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Development of a Road Traffic Noise Prediction Model

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ABSTRACT

Environmental noise is an undesirable byproduct of urbanization. Although we do not notice, this unwanted or excessive sound makes a significant damage to the health of the people and has hazardous impacts on the environment. From the noise sources we interact daily, perhaps the most invasive and difficult to avoid noise source is the transportation noise. The major contributor to the transportation noise is highway traffic noise.

The objective of this work is to develop a road traffic noise prediction model for the roads of Sri Lanka. The developed model is capable of predicting the combined traffic noise generated from vehicles in highways. Traffic flow data used for constructing this model consisted of vehicle noise, vehicle class, vehicle speed and the distance from the traffic flow line was collected from several locations of the Western Province. Microsoft .Net® platform was used for the development of the simulator and the GUI. The predictions made by the model were found to be within ±11dBA accuracy with respect to the actual experimental observations.

1. INTRODUCTION

Highly industrialized living style of modern societies has produced a dramatic impact on the environment. Today, the environment noise has become a worldwide problem. The major contributor to the environment noise is the highway noise. The urbanization and adaptation characteristics of humans have made it difficult to identify the long-term impact due to noise pollution. Although the road noise is not usually loud enough to cause hearing problems, continuous exposure to unacceptable noise levels can create depression, sleep disturbance, annoyance and adverse health effects [1]. According to the WHO [2], the environment noise costs societies 0.2%-2.0% of the gross domestic product (GDP).

In a developing country such as Sri Lanka not much attention has been paid to health hazards due to environment noise. Although the standards for the environment noise is well established [3-7], with the increasing traffic volumes and frequent traffic congestion on urban roads, to our knowledge, attention has been so far paid to improve the traffic flow rather than the noise pollution. The National Environmental Act No. 47 of 1980 [8] has set the maximum permissible noise levels at the boundary of the land in which any source of noise is located. Environmental Impact Assessment (EIA) of Southern Colombo-Katunayaka Expressway Development Project [9] and EIA of Southern Extension of the Baseline Road Project [10] contain some studies on traffic noise carried out by the National Building Research Organization (NBRO). However, independent research related to traffic noise studies is scarce for Sri Lanka. The work presented in this paper is an extension to the initial work carried out at the Department of Physics, University of Colombo in 2002 which produced basic parameters that are essential in modeling vehicular traffic noise levels [11].

Studies on road traffic noise prediction for Asian countries are available on literature [12, 13]. These studies discuss the methodology adopted in the development of traffic noise prediction models for highways. The equivalent noise levels (Leq) for free-flowing traffic in highways can be estimated from these models. A recent study on the problem of traffic noise on urban settings has also been documented elsewhere [14].

2. EXPERIMENTAL PROCEDURE

At the onset of the project, measurement of traffic noise levels from several selected locations was carried out. The factors that affect traffic noise can be categorized as Traffic factors, Metrological factors and Measuring Site factors. A brief description of these factors that are relevant to this work is given below.

Traffic Factors: In this work the traffic is divided into eight main groups, Bus, Car, Double cab, Jeep, Lorry, Motor cycle, Three-wheeler and Van. It was assumed that only these vehicle types contribute to the highway traffic noise and that all vehicles can be categorized into one of these classes. It should be noted that the noise levels can vary even within the selected categories. Mode of operation of vehicles also affects the noise levels. An accelerating vehicle may produce a different level of noise than a vehicle moving at steady speed. Traffic volume and condition of the vehicles can also increase the noise level.

Metrological Factors: Sound levels are affected by meteorological conditions such as wind, temperature and humidity. To minimize the effect from the wind a special windscreen made out of porous polyurethane sponge was used over the microphone. Atmospheric attenuation of the noise reduces the noise level when traveling through the air. Ambient temperature, relative humidity and ambient pressure influence the noise levels too. In all measuring sites air temperature was within the range of -10 °C to 50 °C and humidity was approximately 90%.

Measuring Site Factors: The measuring site may have different conditions that could affect the noise measured. The condition of the road, the adsorption of noise waves by the ground and obstacles such as buildings, walls, trees that reflects sound would affects the measurement. The residual noise generated by other sound sources in the measuring area is a major influence to the noise level and should be minimized as possible.

