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MODELING TRAFFIC NOISE INTENSITY AND COMPARATIVE VALIDATION ANALYSIS OF ARIMA AND MLR MODELS

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ABSTRACT

The traffic noise big data collected from studying traffic situations in Port-Harcourt Nigeria selected trunks A and C roads sub-sectioned as flexible pavements locations 1, 2, and 3 and flexible and rigid pavements locations 4 and 5 respectively has been analyzed by using the multi-linear regression (MLR) technique. Traffic noise is an acoustic hazard affecting mostly people living closest to the roadway pavement. The solution of such a high degree of discomfort on roadside dwellers deserves serious study. This work considered traffic parameters like distance between dwellers and the roadway, traffic count, vehicular speed, traffic periods, etc. in modeling the traffic noise intensity (TNI) of the selected road. The average peak traffic noise for location 1 obtained at various distances of 5m, 10m and 15m from the centre of the roadway are 85.59dB, 84.93dB and 83.97dB respectively, for location 2 are 86.52dB, 85.34dB and 84.26dB respectively, for location 3 are 84.38dB, 83.88dB and 83.32dB respectively, for location 4 are 85.16dB, 84.56dB and 83.55dB respectively, for location 5 Trunk C Flexible Pavement are 55.46dB, 54.36dB and 53.99dB respectively and for Trunk C Rigid Pavement are 60.58dB, 59.58dB and 58.96dB respectively. The traffic noise values for location 1-4 had higher noise intensity and same range, it was categorized as Trunk A flexible pavement and classified as heavy-trafficked routes while location 5 (Trunk C) had lower noise intensity and same range which was classified as light-trafficked routes. MLR predicted the TNI with R^2 (0.2015, 0.2110, 0.1894, 0.2203, 0.2275, 0.1983, 0.4398, 0.4398, 0.3907, 0.3952, 0.3427, 0.3355, 0.3149, 0.1505, 0.1526, 0.1441, 0.002, 0.0012, 0.001) values for the model along the selected routes. From the result, the distance of noise measurement from the centre of the roadway of Trunk C flexible pavement with the most significant p-value of 0.804145, the equivalent traffic volume and traffic speed had p-values of 0.014782 and 3.22E-50 respectively whereas that of Trunk C rigid pavement with the most significant p-value of 0.872625, the equivalent traffic volume and traffic speed had p-values of 0.265025 and 3.67E-61 respectively. The noise level increased more on rigid pavements than that of flexible pavements, which is attributed to more voids on rigid pavements and the higher frictional noise due to increased frictional force between the vehicle tires and road surfaces with the grip being more in rigid pavements. At the end of the exercises, it was observed that ARIMA (R^2 greater 90%) performed better than MLR even with the technical advantage of determining noise difference between interfering points using the auto-correlation factor (ACF) and the partial auto-correlation factor (PACF).

Keywords: *MLR; Noise Intensity; Traffic Volume; Model Prediction; Rigid and Flexible Pavement; Pavement Traction.*

1. INTRODUCTION

Discordant acoustic vibrations emanating from traffic movements is one of the acoustic issues associated with living close or adjacent to the vehicular highways (Muralikrishna and Manickam, 2017). The discomfort of living with the vibratory interferences from the destructive sound waves overlapping with each other from different sources as a result of traffic movements cannot be overstretched (Muralikrishna and Manickam, 2017, Enda and Eoin, 2014). A long-time exposure to such traffic sound emissions alters the mind and body response to external activities and reactions. This makes it a hazardous exposure to the human health and psychology (Muralikrishna and Manickam, 2017). The degree of damage experienced by the victims of this exposure depends on the intensity of the noise, which also depends on the distance from the road section to the residential dwelling (Enda and Eoin, 2014). Again, the type of pavement (flexible or rigid pavement) plays a role also due to the difference I surface traction between the vehicle tires and road surface (Muralikrishna and Manickam, 2017, Enda and Eoin, 2014). Close observation shows that the flexible pavement of asphalt surfacing has a smoother surface with a considerable traction than the rigid pavement of concrete surfacing with a rougher surface (Enda and Eoin, 2014). There have been previous works dedicated to studying this acoustic problem by using predictive models of the traffic noise intensity (TNI). Heavier traffic volumes, vehicular speed, and number of vehicles on the road at one point contribute to the loudness or the degree of the TNI (Muralikrishna and Manickam, 2017). Also, faulty vehicles and defective mufflers contribute to this TNI and these put together adversely affect the roadside dwellers in cities around the world. Road traffic noise models have been developed for a heterogeneous traffic condition by using a graph theory approach deploying some selected parameters related to road traffic systems and subsystems (Gilani and Mir, 2021). In this work the interaction and consistency between traffic volume, carriageway dimensions, number of heavy vehicles, speed of vehicles and frequency of honking events were studied for a period of 3 months and validated with a 9-month data from the surrounding environment (Gilani and Mir, 2021). In this work also, the distance of the roadside dwellers from the roadway was not considered as a key factor. Furthermore, artificial neural network (ANN) and multi-linear regression (MLR) have been used to model traffic noise for four location which represented residential, commercial, silent and industrial zones in India (Ramakrishna et al., 2020). However, in this work, the modeled positions were considered with respect to their distance to the center of the roadway and did not consider different points between the roadway center and the dwelling (Ramakrishna et al., 2020, Arizona-Ogwu and Chinedu, 2011, Izeogu, 1989, Ihemeje and Onyelowe, 2021). The present research work has used the MLR technique to model TNI in Port-Harcourt city, Nigeria considering various traffic parameters, which included the intensity of noise at different points from the center of the roadway and the modeled habitat. Also, trunks A and C roads and pavement types (rigid and flexible pavements) were primarily considered in this work. In the present research work, the outcome of the two model-techniques used to predict traffic noise intensity (TNI) in rigid and flexible pavement of trunks A and C roads in Port-Harcourt, Nigeria was validated by comparing their predictive performance. The autoregressive integrated moving average (ARIMA) and multi-linear regression (MLR) techniques had been used to model a big data (see appendices I to V) collected from the field by observation and measurement of sound using the sound-meter.

2. METHODOLOGY

2.1 Design of Study

This research is directed towards the development of traffic noise intensity models for roads within the Port Harcourt Metropolis. The two major and commonly used types of pavements in Nigeria, flexible and rigid pavements were considered in this study. For the essence of this study, five (5) routes were selected and categorized with the help of Google maps. These five (5) routes consist of three (3) major and very busy flexible routes with similar characteristics, which simulated the behavior of other major routes in Port Harcourt. The other two routes (one rigid and one flexible), which are less busy routes, were selected in order to simulate and compare the traffic noise generated from both types of pavements. Field measurements of traffic noise intensity were done using the sound level meter at a height of one (1) meter above the ground level. The spot speed of vehicles was collected using the spot speed stop watch manual method. Traffic noise intensity models were developed using two model formats; the speed, traffic volume and distance from center of roadway format and the time format. Model format one employed the multiple linear regression while model format two used simple regression and the time series analysis in model development. Probability distribution models (normal, log-normal and uniform distributions) were also employed to study the most likely distribution pattern of the observed traffic noise intensity. A comparative study was carried out to assess the difference in traffic noise generation between flexible and rigid pavements. All models developed in this study were validated using the R^2 statistics for the essence of ranking.

2.2 Description and Categorization of the Study Area

2.2.1 Description of the Study Area

Port Harcourt is the capital and largest city of Rivers State, Nigeria. It lies along the Bonny River and is located in the Niger Delta. As of 2016, the Port Harcourt urban area has an estimated population of 1,865,000 inhabitants, up from 1,382,592 as of 2006 (Arizona-Ogwu and Chinedu, 2011). As of 2009, its total population was estimated at 2,000,000 making it one of the largest metropolitan areas in Nigeria. But that number has greatly increased according to recent studies. The city is located on latitude 4.8156° N and longitude 7.0498° E with an average altitude of about 12 m above mean sea level. From an area of 15.54 km^2 in 1914, Port Harcourt grew uncontrolled to an area of 360 km^2 in the 1980s (Izeogu, 1989, Ihemeje and Onyelowe, 2021). Port Harcourt is highly congested as it is the only major city of the Rivers State. Many significant changes have been experienced in terms of urbanization, industrialization, expansion of road network, and infrastructure. The city has been subjected to persistent road traffic and commercial activities due to increase in development, and expansion of the economy. Figure 1 presents the map of Port Harcourt according to traffic flow situation in the city.

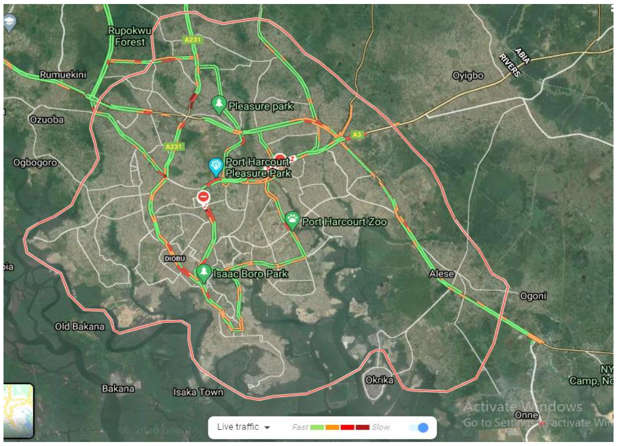

Figure 1: Map of Port Harcourt classifying areas according to traffic flow situation (Ihemeje and Onyelowe, 2021, Google Maps Inc, 2020).

2.2.2. Categorization of pavement routes

This study was based on traffic noise measurements in terms of average speed, traffic volume and distance of noise measuring instrument from center of roadway and also in terms of time of noise measurement, at five different locations; the first three locations (Locations 1 -3) were selected from areas with high traffic characteristics and the other two locations (Locations 4 and 5) selected from areas with low traffic characteristics. Locations 1-3 were assessed for the purpose of assessing and modelling the average noise generated from Trunk A flexible pavements of Port-Harcourt while Locations 4 and 5 were assessed for two reasons, one reason is to assess and model the average noise generated from Trunk C roads in Port Harcourt and to also ascertain the difference in noise level between rigid and flexible pavement in Port Harcourt. Location 1 was mounted at a place of latitude, 4.88629^0N and longitude, 7.14276^0E; Location 2 was mounted at a location with latitude 4.88971^0N and longitude 6.88355^0E while Location 3 has latitude of 4.93247^0N and longitude 7.00303^0E. All these locations are indicated with blue prints shown in Figure 2 (a). They are all Trunk A roads. Locations 4 and 5 (L4 and L5) were stationed at latitude 4.89968^0N, longitude 6.91798^0E and latitude 4.89207^0N and longitude 6.91429^0E respectively (Figure 2 (b)). They are both Trunk C roads with similar traffic characteristics.

(a)

(b)

Figure 2: Categorization of routes used for traffic noise study (Ihemeje and Onyelowe, 2021, Google Maps Inc, 2020).

2.3. Field Data Collection

All data collected in this study were obtained through simple and well thought out procedures. Average values of all required parameters were recorded for every fifteen (15) minutes of data observation. Data collected or determined in this study include, traffic noise intensity, traffic speed and traffic volume. In the course of data collection, the data collection team was separated into three teams. Team A was in charge of traffic noise measurement, Team B collected data for traffic speed calculation and Team C was into traffic counting. Data collection was done daily for fifteen (15) hours in a span of two (2) weeks. Measurement of data was done simultaneously in all the routes considered in this study. Details of these parameters collection are hereby presented in this section.

