.3G
\]

(5)

Where \( G \) is gradient of the road only applicable for uphill flow of vehicles

\[
\Delta p = -10 \log(A)
\]

(6)

Equation 6 is applicable to bituminous impervious road surfaces for roads with vehicle speed less than 75 km/h; pervious road surfaces have a value of -3.5dB(A)

\[
\Delta d = 10 \log(d/13.5) \text{ dB(A)}
\]

(7)

Where \( d = 5 \text{ m} \) is the distance from the centre of the road to the receptor and \( d' \) is the shortest slant distance between a road (source) and receptor;

\[
d' = \sqrt{(d+3.5)^2 + h^2} \text{ (0.5)}
\]

(8)

Where \( h = 1.5 \text{ m} \) is the difference in height above ground between the source and receptor

\[
\Delta a = 10 \log(O/180) \text{ dB(A)}
\]

(9)

Where \( O = 127^\circ \) is the angle of the view of the road in degrees;

\[
\Delta r = \left(1.5 \left(\frac{\text{Os}}{O}\right) 180^\circ\right) \text{ dB(A)}
\]

(10)

Where \( \text{Os} = 1^\circ \) is the sum of angles by all the reflecting facades (i.e. individual buildings) on the opposite side of the road to the receptor.

Finally, since the CoRTN model is based on \( L_{10} \) values, a conversion to \( L_{eq} \) is needed. Equivalent noise level (\( L_{eq} \)) is calculated from the following empirical relationship

\[
L_{eq} = 0.94 L_{10} + 0.77 \text{ dB(A)}
\]

(11)

4. Results and Discussion

4.1 Traffic Composition and Volume

Results of traffic composition and volume are presented in Table 1. The percentage of HV is the ratio of the volume of HV to the total volume (TV) in percentage. For the three study locations, the percentage of HV ranged between 10.96 to 24.05%; this is an indication of an appreciable number of HV present at the study location, thereby contributing to noise generation. The highest TV of 12,760 vehicles per hour was recorded at Ife Garage followed by Akure Garage with a TV of 9077 veh/hr and Oka Garage recorded TV of 7226 veh/hr during the morning periods (7 – 8 am). There was a decrease in volume during the afternoon period and a gradual increase was observed in the evening period (3 – 4 pm). The results obtained from these locations confirmed that the areas are densely populated, in which commercial activities, public administration and public services are present indicating high volume of traffic and by extension high level of traffic noise being generated during the rush hours (7 – 8 am and 3 – 4 pm) when traffic is at its peak.

4.2 Speed

The speed of vehicles was observed at the three study locations; the result in Table 2 showed the highest speed of 73.87 km/hr recorded during which traffic volume was low and vehicles were travelling at a free speed. As a rule of thumb, tyre-road interaction is the main cause of noise above 55 km/hr for most cars, and above about 70 km/hr for lorries with engine noise predominating at lower speeds, although changes in technology mean that rolling noise can now dominate at speeds above 20-40 km/hr for new cars and at 30-60 km/hr for new lorries. However, the values of speed observed at the three study locations ranges between 43.49 km/hr and 73.87 km/hr; this indicates that the speed of vehicles at the study locations is characteristically high but are within the 75km/hr standard speed limit for CoRTN model.

4.3 Traffic Noise

Traffic noise were measured during morning, afternoon and evening period. The result of measured traffic noise in Table 3 indicates that traffic noise levels were high during the morning and evening periods, and the highest traffic noise level of 76.1 dB(A) was recorded during evening period. All measured traffic noise levels exceeded WHO permissible limit of 60 dB(A) and results show that about 90% of traffic noise levels at the study locations investigated were above the benchmark set by WHO for traffic, commercial and industrial areas of 70 dB(A) by 6 dB(A) causing hearing impairment; this explains that the CBD of Ondo town has fallen into a situation of traffic noise pollution.

4.4 Fitting Measured Traffic Noise Data into CoRTN Model

Measured traffic noise data collected were fitted into CoRTN model in Equation 1 and calibrated for the study area. It should however be noted that \( \Delta g \), which is adjustment for the gradient of a road section for uphill flow of vehicles is not applicable to any of the study locations and is therefore not considered in the model equation. Likewise, \( \Delta s \) which is the correction for shielding (barriers) between the road (source) and receptor is not considered in the model equation. The CoRTN model as applicable to the study locations is in Equation (12)

\[
L_{10} = L_o + \Delta f + \Delta p + \Delta d + \Delta a + \Delta r
\]

(12)

The CoRTN model as applicable to the study location in Equation 12 to which the measured traffic noise data were fitted is further expanded in Equation 13.

\[
L_{10} = \left(42.82 + 10 \log q + (33 \log \left( \nu + 40 + \left( \frac{500}{\nu} \right) \right) + 10 \log \left(1 + \frac{5p}{\nu} \right) - 68.8 + (-\Delta p) + (-\Delta a) + (\Delta r) + (-10 \log \left(\frac{d' = (d + 3.5)^2 + h^2/180}{13.5}\right) \right) \right)
\]

