Comparison of Regression Model Concepts for Estimating Traffic Noise

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Authors’ contributions

This work was carried out in collaboration between both authors. Author AVE designed the study, wrote the protocol, carried out the field work, performed the statistical analysis, managed the analyses of the study and wrote the first draft of the manuscript. Author ATJ reviewed the draft and contributed to the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Traffic noise at two locations which are Rumuokoro and Rumuola in Port Harcourt city, Rivers state Nigeria was studied. The study was done for 3 days at each location. Variables such as atmospheric parameters and traffic density were measured along with the noise measurement. The atmospheric parameters measured were temperature, relative humidity and wind speed. Traffic density includes number of small cars and trucks per 20m radius. Three empirical model concepts were proposed, calibrated using multiple regression analysis and validated by cross validation and coefficient of determination ($R^2$). The models are a linear model, a polynomial model and an exponential model. The coefficient of determination for the linear model ranged from 0.25 to 0.94 at Rumuokoro and 0.29 to 0.86 at Rumuola. The coefficient of correlation for the polynomial model ranged from 0.062 to 0.998 at Rumuokoro and 0.05 to 0.998 at Rumuola. The coefficient of correlation for the exponential model ranged from 0.28 to 0.92 at Rumuokoro and 0.45 to 0.89 at Rumuola. The exponential model was concluded to be the best model concept because of its performance in predicting noise levels using data from other days with moderately high and consistent coefficient of determination at both locations. However, if extrapolation is not to be considered, the polynomial model concept is very useful.
1. INTRODUCTION

Noise may be seen as unwanted sound, consequently it can be considered as the wrong sound in the wrong place at the wrong time. Noise does affect aquatic life as well as humans in the natural environment [1]. It annoys and hurts people both psychologically and physiologically [2]. Noise health effects are the health consequences of elevated sound levels. It is possible that increased workplace noise or other noise can cause hearing loss, hypertension, ischemic heart disease, annoyance and sleep disturbances. Previous studies have shown that even though people in residential areas are exposed to the same noise level, annoyance and sleep disturbance may vary depending on their sensitivity [3,4]. Studies reveal too that possible changes in the immune system and birth defects have been attributed to noise exposure [5]. As one grows old, presbycusis may occur naturally [6]. In many developed nations the cumulative impact of noise is sufficient to cause hearing loss of a large number of people in their lifetime [7,8]. It is also observed that high noise levels can cause stress, increase workplace accident rates, and stimulate aggression and other anti-social behaviours [9].

There is a possibility that higher road traffic noise will raise the risk of heart diseases [10]. Aircrafts, vehicles, industries and listening to loud music over an extended period of time are the most significant sources of noise that affects human health. Environmental noise is not only harmful to humans, it also affects wildlife. Some animals are extremely sensitive to sound, and anthropogenic noise pollution can affect the way they communicate between each other, mate and hunt [11].

Fast growing vehicle population in urban areas in the recent years, has resulted in considerable increase in traffic on roads causing alarming noise pollution. Noise levels increases with traffic volume in an exponential manner [12]. Most people in Nigeria would not recognize noise as an insidious pollutant or attribute it to any physiological impacts, though they may consider it as nuisance during the sleeping hours [13,14]. In Port Harcourt city like many other developing cities, traffic noise pollution is a major component of environmental pollution and now it seems to have come to stay. It is possible that a model can be generated that predicts the noise pollution level with a given a traffic density. It is therefore the aim of this study to investigate three different model concepts that help determine traffic noise in the given location with associated atmospheric parameters and traffic density as independent variables.

2. MATERIALS AND METHODS

2.1 Area of Study

The study was carried out at two different intersections which are Rumuola and Rumuokoro with coordinates Longitude 7.004871, Latitude 4.831786 and Longitude 6.997744, Latitude 4.867166 respectively. Both locations are in Ohio / Akpor Local Government Area, Rivers State. This is as shown in Fig. 1. These sites are one of the busiest locations in Port Harcourt city on a daily basis. Rumuokoro intersection is where two major roads, East-West road and Ikwerre road intersect making it a very busy and high traffic area. Rumuola is a dual carriageway with a two lane overfly with vehicles going towards and from Abia State.