When selecting the measuring site all possible precautions should be taken to minimize some of the affects mentioned above. These factors are,

- Minimum influence of reflection
- Minimum residual noise
- Good road conditions
- Good free flow of traffic

In this project traffic noise levels were measured in several selected sites located in the Western Province. These sites have different road conditions that cover most of the highways of Sri Lanka.

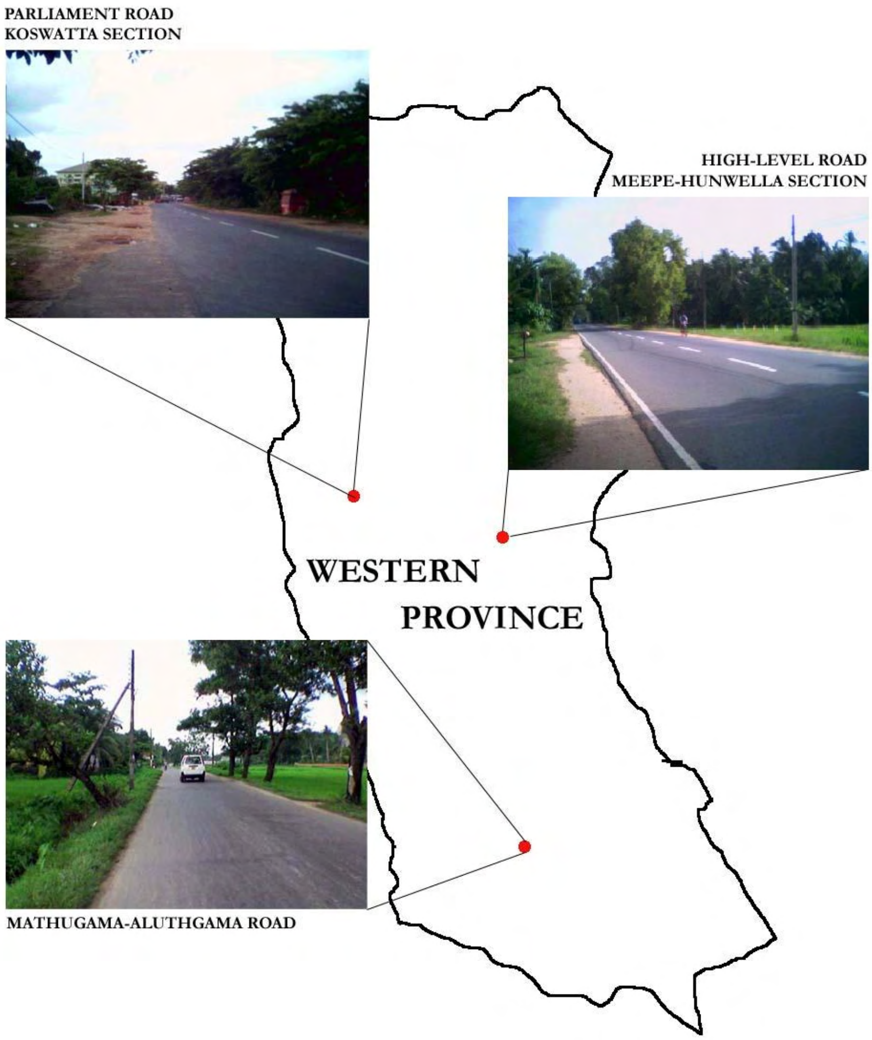

Figure 1: Site map showing the selected locations

Measuring Equipment: Following equipments were used in this project for data collection and measurements. Technical details of these equipments are given in reference [15].

- RION NL-04 Integrating sound level meter for noise level measurements
- Radar speed gun for speed measurements
- Standard 50m plastic tape for distance measurements
- Q&Q sports stop watch for time measurements

Uncontrolled Traffic Approach: In the uncontrolled approach, the only controlled parameter by the researcher is the distance from the middle of the road to the recipient. The flow of traffic is not disturbed. Noise level at a selected distance from the middle of the road and the speed is measured from each isolated vehicle that uses the road. The measurements are repeated for different distances from the centre of the road. Then the collected data can be categorized and analyzed to investigate the variation of noise level with the speed and the distance.

In this work, it was decided to use the uncontrolled traffic approach. Vehicles were categorized into eight types as Bus, Car, Double cab, Jeep, Lorry, Motor cycle, Three-wheeler and Van. Six measuring distances were selected, namely, 2.5m (L_1), 5.0m (L_2), 7.5m (L_3), 10.0m (L_4), 12.5m (L_5) and 15.0m (L_6). Noise and speed measurements were taken from isolated vehicles for each distance.