Instrument used in traffic noise intensity measurement include; a precision-grade sound level meter (according to IEC 51, ANSI S1.4 type), 1/2-in.condenser microphone, and 1/3-octave filter with frequency range and measuring level range of 31.5 Hz–8 KHz and 35–130 dB, respectively and a stop watch to observe time intervals during reading. The sound measuring instrument was held firmly against a constructed wooden pole with the microphone pointing at the road in predetermined distances of 5m, 10m and 15m from the center of the road way and sound measurements were taken under suitable metrological conditions, maintaining a height of 1m above the road way. Traffic noise intensities measured in, L_{Ai} (A-weighted instantaneous sound pressure level) was recorded at intervals of fifteen (15) seconds for a period of 15 minutes.

The spot speed study was adopted in the determination of traffic speed. It involves the use of a stop watch from which the time required for a vehicle to traverse a predetermined length is recorded. The spot speed method of speed determination generally involves the following procedures; determination of appropriate study length, selection of proper layout and observation position, recording observations on speed data form and calculating vehicular speeds.

In spot speed studies, the Institute of Traffic Engineers 1965 recommended certain base lengths for spot speed determination at different average speed ranges of the traffic stream as shown in Table 1. The recommendation is intended to make speed calculation straight forward and less confusing. If the lengths recommended in Table 3.1 are not appropriate, another length can be used for reliable observer reaction times.

Table 1. Basic Lengths for Spot Speed Determination (Ihemeje and Onyelowe, 2021).

S.No	Average speed of traffic stream (km/h)	Base Length (m)
1	Less than 40	27
2	40 to 65	54
3	Greater than 65	810

For the purpose of this study, a study length of twenty (20) meters was used during stop watch spot speed study.

2.4. Traffic Noise Modelling

Traffic noise modelling was conducted by using the standard requirements contained in previous works. This is related the total traffic noise of a roadway to average speed of traffic stream, the average traffic volume and the distance of noise measurement from the center of roadways selected. Multiple linear regression method was used in developing the models. The observed data were also checked against possible probability distribution patterns such as the normal, log-normal and uniform distribution patterns.

2.4.1. Regression Analysis

The simple and multiple linear regression and ARIMA procedures were analyzed using the MINITAB software. The simple regression analysis employed here is the second degree polynomial regression. The multiple linear regressions employed here is that with the traffic speed, traffic volume and distance of noise measuring instrument from center of roadway as the independent variables.

3. RESULTS AND DISCUSSIONS

3.1 Traffic Noise Intensity Results for Analysis of Trunk A Flexible Pavements; Locations 1-3

Figure 3 presents the results for the traffic noise intensity of location 1 for the different distances (5m, 10m, and 15m) from the centre of the roadway. The noise as recorded reduces as the distance from the centre of the roadway increases. The average peak noise value of 85.59dB was recorded in the 525th minute (at 5:45pm) for a distance of 5m from the roadway centre. At a distance of 10m from the roadway centre, an average peak noise value of 84.93dB was recorded in the 540th minute (6:00pm). An average peak noise value of 83.97dB was recorded in the 600th minute (7:00pm) at a distance of 15m from the roadway centre. Details of this result are shown in supplementary material, appendix 1.

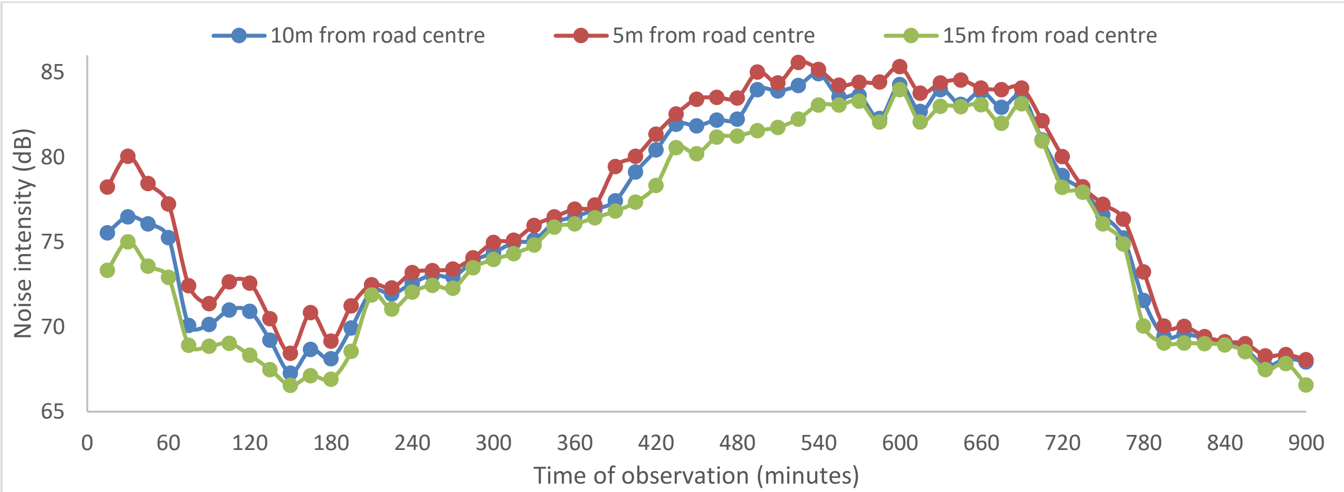

Figure 3. Average Traffic Noise Intensity for Location 1

The traffic noise intensity results for location 2 are presented as shown in Figure 4. The results displayed showed that the traffic noise intensity reduces as the distance from the roadway centre increases. The average peak noise value of 86.52dB was recorded in the 525th minute (at 5:45pm) for a distance of 5m from the roadway centre. At a distance of 10m from the roadway centre, an average peak noise value of 85.34dB was recorded in the 600th minute (7:00pm). An average peak noise value of 84.26dB was recorded in the 540th minute (6:00pm) at a distance of 15m from the roadway centre. Details of this result are shown in the supplementary material, appendix II.

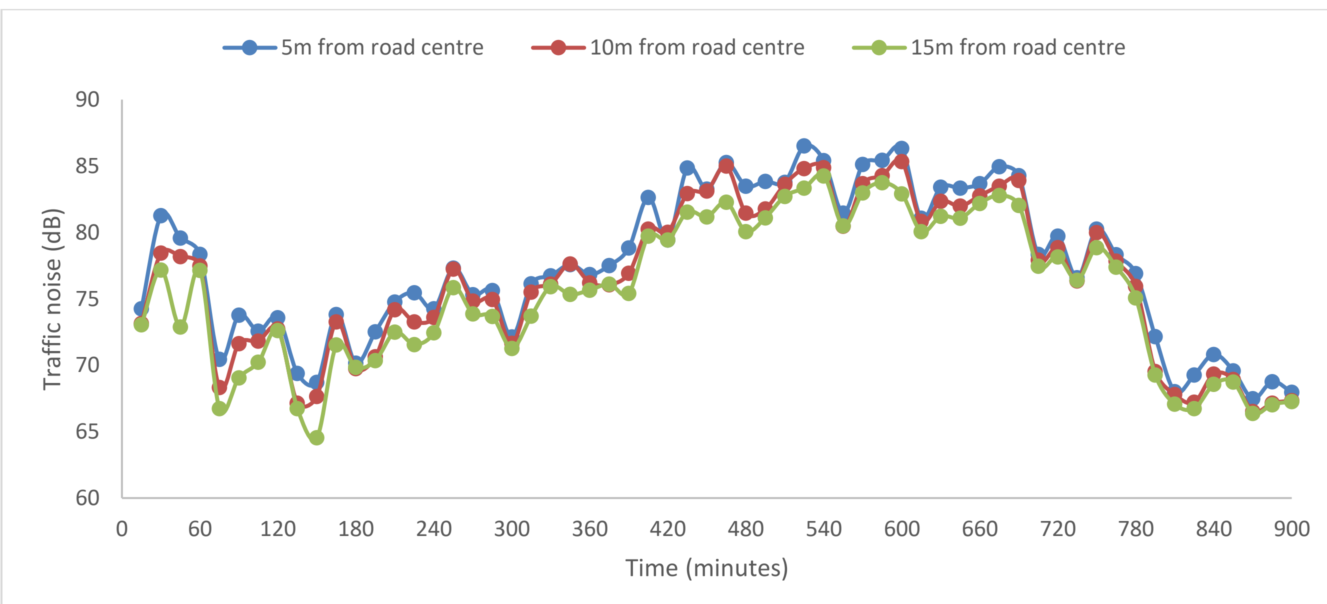

Figure 4. Average Traffic Noise Intensity for Location 2

Figure 5 presents the results for the traffic noise intensity of location 3 for the different distances (5m, 10m, and 15m) from the centre of the roadway. The noise as recorded reduces as the distance from the centre of the roadway increases. The average peak noise value of 84.38dB was recorded in the 540th minute (at 6:00pm) for a distance of 5m from the roadway centre. At a distance of 10m from the roadway centre, an average peak noise value of 83.88dB was recorded in the 540th minute (6:00pm). An average peak noise value of 83.32dB was recorded in the 540th minute (6:00pm) at a distance of 15m from the roadway centre. Details of this result are shown in the supplementary material, appendix III.

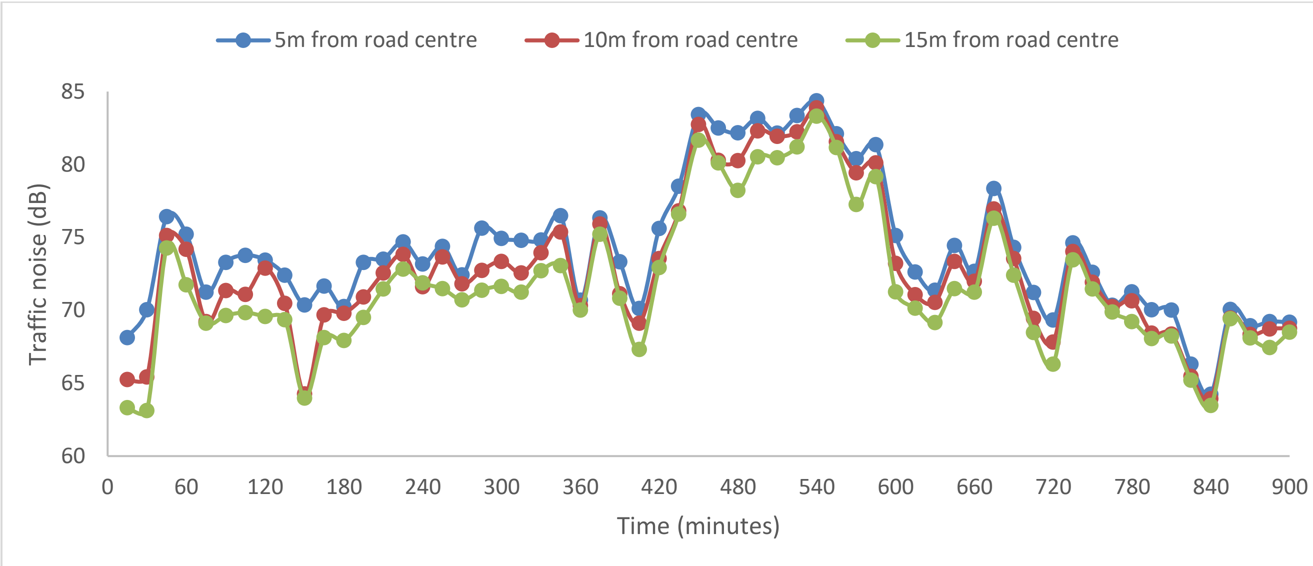

Figure 5. Average Traffic Noise Intensity for Location 3

The mean average traffic noise intensity results for the three locations (flexible pavements, trunk A roads) are presented as shown in Figure 6. The results displayed showed that the mean average traffic noise intensity of Trunk A flexible pavements reduces as the distance from the roadway centre increases. Mean average peak noise value of 85.16dB was obtained in the 525th minute (at 5:45pm) for a distance of 5m from the roadway centre. At a distance of 10m from the roadway centre, the mean average peak noise value of 84.56dB was obtained in the 540th minute (6:00pm). An average peak noise value of 83.55dB was obtained in the 540th minute (6:00pm) at a distance of 15m from the roadway centre.