2.2 Sampling Method

A field reconnaissance was carried out to inform the authorities of the intended research, to get a picture of the study area and to identify possible obstacles to the research. Three (3) days were selected to be sampling days at each location. Sampling was done from 6am to 6pm for the 3 days at each location. Sampling period was for 15 minutes within every hour. Many studies rely on such short term measures and other work has also shown good repeatability of noise measurement durations as short as 5 minutes. 15 minutes averages, although slightly skewed, are reasonable approximates of longer term measures. Davies et al. [15] carried out a study to examine how representative of longer exposure periods 5 min samples were, by analysing an associated dataset containing 24h of consecutive 1 min average Leq’s at 30 roadside sites in Vancouver. A simulation study was run, where 5 minutes daytime averages were randomly extracted from the 30 sites and compared with 24 hours averages. The mean correlation was 0.97 and standard deviation was 2.0. Hence, a 15 minute sampling period was ideal for use in this study.
The following data were recorded at the site.

1. Atmospheric characteristics such as wind speed, wind direction, humidity and ambient temperature.
2. Traffic data based on various classifications of vehicles.
3. Noise level.

2.2.1 Atmospheric data

Atmospheric data such as air temperature and humidity was measured at the time of noise measurement. The air temperature in °C and humidity in % was recorded using a digital thermometer and a hand held digital thermohygrometer.

2.2.2 Wind speed

An Anemometer was used to measure the wind speed. Maximum values were taken during measuring time.

2.2.3 Traffic database

The traffic database is divided into two categories, namely road geometry and traffic flow. The road geometry includes road width and segment length. The traffic flow comprises vehicle type and traffic volume. The vehicle count was done hourly for various classifications of vehicles namely small cars, buses and trucks during the measurement time period of 12 hours on all sides of the road per 20m radius.

2.2.4 Noise measurements

For traffic noise problems it is useful to know the equivalent continuous sound level $L_{eq}$. Noise level was obtained using a sound level meter. The sound level meter was suitably calibrated before taking the measurements. The meter was placed at the median of the road at an elevation of approximately 1.2 meters. This is so as to capture noise levels from both carriages of the road.

The noise levels in decibels observed by each category of vehicles were recorded manually in a predesigned form. The speed of wind may affect the accuracy of this measurement, as such the sound level meter was provided with a windscreen for minimizing the influence of wind during the measurement. These screens are commonly spherical balls or porous foamed plastic that fit over the microphone, and will have negligible effect on the frequency response of the microphone. Readings was taken between 0 to 15 minutes every hour.
3. MATHEMATICAL METHODS

3.1 Model Derivation

Regressit, a statistical add-in in Microsoft Excel was employed to find the mathematical model with the best correlation to best predict noise levels. The model was based on the function.

\[ N = f(T, R, W, V_c, V_t) \]

Where;

- \( N \) = Noise level (dBA)
- \( T \) = Temperature (°C)
- \( R \) = Relative humidity (%)
- \( W \) = Wind speed (m/s)
- \( V_c \) = Number of Small cars per 20 m radius
- \( V_t \) = Number of Trucks per 20 m radius.

Scatter diagrams where plotted to find possible relationship between the variables. Trend lines were fitted to clearly visualize the relationships. These are shown as Figs. 2 to 6. A positive upward trend is observed in Figs. 2, 4, 5 and 6 while a negative downward trend is observed in Fig. 3. These scatter plots show that noise levels are directly related to ambient temperature, wind speed, number of cars and trucks. However, noise levels are inversely related to relative humidity.

Based on the relationships observed in the scatter diagrams, three model types were assumed. They are as follows:

**Linear Model:** A model in which the variables are combined linearly usually with an exponent of 1 is referred to as a linear model. Equation (1) shows the linear model concept that was used for noise prediction when the other random variables are known.

\[ N_1 = a_0 + a_1T + a_2R + a_3W + a_4V_c + a_5V_t \quad (1) \]

**Polynomial Model:** Models in which the variables are raised to a power greater than 1 are polynomial models. Equation (2) presents a polynomial model concept for noise estimation.

\[ N_2 = a_0 + a_1T + a_2R + a_3W + a_4V_c + a_5V_t + a_6T^2 + a_7R^2 + a_8W^2 + a_9V_c^2 + a_{10}V_t^2 \quad (2) \]

**Exponential Model:** Equation (3) presents an exponential model concept for noise estimation.

\[ N_3 = \frac{a_0 r^{a_1} W^{a_2} V_c^{a_3}(1+V_t)^{a_4}}{R^{a_5}} \quad (3) \]

Where \( a_0, a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9 \) and \( a_{10} \) are constants obtained from regression analysis.

The trend in modelling is to collate data, establish relations via mathematical equations, and calibrate such equation in the way of assigning values to associated constants and adopting such equation for predictions [16,17]. To obtain the polynomial and exponential model using Regressit, variable transformations were done to obtain the modified parameters. These modified parameters then served as predictor variables in the model formulation. The values of the measured noise levels (\( N_i \)) were compared with predicted values and the coefficient of correlation was calculated for the different model forms.