Since under uncontrolled approach, the traffic flow is not disturbed and data are collected under real conditions, a more realistic model development is possible than using the controlled approach.

3. DESIGN OF THE NOISE MODEL

In this work, a total of 650 data pairs were collected from eight different vehicle categories. Contribution of each vehicle type to the data sample is shown in figure 2.

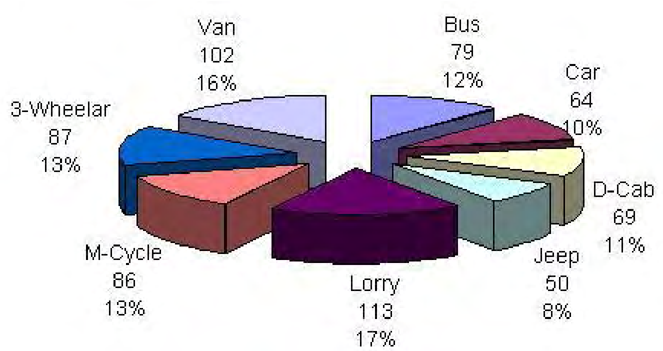

Figure 2: Contribution of each type of vehicle category

Fitting a general model requires knowing the equation of the function that describes the variation of noise levels with dependent variables and initial estimation of the parameters. This can be carried out by fitting models to each vehicle type for each dependent variable individually by keeping the remaining variables fixed. Previous work [10] has shown that the noise variation with the distance of the vehicle is in logarithmic form and the noise variation with the speed of the vehicle is in linear form. Since these are the only two dependent variables, individual models were fitted for all 8 vehicle types. The results are summarized in table 1.

Table 1: Results of parameter determination from individual models

Vehicle Type	Variation With Distance (y=noise in dB, d=distance in m)	Variation With Speed (y=noise in dB, s=speed in kmh^{-1})
Bus	y = -16.397Ln(d) + 83.69	y = 0.5947s + 21.28
Car	y = -16.748Ln(d) + 74.16	y = 0.9260s + 03.28
Double-Cab	y = -23.931Ln(d) + 86.64	y = 0.4420s + 17.60
Jeep	y = -13.569Ln(d) + 75.53	y = 0.0810s + 51.06
Lorry	y = -14.714Ln(d) + 78.03	y = 0.0972s + 52.69
Motorcycle	y = -16.214Ln(d) + 75.69	y = 0.5626s + 22.75
Three-wheeler	y = -17.895Ln(d) + 81.69	y = 1.0225s + 10.63
Van	y = -18.094Ln(d) + 81.14	y = 0.6568s + 25.59

In figure 3 and 4 we show the fitted results for one vehicle type, CAR. Similar results were observed for all vehicle types.