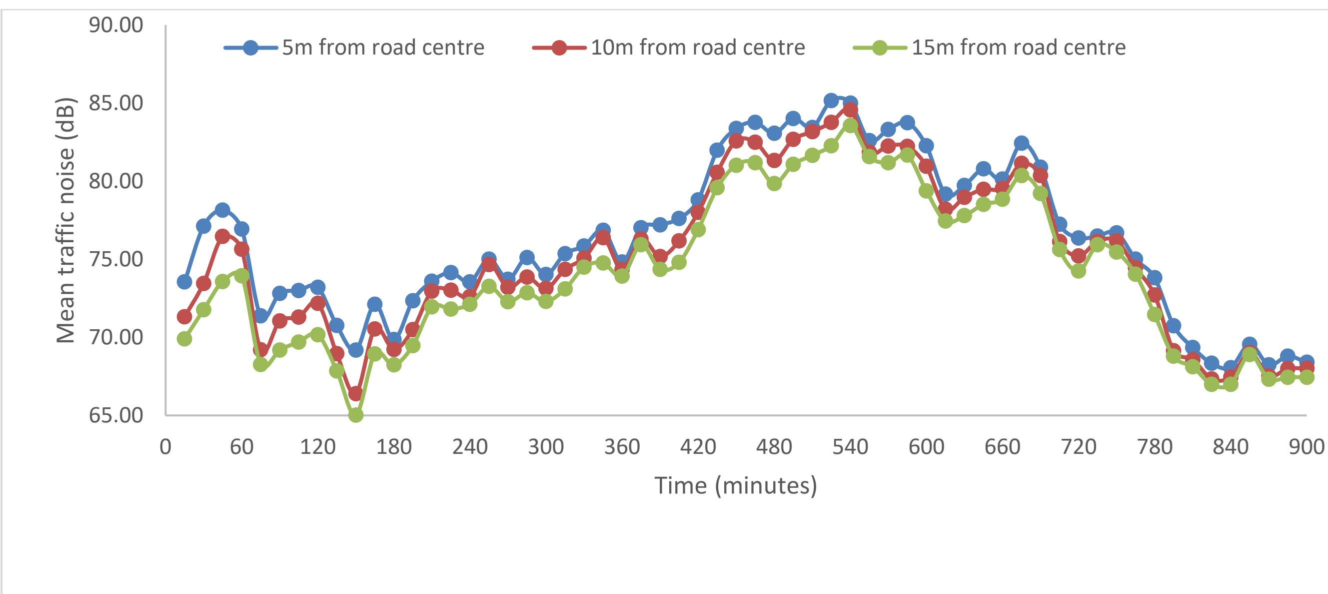

Figure 6. Mean Average Traffic Noise Intensity for Trunk A Flexible Pavements

3.2. Traffic Noise Intensity Results for Analysis of Trunk C Pavements; Locations 4 and 5

The traffic noise intensity results for location 4 are presented as shown in Figure 7. The results displayed showed that the traffic noise intensity reduces as the distance from the roadway centre increases. The average peak noise value of 55.41dB was recorded in the 525th minute (at 5:45pm) for a distance of 5m from the roadway centre. At a distance of 10m from the roadway centre, an average peak noise value of 54.36dB was recorded in the 600th minute (7:00pm). An average peak noise value of 53.99dB was recorded in the 600th minute (6:00pm) at a distance of 15m from the roadway centre. Details of this result are shown in the supplementary, appendix IV.

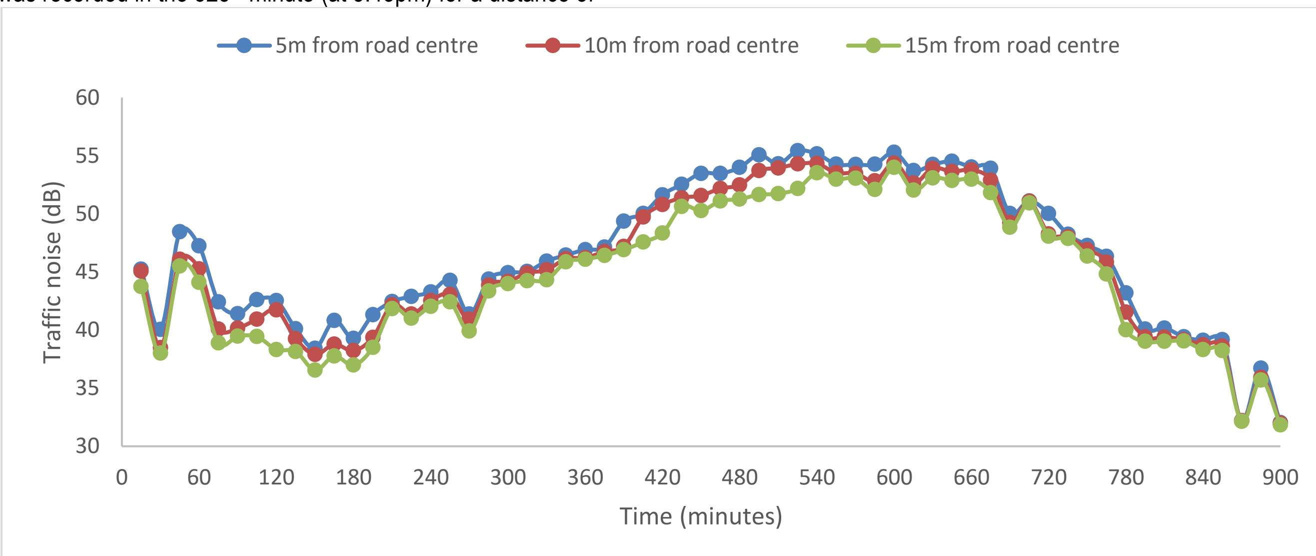

Figure 7. Average Traffic Noise Intensity for Location 4

Figure 8 presents the results for the traffic noise intensity of location 5 for the different distances (5m, 10m, and 15m) from the centre of the roadway. The noise as recorded reduces as the distance from the centre of the roadway increases. The average peak noise value of 60.58dB was recorded in the 600th minute (at 7:00pm) for a distance of 5m from the roadway centre. At a distance of 10m from the roadway centre, an average peak noise value of 59.58dB was recorded in the 525th minute (5:45pm). An average peak noise value of 58.96dB was recorded in the 600th minute (7:00pm) at a distance of 15m from the roadway centre. Details of this result are shown in the supplementary material, appendix V.

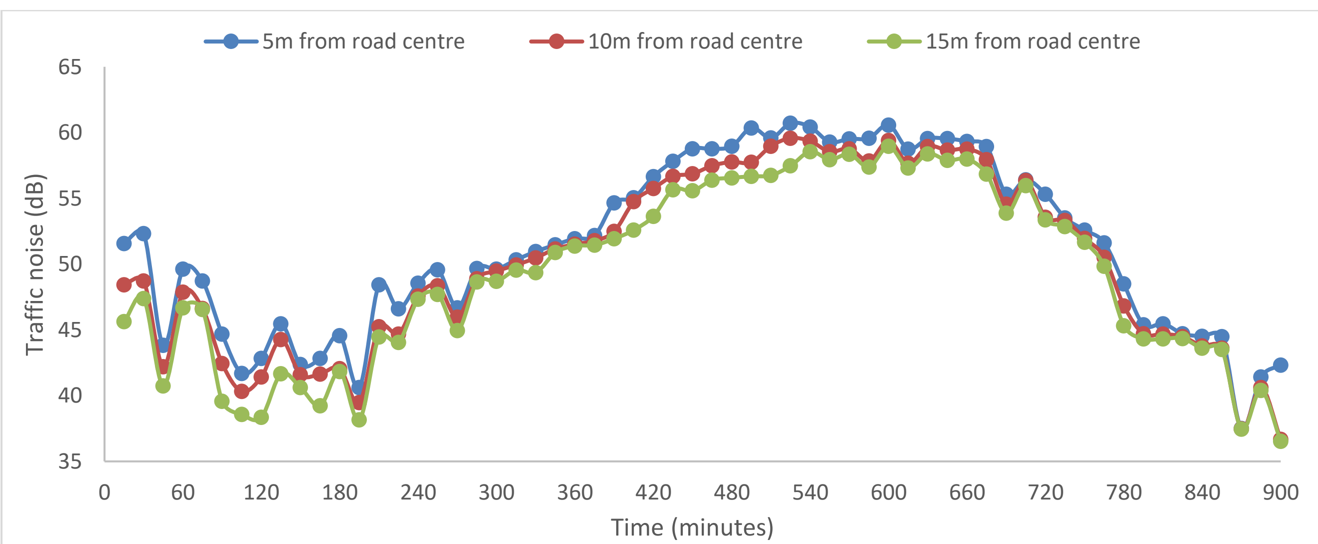

Figure 8. Average Traffic Noise Intensity for Location 5

3.3. Analysis of Results and the Development of Traffic Noise Intensity MLR and ARIMA Models

Models of the types 1 and 2 format were developed in this section using multiple linear regression analysis enabled in Microsoft excel. The traffic noise intensities for the different road sections were modelled against the average traffic volume (PCU), average traffic speed and the distance of noise measurement from the roadway centre.

3.3.1. Model Type I Development of Traffic Noise for Location 1

Table 2 presents the summary of the model type 1 regression analysis of the traffic noise intensity prediction for location 1. From the model coefficient values, the coefficient of the distance from the centre of the roadway is negative implying that, as the distance of noise measurement from the roadway centre increased, the traffic noise intensity value decreased. The multiple linear regression models as obtained from the regression analysis displayed in Table 2 is thus given by Equation 1.

$$Traffic\ Noise(dB) = -0.12252D + 0.04797\,TV + 1.11148S \quad (1)$$

Where; D = distance from roadway centre
TV = PCU of traffic volume
S = average speed of vehicles

Table 2. Summary of regression statistics of the traffic noise modelling of location 1

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997382461
R Square	0.994771774
Adjusted R Square	0.989062981
Standard Error	5.566095401
Observations	180

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1043382.776	347794.259	11225.8987	1.1E-200
Residual	177	5483.710989	30.981418		
Total	180	1048866.487			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Distance (m)	-0.123	0.101	-1.213	0.22670312	-0.322	0.077	-0.322	0.077
Traffic volume (PCU)	0.048	0.016	3.085	0.00236284	0.017	0.079	0.017	0.079
Speed (km/hr)	1.111	0.029	37.819	1.0228E-86	1.053	1.169	1.053	1.169

3.3.2. Model Type I Development of Traffic Noise for Location 2

Table 3 presents the summary of the model type 1 regression analysis of the traffic noise intensity prediction for location 2. In this case, the coefficient of the distance from the centre of the roadway is positive implying that, as the distance of noise measurement from the roadway centre increased, the traffic noise intensity value increased. The multiple linear regression model as obtained from the regression analysis displayed in Table 3 is thus given by Equation 2.

$$Traffic\ Noise(dB) = 0.028707D + 0.111535\ TV + 0.966019S \quad (2)$$

Where; D = distance from roadway centre
TV = PCU of traffic volume
S = average speed of vehicles

Table 3. Summary of regression statistics of the traffic noise modelling of location 2

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99618
R Square	0.992375
Adjusted R Square	0.986639
Standard Error	6.750172
Observations	180