4. RESULTS AND DISCUSSION

4.1 Model Calibration/ Coefficient Estimation

Table 1 show the results obtained from the sampling location. Regressit, was used to estimate the various coefficients for Equations 1 to 3. To obtain the exponential model, the exponential functions will be first expressed linearly. This is as shown as Equation (4)

\[ \ln N = \ln a_o + a_1\ln T + a_2\ln W + a_3\ln V_c + a_4\ln(1+V_t) + a_5\ln R \quad (4) \]

Let \( \ln a_o = b \) (intercept)

Therefore \( a_o = e^b \)

4.2 Model Validation

Cross validation was used to validate the models. Data for each day was used to calibrate the model types assumed and each model was used to fit data from other days. The coefficients of determination \( R^2 \) was then obtained. Tables 1 and 2 show the coefficients of determination obtained from the cross validation process. Observations made from Table 1 show that a linear model produced coefficients of determination ranging from 0.25 to 0.94. However, the cross validation process shows that the \( R^2 \) value of 3 out of 9 dataset were below 0.5 which was chosen to indicate moderately correlated. The polynomial model
of the second order has correlation estimates with values ranging from 0.062 to 0.998. This model type failed to adequately predict Noise levels from other days as can be seen in the low R^2 values. However, it shows good fit with the data used in its calibration which could be due to redundancy of the transformed independent variables. The exponential model has coefficients of determination ranging from 0.28 to 0.92. This model type performed better when compared with the previous models as it was able to predict Noise levels from 7 out of 9 dataset at other days with R^2 above 0.5.

Table 2 shows that the linear model at Rumuola has coefficients of determination ranging from 0.29 to 0.86. At this location, the linear model failed to adequately predict Noise levels for other...
days as can be seen in the low correlation estimates except with the data used in its calibration. The polynomial model of the second order has correlation estimates with values ranging from 0.05 to 0.998. This model type showed good correlation with 5 of the 9 dataset which was mostly the data used in its calibration. The exponential model has correlation coefficients ranging from 0.45 to 0.89. This model type performed better at this location just as at the previous location when compared with the other models as it showed good correlation with 8 of the 9 dataset with all the values above 0.6.

Table 1. Coefficient of determination “R²” at Rumuokoro from cross validation

| Model type | Model description | Day 1 R² | Day 2 R² | Day 3 R² |
|------------|-------------------|----------|----------|----------|
| Linear     | N₁ = a₀ + a₁T + a₂R + a₃W + a₄V₉ + a₅Vᵣ | 0.84     | 0.28     | 0.75     |
|            |                   | Day 2    | 0.57     | 0.43     | 0.61     |
|            |                   | Day 3    | 0.67     | 0.25     | 0.94     |
| Polynomial | N₂ = a₀ + a₁T + a₂R + a₃W + a₄V₉ + a₅Vᵣ + a₆T² + a₇R² + a₈W² + a₉V₉² + a₁₀Vᵣ² | 0.998    | 0.15     | 0.48     |
|            |                   | Day 2    | 0.33     | 0.91     | 0.062    |
|            |                   | Day 3    | 0.29     | 0.11     | 0.99     |
| Exponential| N₃ = \(a₀T^{a₁W^{a₃Vᵣ^{a₄}(1+V₉)^{a₅}}}/R^{a₆}\) | 0.87     | 0.34     | 0.58     |
|            |                   | Day 2    | 0.71     | 0.54     | 0.67     |
|            |                   | Day 3    | 0.72     | 0.28     | 0.92     |

Fig 7. Exponential model at Rumuokoro

Fig 8. Exponential model at Rumuola
Plots of estimated variables and actual variables were made as seen in Figs. 7 and 8 using the exponential model for Rumuokoro and Rumuola location. The plot is seen to almost line on top of the actual values which is an indication of the measure of the goodness of fit. Clearly this model type fits the Noise data well.

5. CONCLUSIONS

It can be concluded from the multiple regression analysis done on traffic noise and atmospheric data that an Exponential model as shown in Equation 3 is the best model concept for estimating traffic noise where temperature, relative humidity, wind speed and traffic density (small cars and trucks) are the independent variables. Coefficient of determination (R²) as high as 0.92 can be achieved using this model type. However, if extrapolation is not considered, the results also show that the polynomial model is very useful in predicting Noise levels coefficient of determination as high as 0.998.

The researchers recommend that other variables can be considered in improving the model. Variables such as vehicle speed, the number of mini vehicles and the percentage of vehicles that are over 3 years could be considered.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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