(13)

The CoRTN model in Equation 13 was used to obtain the predicted traffic noise data for the study locations in Table 4. Since the CoRTN model is based on \( L_{10} \) values, a conversion to \( L_{eq} \) which is equivalent noise level, is needed to enhance the comparison of predicted traffic noise levels with the measured traffic noise levels. Equation 11 was used for the conversion of
$L_{10}$ to $L_{eq}$ and the result is shown in Table 5. The traffic noise levels were high during the morning and evening period. Ife Garage recorded the highest noise levels as a result of increase in traffic volume followed by Oka roundabout albeit it had the least traffic volume, but the traffic noise levels were higher than that of Akure Garage due to high volume of HV. The highest predicted equivalent noise level of 75.67 dB(A) is obtained during the morning period at Ife Garage which is a value that is higher than the permissible limit in the WHO standard.

<table>
<thead>
<tr>
<th>Table 1: Traffic Composition and Volume Data.</th>
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<tbody>
<tr>
<td>Location</td>
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<tr>
<td>Time</td>
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<tr>
<td>Light Vehicle (LV)</td>
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<tr>
<td>Heavy Vehicle (HV)</td>
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<tr>
<td>Heavy Vehicle (% HV)</td>
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<td>Total Volume (TV)</td>
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<tr>
<th>Table 2: Summary of Speed Data Collected for Seven (7) Days.</th>
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<tbody>
<tr>
<td>Ife Garage</td>
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<tr>
<td>Speed data (km/h)</td>
</tr>
<tr>
<td>54.76</td>
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<tr>
<td>57.29</td>
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<tr>
<td>61.53</td>
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<tr>
<td>63.54</td>
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<tr>
<td>59.06</td>
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<td>65.39</td>
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<td>67.99</td>
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<tr>
<th>Table 3: Measured Traffic Noise Levels dB(A).</th>
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<tr>
<td>Ife Garage</td>
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<tr>
<td>Measured $L_{eq}$ (dB(A))</td>
</tr>
<tr>
<td>75.9</td>
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<tr>
<td>73.7</td>
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<td>75.5</td>
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<td>76.0</td>
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<td>71.1</td>
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<td>68.8</td>
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<tr>
<th>Table 4: CoRTN Predicted Noise Levels ($L_{10}$)</th>
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<tbody>
<tr>
<td>Ife Garage</td>
</tr>
<tr>
<td>Predicted $L_{eq}$ (dB(A))</td>
</tr>
<tr>
<td>79.68</td>
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<tr>
<td>77.06</td>
</tr>
<tr>
<td>78.94</td>
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<tr>
<td>79.34</td>
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<td>79.42</td>
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<tr>
<td>75.57</td>
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<tr>
<td>72.18</td>
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</table>
4.5 Validation of CoRTN Model for the Study Locations

New set of data (traffic composition, traffic volume, speed and traffic noise levels) were collected from each location and to validate the CoRTN traffic noise prediction model for the study locations. The performance of the CoRTN model in predicting the traffic noise levels were evaluated by comparing the CoRTN noise prediction values and the newly measured traffic noise values. The differences between the measured and predicted traffic noise levels were in the range of -0.51 dB(A) to 2.09 dB(A); the mean difference is 1.19. The model correlated well with the measured values with an $R^2$ of 0.94 as indicated in Fig. 3.

![Fig. 3 Scatter plot of measured traffic noise levels and Predicted CoRTN traffic noise levels.](image)

5. Conclusion

This research has examined the Calculation of Road Traffic Noise (CRTN) model for predicting traffic noise in the study location. The CoRTN traffic noise model was validated with measured traffic noise levels and found to be producing statistically significant coefficient of determination ($R^2$) value of 0.943. The differences between the measured traffic noise levels and predicted CoRTN values were in the range of -0.51 dB(A) to 2.09 dB(A) and the mean difference of 1.19 dB(A). However, difference between the field measured noise levels and the modeled noise levels is deduced to be satisfactory since it is within the +/- 3.0 (dB(A) allowed by Federal Highway Administration (FHWA). The model, therefore, performs reasonably well under different traffic conditions and could be implemented for the prediction of road traffic noise in Central Business District of Ondo town.

Traffic volume, traffic composition and speed largely influenced the noise levels; the violations of the limit noise levels were the gravest during the morning and night-time measurement interval caused due to high traffic intensity. The predicted equivalent noise level at the study locations are characteristically higher than the 70 (dB(A) which is the benchmark set by WHO for traffic, commercial and industrial areas. It is therefore necessary to take serious mitigation measures to reduce and control noise pollution at all locations which are proven to be endangered, first of all by limiting vehicle speed, maintaining of road surface, and implementing noise control measures.

It is hereby recommended that traffic noise prediction models should be considered as a key factor in design of roads and transportation planning. This will help the residents close to an existing and proposed road to be aware of the dangers inherent in
the levels of traffic noise being generated by the vehicles moving on the roadway.

References