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1049578	349859.3	7678.277	2.8E-186
Residual	177	8064.972	45.56482		
Total	180	1057643			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Distance (m)	0.028707	0.120929	0.237391	0.812628	-0.20994	0.267355	-0.20994	0.267355
Traffic volume (PCU)	0.111535	0.022953	4.859367	2.58E-06	0.066239	0.156831	0.066239	0.156831
Speed (km/hr)	0.966019	0.041033	23.54248	2.05E-56	0.885042	1.046996	0.885042	1.046996

3.3.3. Model Type I Development of Traffic Noise for Location 3

Table 4 presents the summary of the model type 1 regression analysis of the traffic noise intensity prediction for location 3. Here, the coefficient of the distance from the centre of the roadway is negative implying that, as the distance of noise measurement from the roadway centre increased, the traffic noise intensity value decreased. The multiple linear regression model as obtained from the regression analysis displayed in Table 4 is thus given by Equation 3.

$$Traffic\ Noise(dB) = -0.05146D + 0.026169\ TV + 1.047805S \quad (3)$$

Where; D = distance from roadway centre
TV = PCU of traffic volume
S = average speed of vehicles

Table 4. Summary of Regression statistics of the Traffic noise modelling of Location 3

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997244
R Square	0.994496
Adjusted R Square	0.988784
Standard Error	5.466428
Observations	180

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	955699.5	318566.5	10660.87	9.7E-199
Residual	177	5289.086	29.88184		
Total	180	960988.6			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Distance (m)	-0.05146	0.097829	-0.52603	0.599528	-0.24452	0.1416	-0.24452	0.1416
Traffic volume (PCU)	0.026169	0.016674	1.569467	0.118325	-0.00674	0.059074	-0.00674	0.059074
Speed (km/hr)	1.047805	0.028712	36.49359	2.76E-84	0.991143	1.104467	0.991143	1.104467

3.3.4. Model Type I Development of Traffic Noise for Trunk A Flexible Pavements

Table 5 presents the summary of the model type 1 regression analysis of the traffic noise intensity prediction for Trunk A Flexible Pavements. Here, the coefficient of the distance from the centre of the roadway is negative implying that, as the distance of noise measurement from the roadway centre increased, the traffic noise intensity value decreased. The multiple linear regression model as obtained from the regression analysis displayed in Table 5 is thus given by Equation 4.

$$Traffic\ Noise(dB) = -0.07326D + 0.074056\,TV + 1.029669S \quad (4)$$

Where; D = distance from roadway centre
TV = PCU of traffic volume
S = average speed of vehicles

Table 5. Regression statistics of Traffic noise modelling of Flexible Pavements (Trunk A)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.997649
R Square	0.995303
Adjusted R Square	0.989601
Standard Error	5.20561
Observations	180

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1016455	338818.5	12503.28	8.5E-205
Residual	177	4796.412	27.09838		
Total	180	1021252			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Distance (m)	-0.07326	0.093927	-0.77998	0.436444	-0.25862	0.1121	-0.25862	0.1121
Traffic volume (PCU)	0.074056	0.018124	4.085961	6.65E-05	0.038288	0.109824	0.038288	0.109824
Speed (km/hr)	1.029669	0.031673	32.50981	1.51E-76	0.967164	1.092173	0.967164	1.092173

3.3.5. Model Type I Development of Traffic Noise for Trunk C Flexible Pavements

Table 6 presents the summary of the model type 1 regression analysis of the traffic noise intensity prediction for Trunk C Flexible Pavements (Location 4). Here, the coefficient of the distance from the centre of the roadway is negative implying that, as the distance of noise measurement from the roadway centre increased, the traffic noise intensity value decreased. The multiple linear regression model as obtained from the regression analysis displayed in Table 6 is thus given by Equation 5.

$$Traffic\ Noise(dB) = -0.02726D + 0.048429\,TV + 0.998035S \quad (5)$$

Where; D = distance from roadway centre
TV = PCU of traffic volume
S = average speed of vehicles

Table 6. Regression statistics of Traffic noise modelling of Flexible Pavements (Trunk C)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.991135
R Square	0.982349
Adjusted R Square	0.9765
Standard Error	6.171606
Observations	180

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	375212.7	125070.9	3283.673	3.3E-154
Residual	177	6741.705	38.08873		
Total	180	381954.4			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Distance (m)	-0.02726	0.109772	-0.24836	0.804145	-0.24389	0.189368	-0.24389	0.189368
Traffic volume (PCU)	0.048429	0.019672	2.461798	0.014782	0.009607	0.087251	0.009607	0.087251
Speed (km/hr)	0.998035	0.04728	21.10908	3.22E-50	0.90473	1.09134	0.90473	1.09134

3.3.6. Model Type I Development of Traffic Noise for Trunk C Rigid Pavements

Table 7 presents the summary of the model type 1 regression analysis of the traffic noise intensity prediction for Trunk C Rigid Pavements (Location 5). Here, the coefficient of the distance from the centre of the roadway is negative implying that, as the distance of noise measurement from the roadway centre increased, the traffic noise intensity value decreased. The multiple linear regression model as obtained from the regression analysis displayed in Table 7 is thus given by Equation 6.

$$Traffic\ Noise(dB) = -0.02248D - 0.02278\,TV + 1.188122S \quad (6)$$

Where; D = distance from roadway centre
TV = PCU of traffic volume
S = average speed of vehicles

Table 7. Regression statistics of Traffic noise modelling of Rigid Pavements (Trunk C)

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.988283
R Square	0.976703
Adjusted R Square	0.97079
Standard Error	7.803663
Observations	180

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	451882	150627.3	2473.471	1.4E-143
Residual	177	10778.8	60.89715		
Total	180	462660.8			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Distance (m)	-0.02248	0.140025	-0.16056	0.872625	-0.29882	0.253851	-0.29882	0.253851
Traffic volume (PCU)	-0.02278	0.020375	-1.11813	0.265025	-0.06299	0.017427	-0.06299	0.017427
Speed (km/hr)	1.188122	0.046594	25.49973	3.67E-61	1.096172	1.280072	1.096172	1.280072

3.3.7. Summary of Developed Models

All models developed in this study are hereby presented in Tables 8 and 9. The MLR models for every location were presented for easy access and evaluation in Table 8.

Table 8. MLR Models Developed in this study for Traffic Noise Prediction

S/N	Road Type	MLR Model
1	T.A; Location 1- Flexible Pavement	$-0.12252D + 0.04797\,TV + 1.11148S$
2	T.A; Location 2- Flexible Pavement	$0.028707D + 0.111535\,TV + 0.966019S$
3	T.A; Location 3- Flexible Pavement	$-0.05146D + 0.026169\,TV + 1.047805S$
4	T.A; Flexible Pavement- General	$-0.07326D + 0.074056\,TV + 1.029669S$
5	T.C; Flexible Pavement- General	$-0.02726D + 0.048429\,TV + 0.998035S$
6	T.C; Rigid Pavement- General	$-0.02248D - 0.02278\,TV + 1.188122S$

The collected data in appendices I to V were analyzed using ARIMA to predict models for traffic noise intensity in Port-Harcourt roads as follows; All the ARIMA models developed in this study are hereby presented in Table 9. The ARIMA models for every location were presented for easy access, comparison and evaluation.

Table 9. Models Developed in this study for Traffic Noise Prediction

S/N	Road Type	ARIMA Model		
		5m	10m	15m
1	T.A; Location 1- Flexible Pavement	ARIMA (0, 2, 8)	ARIMA (0, 2, 8)	ARIMA (0, 2, 1)
2	T.A; Location 2- Flexible Pavement	ARIMA (0, 2, 4)	ARIMA (0, 2, 4)	ARIMA (0, 2, 2)
3	T.A; Location 3- Flexible Pavement	ARIMA (0, 2, 1)	ARIMA (0, 2, 2)	ARIMA (1, 2, 3)
4	T.A; Flexible Pavement- General	ARIMA (0, 2, 1)	ARIMA (0, 2, 1)	ARIMA (0, 2, 1)
5	T.C; Flexible Pavement- General	ARIMA (0, 2, 1)	ARIMA (0, 2, 1)	ARIMA (0, 2, 1)
6	T.C; Rigid Pavement- General	ARIMA (0, 2, 4)	ARIMA (0, 2, 4)	ARIMA (0, 2, 4)

3.4. Discussion of Findings

3.4.1. Effect of Speed, Distance from Road centre and Traffic Volume on Traffic Noise Intensity Generation

As deduced from the analysis of the significance of traffic noise determinants considered in this study, the distance of noise measurement from the roadway centre is the most significant for all the category of pavement considered (in terms of p-value evaluation). This implies that the distance from the road centre has the most effect (though, negative) on the traffic noise generated from a roadway. This shows that a little change in the distance from the roadway centre will most drastically affect the traffic noise generation from such pavements. However, in terms of the model coefficients values, the average speed of vehicles seems to have the most telling effect on the traffic noise generation as higher coefficient values were obtained. This is an indication that as the average speed of vehicles increases, a significant positive change will be noticed on the pavement.

From the inspection of the traffic noise prediction models (MLR models), the effect of average speed of vehicles on traffic noise generation is more significant on rigid pavements as compared to that of flexible pavement as can be inferred from their coefficient values. This implies that when there is a similar increase in speed on a flexible pavement and rigid pavement, the increase in traffic noise is likely to be more on rigid pavements than flexible pavements. This can be attributed to the frictional force between the vehicle tires and the road surface with the grip being more in rigid pavement than flexible pavement.

3.4.2. Performance of Developed Traffic Noise Intensity Models

The regression analysis conducted on the MLR models produced very high adjusted R^2 values.
In the validation studies of the MLR models, specific distances were selected.

3.4.3. Traffic Noise Generation Comparison of Trunk A and Trunk C Flexible Pavements

From the analysis conducted to compare the traffic noise generated from Trunk A and Trunk C flexible pavements, traffic noise generation was generally more for Trunk A flexible pavements than Trunk B flexible pavements. This difference in noise generation values can be attributed to the traffic characteristics of both roadways. It has been established in this study, that traffic noise increases with increase in traffic volume and mostly traffic speed. The speed limit allowed for a

Trunk A flexible pavement is far higher than those allowed for Trunk C flexible pavements.

The percentage difference analysis revealed that although the Trunk A flexible pavement generally produced higher traffic noise, the noise difference is more in the morning and night hours as opposed to the difference in the day time hours. This may be attributed to the increase in the background noise which is basically more significant during the day as compared to the morning and night hours.

3.4.4. Traffic Noise Generation Comparison of Flexible and Rigid Pavements

As deduced from the analysis comparing the traffic noise generated from flexible and rigid pavements, traffic noise generated from rigid pavement are generally higher than those generated from flexible pavement. The difference in the noise generated can be attributed to the physical conditions of the roadways. Rigid pavements generally have more voids compared to flexible pavements, hence more noise production. Moreover, the interaction of vehicle tires with pavements is more in rigid pavements than flexible pavements.

In the percentage difference analysis, the morning hours offers the most significant difference between flexible and rigid pavements. This may also be attributed to reduction in the background noise in this period.

3.5. Validation and Comparison of ARIMA and MLR Models for Location 1

Figure 9 to Figure 11 presents the results of the analysis for the validation and comparison of Type I (MLR) and Type II (ARIMA) traffic noise prediction models for location 1 at the distances of 5m, 10m and 15m from the roadway centre [9]. From the various plots (Figure 9 to Figure 11), the R^2 for the Type II model were higher in comparison to the R^2 for the MLR model. For noise measurement at a distance of 5m from the road centre, a very low R^2 value of 0.2015(20.15%) was obtained as opposed to the very high R^2 value of 0.9574 (95.74%) obtained for the ARIMA model (Figure 9). In Figure 10, at a distance of 10m from the roadway centre, a R^2 value of 95.76% was obtained for the ARIMA model which is far higher than the R^2 value of 21.1% obtained for the Type I model. For a distance of 15m (Figure 11), R^2 value of 18.94% was obtained for the Type I model which is also far lower than the R^2 of 95.17% obtained for the ARIMA model.

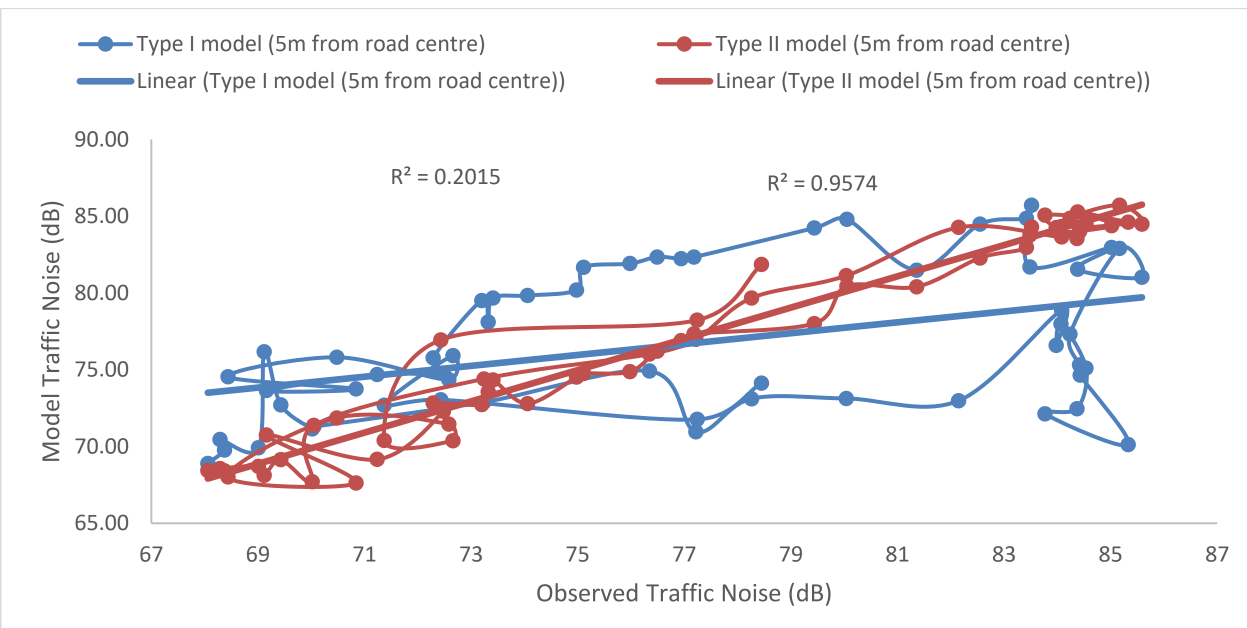

Figure 9. Validation of Traffic Noise Models for Location 1; Type I and II models (5m from road centre)

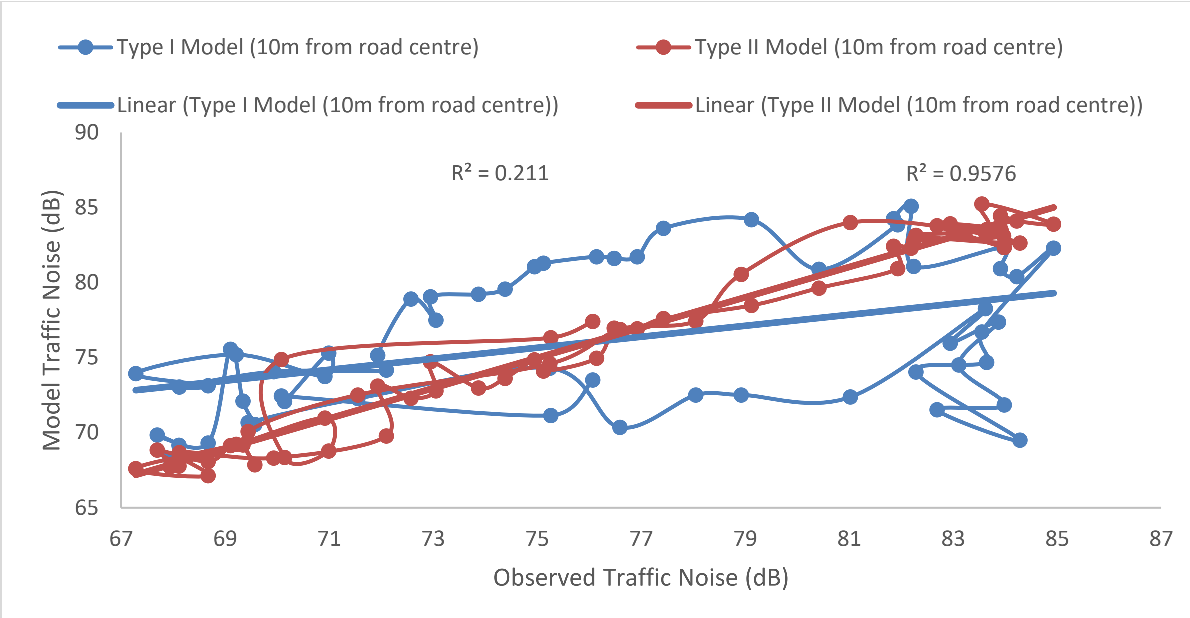

Figure 10. Validation of Traffic Noise Models for Location 1; Type I and II models (10m from road centre)

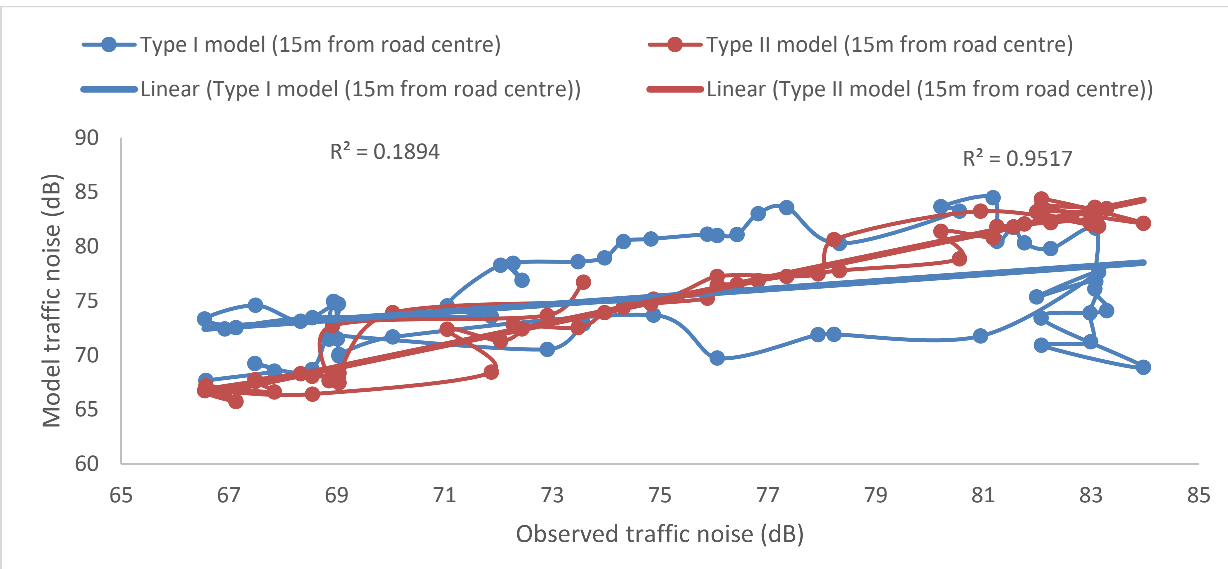

Figure 11. Validation of Traffic Noise Models for Location 1; Type I and II models (15m from road centre)

3.6. Validation and Comparison of Type I and II Models for Location 2

Figure 12 to Figure 14 presents the results of the analysis for the validation and comparison of Type I (MLR) and Type II (ARIMA) traffic noise prediction models for location 2 at the distances of 5m, 10m and 15m from the roadway centre. From the various figures (Figure 12 to Figure 14), the R^2 for the Type II model were also higher in comparison to the R^2 for the Type I model. For noise measurement at a distance of 5m from the road centre, a very low R^2value of 0.2203(22.03%) was obtained as opposed to the high R^2 value of 0.788 (78.8%) obtained for the Type II model (Figure 12). In Figure 13, at a distance of 10m from the roadway centre, a R^2 value of 79.5% was obtained for the Type II model which is far higher than the R^2 value of 22.75% obtained for the Type I model. At a distance of 15m (Figure 14), R^2 value of 19.83% was obtained for the Type I model which is also far lower than the R^2 of 74.46% obtained for the Type II model.

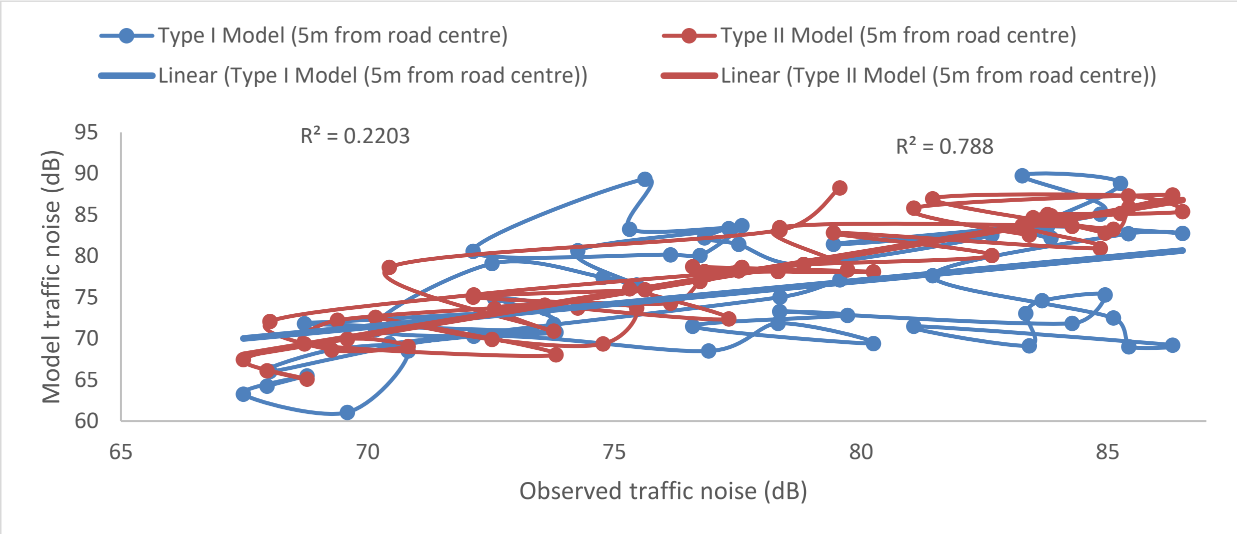

Figure 12. Validation of Traffic Noise Models for Location 2; Type I and II models (5m from road centre)

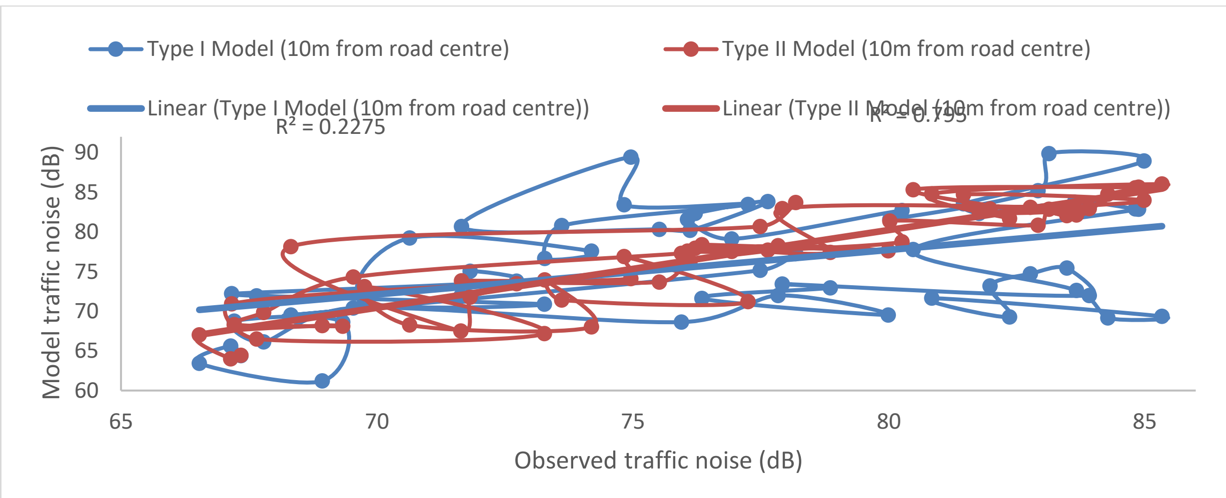

Figure 13. Validation of Traffic Noise Models for Location 2; Type I and II models (10m from road centre)

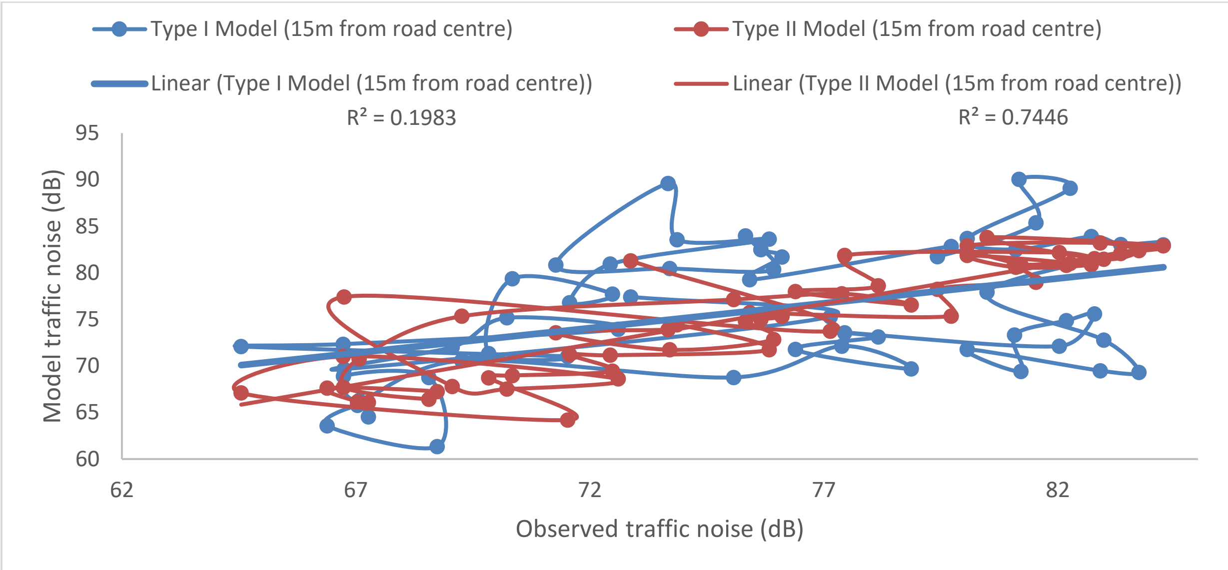

Figure 14. Validation of Traffic Noise Models for Location 2; Type I and II models (15m from road centre)

3.7. Validation and Comparison of Type I and II Models for Location 3

Figure 15 to Figure 17 presents the results of the analysis for the validation and comparison of Type I (MLR) and Type II (ARIMA) traffic noise prediction models for location 3 at the distances of 5m, 10m and 15m from the roadway centre. As can be noticed from the various figures (Figure 15 to Figure 17), although, the R^2 for the Type II model were lower in comparison to those from Location 1 and Location 2, they were far higher than those of the Type I model. For noise measurement at a distance of 5m from the road centre, a relatively good R^2 value of 0.4398(43.98%) was obtained but still fell short of the R^2 value of 0.6303 (63.03%) obtained for the Type II model (Figure 15). In Figure 16, at a distance of 10m from the roadway centre, a R^2 value of 55.15% was obtained for the Type II model which is higher than the R^2 value of 39.07% obtained for the Type I model. At a distance of 15m (Figure 17), R^2 value of 39.52% was obtained for the Type I model which is also lower than the R^2 of 52.37% obtained for the Type II model.

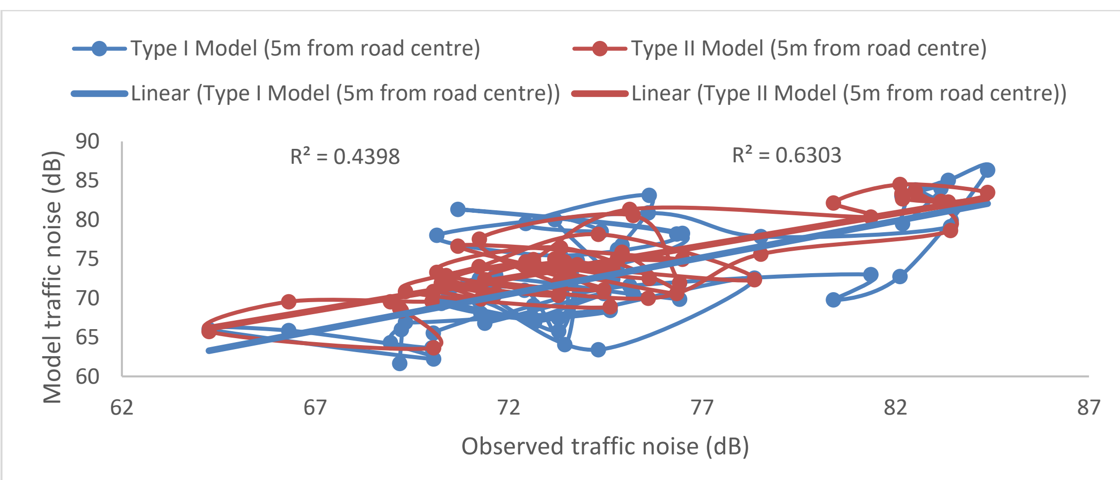

Figure 15. Validation of Traffic Noise Models for Location 3; Type I and II models (5m from road centre)

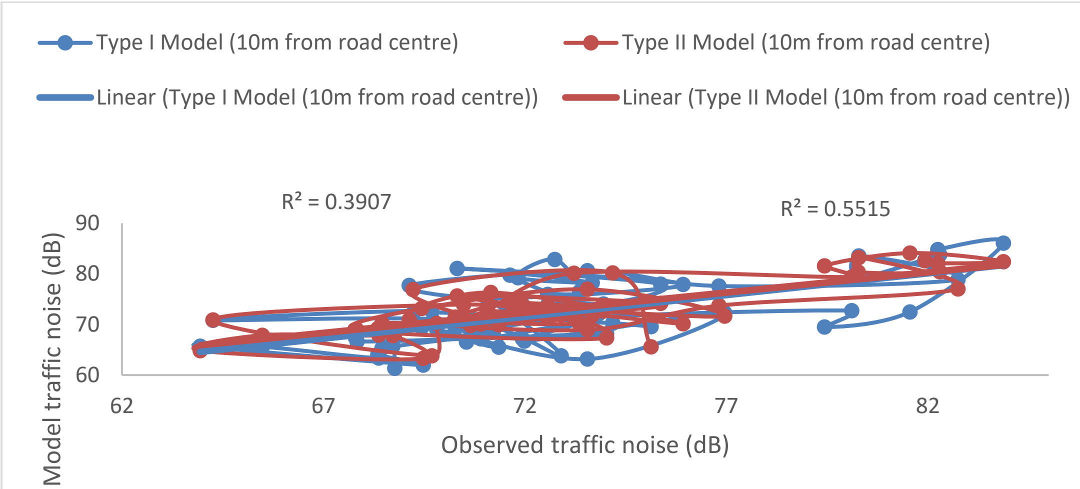

Figure 16. Validation of Traffic Noise Models for Location 3; Type I and II models (10m from road centre)

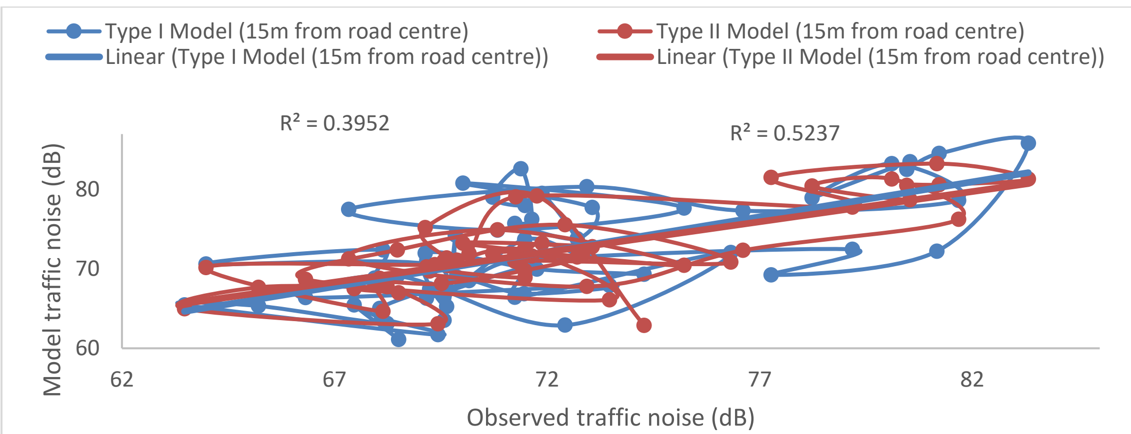

Figure 17. Validation of Traffic Noise Models for Location 3; Type I and II models (15m from road centre)

3.8. Validation and Comparison of Type I and II Models for Trunk A Flexible Pavement

Figure 18 to Figure 20 presents the results of the analysis for the validation and comparison of Type I (MLR) and Type II (ARIMA) traffic noise prediction models for Trunk A flexible pavement at the distances of 5m, 10m and 15m from the roadway centre. From the various figures (Figure 18 to Figure 20), which represents the overall evaluation of traffic noise for Trunk A flexible pavement, the R^2 for the Type II models were also higher in comparison to the R^2 for the Type I models. For noise measurement at a distance of 5m from the road centre, a low R^2value of 0.3427(34.27%) was obtained as opposed to the high R^2 value of 0.8713 (87.13%) obtained for the Type II model (Figure 18). In Figure 19, at a distance of 10m from the roadway centre, a R^2 value of 85.23% was obtained for the Type II model which is far higher than the R^2 value of 33.55% obtained for the Type I model. At a distance of 15m (Figure 20), R^2 value of 31.49% was obtained for the Type I model which is also far lower than the R^2 of 87.72% obtained for the Type II model.

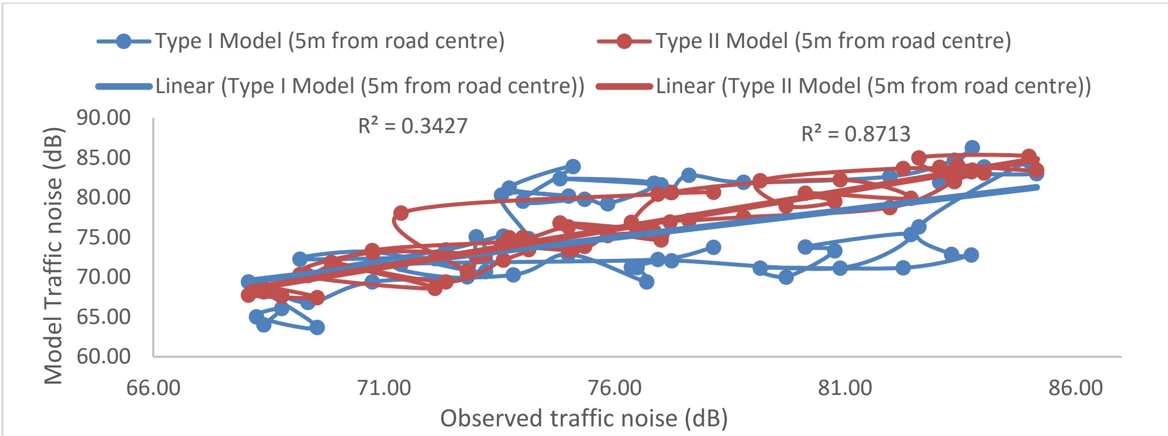

Figure 18. Validation of Traffic Noise Models for Trunk A Flexible Pavement; Type I and II models (5m from road centre)

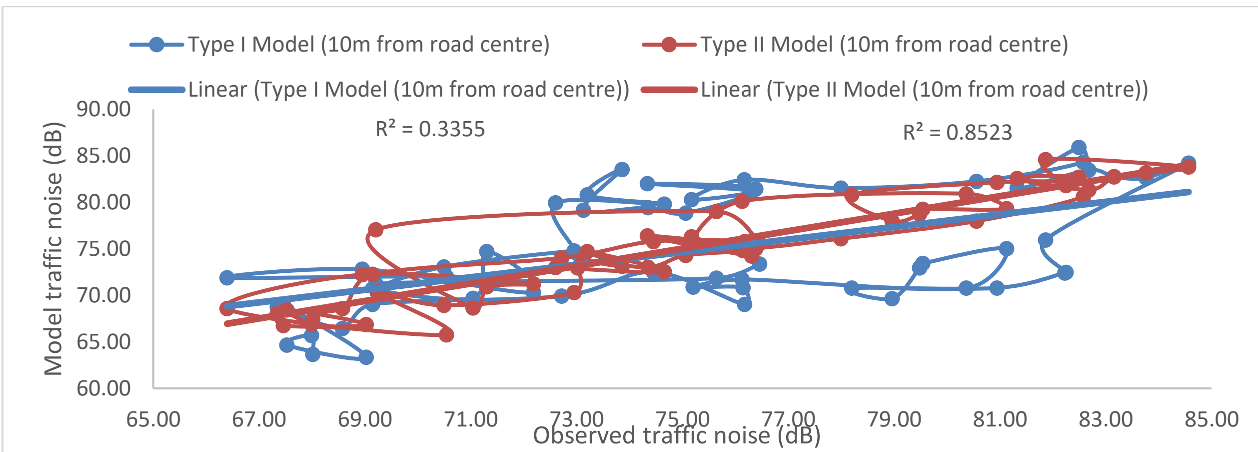

Figure 19. Validation of Traffic Noise Models for Trunk A Flexible Pavement; Type I and II models (10m from road centre)

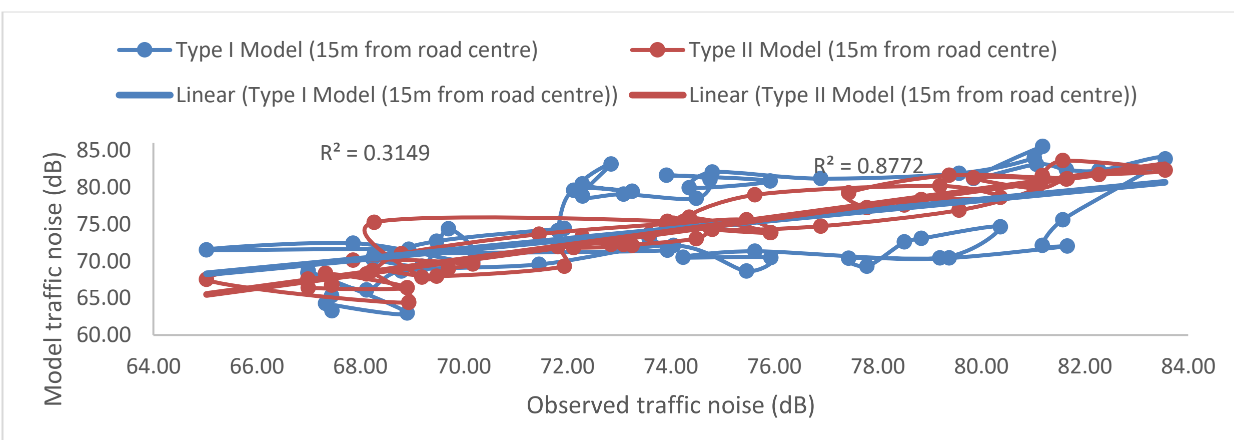

Figure 20. Validation of Traffic Noise Models for Trunk A Flexible Pavement; Type I and II models (15m from road centre)

3.9. Validation and Comparison of Type I and II Models for Trunk C Flexible Pavement

Figure 21 to Figure 23 presents the results of the analysis for the validation and comparison of Type I (MLR) and Type II (ARIMA) traffic noise prediction models for Trunk C flexible pavement at the distances of 5m, 10m and 15m from the roadway centre. From the various figures (Figure 21 to Figure 23), the R^2 for the Type II model were higher in comparison to the R^2 for the Type I model. For noise measurement at a distance of 5m from the road centre, a very low R^2 value of 0.1505(15.05%) was obtained as opposed to the high R^2 value of 0.8307 (83.07%) obtained for the Type II model (Figure 21). In Figure 22, at a distance of 10m from the roadway centre, a R^2 value of 83.5% was obtained for the Type II model which is far higher than the R^2 value of 15.26% obtained for the Type I model. At a distance of 15m from road centre (Figure 23), R^2 value of 14.41% was obtained for the Type I model which is also far lower than the R^2 of 83.61% obtained for the Type II model.

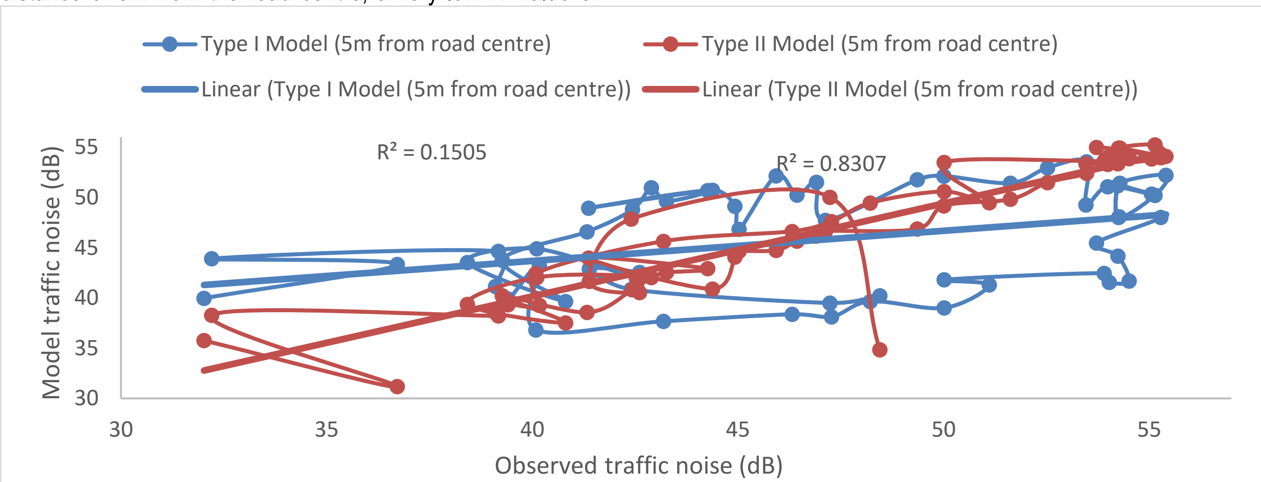

Figure 21. Validation of Traffic Noise Models for Trunk C Flexible Pavement; Type I and II models (5m from road centre)

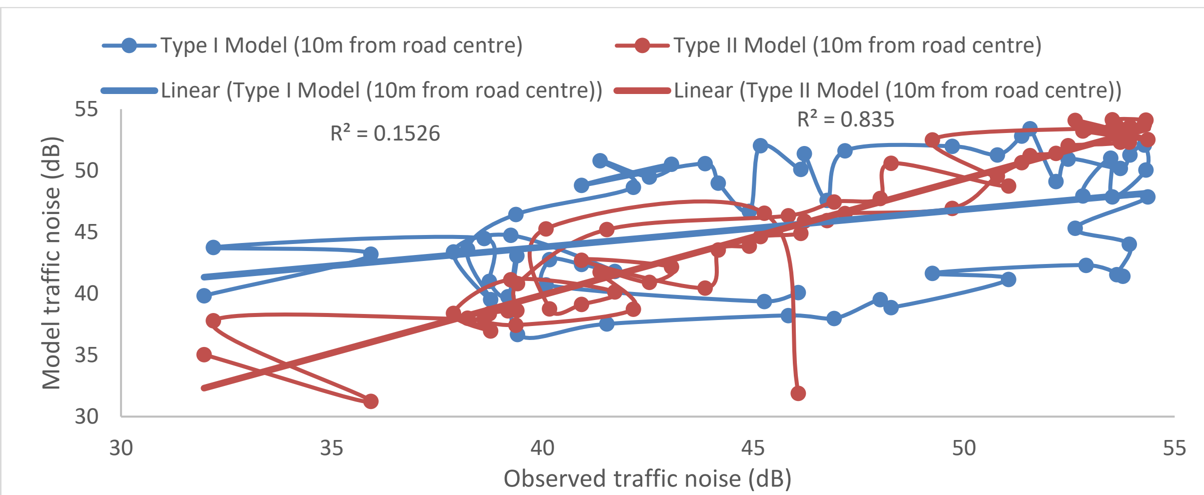

Figure 22. Validation of Traffic Noise Models for Trunk C Flexible Pavement; Type I and II models (10m from road centre)

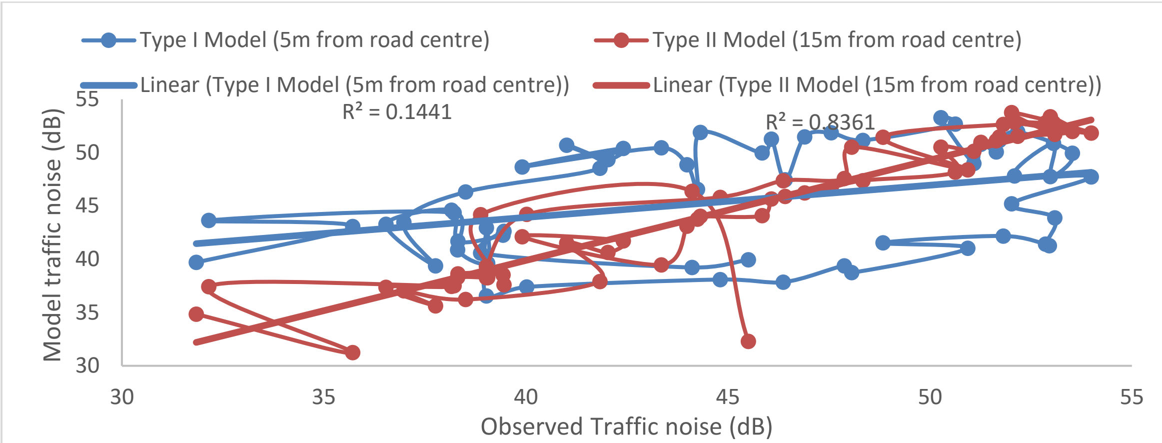

Figure 23. Validation of Traffic Noise Models for Trunk C Flexible Pavement; Type I and II models (15m from road centre)

3.10. Validation and Comparison of Type I and II Models for Trunk C Rigid Pavement

Figure 24 to Figure 26 presents the results of the analysis for the validation and comparison of Type I (MLR) and Type II (ARIMA) traffic noise prediction models for Trunk C rigid pavement at the distances of 5m, 10m and 15m from the roadway centre. For the Trunk C rigid pavement traffic noise models evaluation, the Type I model performed extremely badly. From the various figures (Figure 24 to Figure 26), at a distance of 5m from the road centre, a very low R^2 value of 0.002(2%) was obtained as opposed to the very high R^2 value of 0.876 (87.6%) obtained for the Type II model (Figure 24). In Figure 25, at a distance of 10m from the roadway centre, a R^2 value of 90.3% was obtained for the Type II model which is far higher than the R^2 value of 1.2% obtained for the Type I model. At a distance of 15m (Figure 26), R^2 value of 1% was obtained for the Type I model which is also far lower than the R^2 of 88.03% obtained for the Type II model.

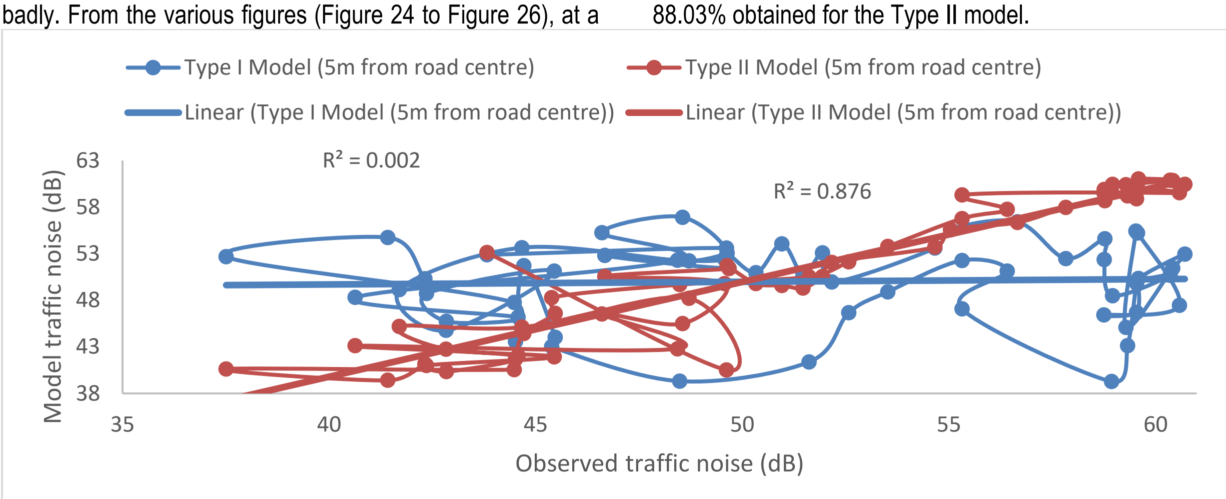

Figure 24. Validation of Traffic Noise Models for Trunk C Rigid Pavement; Type I and II models (5m from road centre)

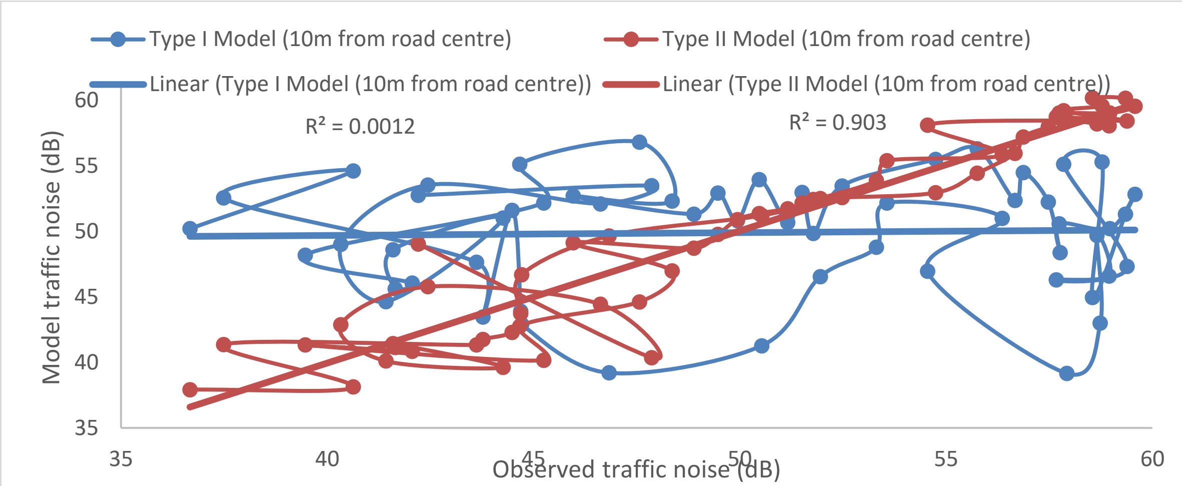

Figure 25. Validation of Traffic Noise Models for Trunk C Rigid Pavement; Type I and II models (10m from road centre)

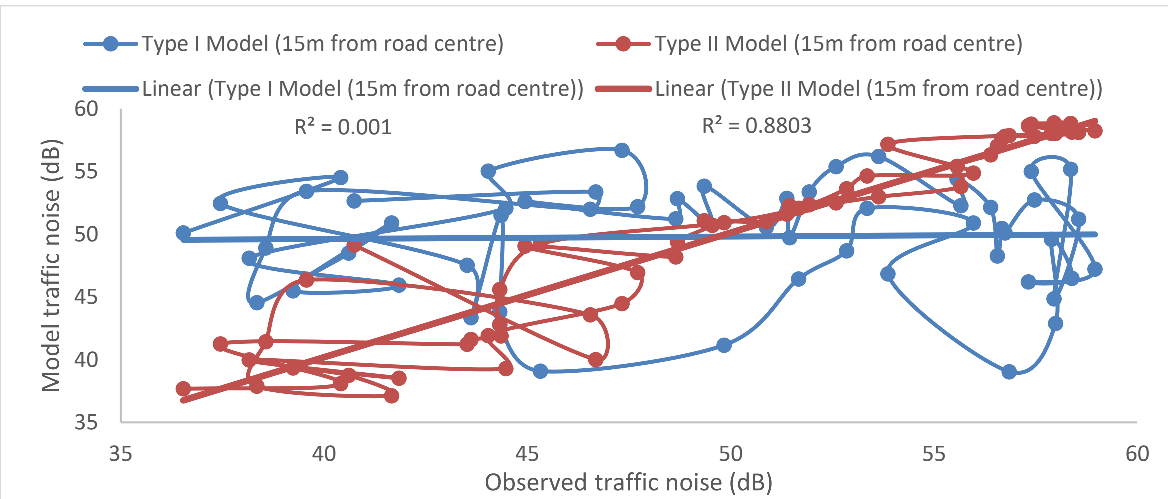

Figure 26. Validation of Traffic Noise Models for Trunk C Rigid Pavement; Type I and II models (15m from road centre)

3.11. Performance of Developed Traffic Noise Intensity Models (MLR and ARIMA)

The regression analysis conducted on the MLR (Type I) models produced very high adjusted R^2 values. The diagnosis analysis carried out on the ARIMA (Type II) models using correlograms, revealed that the models can be relied on in predicting the traffic noise generated from pavements. The diagnosis analysis made sure that the ARIMA model selected considered every detail in its development. In the validation and comparative studies of the Type I and Type II models, specific distances were selected such that the comparison of both model types can be made. From the analysis conducted, Type II models performed far better than the Type I models for all categories of pavements considered. In short for the rigid pavement types, the Type I models performed extremely badly as most of the R^2 values were below 3%. The Type II (ARIMA) models had very high R^2 values and were far better in performance. This can be attributed to the fact that ARIMA models uses the recent history of a variable to predict that variable while multiple linear regression models use the influence of other variables to perform the outcome of a particular variable. This is the main reason why the multiple linear regression (Type I) models performed poorly for case specific distances.

4. CONCLUSIONS

Following the discussions and outcomes of this study, the following conclusions can be drawn;

i. The selected road pavements for the traffic noise study were categorized into Trunk A flexible pavement as Location 1-3, while Location 4 and 5 were categorized as Trunk C to ascertain the differences in noise level between rigid and flexible pavements.

ii. In consideration of the p-value for traffic noise generation, distance from centre of the road way has more significant effect on traffic noise, though negative. However, when the model coefficients are given a higher consideration, the average speed of vehicles has a higher telling effect on the traffic noise generation. The average noise levels at various distances of flexible pavement location 1-3 and Trunk A flexible pavement evaluated exceeded the permissible limit of 70dB.

iii. The Type I (Multiple Regression Analysis) and Type II (ARIMA-Time Series Modelling) models developed in this study can be used for traffic noise prediction as evident from the regression analysis and the ARIMA (p, d, q) test carried out. Generally, the R^2 values of type II model were higher in comparison to the R^2 value for the type I model along selected routes.

iv. For case specific distances, the Type II models performed far better than the Type I models. The Type I models performed extremely badly as most of the R^2 values were below 3%. The Type II (ARIMA) models had very high R^2 values and were far better in performance. The following were achieved from the scatter plots and charts.
  a) The noise level increases with increased total number of vehicles in most cases.
  b) The noise level increases with increase in speed of vehicles in most cases.
  c) The noise level decrease with increase in distance.

v. Although the noise generated in a Trunk A flexible pavement is more than that from a Trunk C flexible pavement, this noise difference is higher in the morning and night hours. The noise level increases more on rigid pavements than that of flexible pavements, which is attributed to more voids on rigid pavements and the frictional force between the vehicle tires and road surfaces with the grip being more in rigid pavements.

5. RECOMMENDATIONS

The following recommendations are made;

i. Road side dwellers should avoid staying too long within areas less than 15 meters from the center of the road way.
ii. Traffic laws against horning in sensitive areas should be made and enforced to reduce traffic noise levels and right of way of busy routes should be made depending on the predicted noise levels of such routes.
iii. More states and roads can be covered in order to be able to satisfactorily predict noise generated from a flexible and rigid pavement of the Niger Delta in further works.

6. CONTRIBUTIONS TO KNOWLEDGE

After a successful completion of this work, the researcher has contributed enormously to knowledge in the following ways;

i. The multiple linear regression and ARIMA models developed can be used as standards in the prediction of traffic noise generated from rigid and flexible pavements.

ii. The period of highest percentage difference between Trunk A and C flexible pavements were revealed.

iii. The period of highest percentage difference between flexible and rigid pavement noise generation was also revealed.

Conflict of Interest Statement

There is no conflict of interest reported by the authors that could affect the publication of this research paper.

Data Availability Statement

The data supporting the outcome of this research has been reported in this work.

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