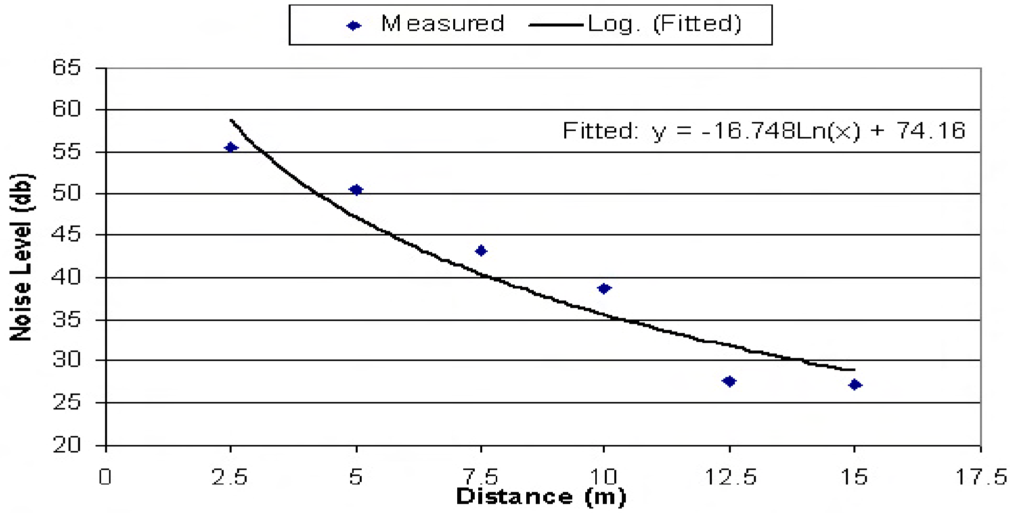

Figure 3: Variation of noise level with distance for CAR at speed 40 kmh^{-1}

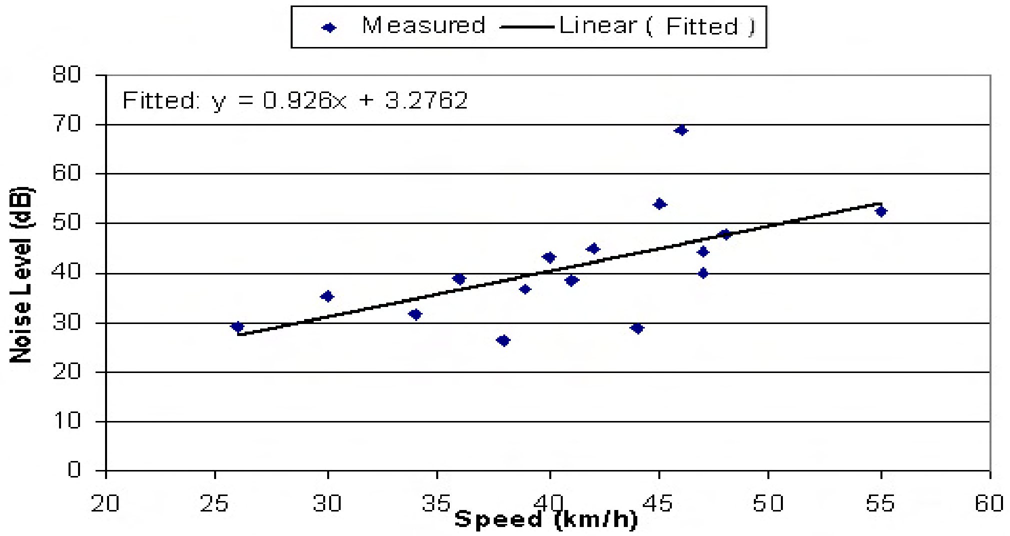

Figure 4: Variation of noise level with speed for CAR at distance 7.5 meters

Above graphs demonstrate that vehicular noise is varying logarithmically with distance and linearly with speed of the vehicle. Note that data contains different vehicles for each individual measurement and thus, the measurements can sustain a substantial scatter from ideal behaviour.

For the general design of the model, the statistical package S-PLUS® was used. Linear regression models, model a numeric response variable, y, as a linear combination of predictor variables, x_j, for j=1,...,p. A linear regression model has the form:

$$y_i = \beta_0 + \sum_{j-1}^{p} \beta_j x_{ij} + \varepsilon_i$$

for i=1,2,...,n, where n is the number of observations, and ε_i is the error for the i[th] observation. To make inferences regarding the fitted parameters of the model, the following assumptions were made.

- The ε_i are independent and identically distributed.
- The ε_i have mean zero and (finite) variance, σ^2.
- The ε_i are distributed according to the normal distribution.

Least-squares estimates of the coefficients in the model, $\hat{\beta}_j$: j=0,1,...,p are determined by minimizing the Residual Sum of Squares relative to the coefficients.

For the regression, measured noise values of vehicle types were given as the dependent variables and distance and speed as independent variables. The general formula for the developed model was in the form:

$$N = a_0 s + b_0 \ln(d) + c_0$$

where a_0, b_0 and c_0 are constants, s is the speed and d is the distance. Final model fitted parameters for each type of vehicle are given in table 2.

Table 2: Model parameters and coefficients for each vehicle type

Vehicle Type	Formula For Noise (y=noise in dB, s=speed in kmh^{-1}, d=distance in m)	±Std. Error (dB)
Bus	y = 53.07 + 0.7772s - 16.58Ln(d)	9.50
Car	y = 44.56 + 0.5047s - 12.84Ln(d)	8.66
Double-Cab	y = 60.05 + 0.4009s - 17.32Ln(d)	7.46
Jeep	y = 67.23 + 0.2206s - 13.24Ln(d)	6.92
Lorry	y = 79.89 + 0.1812s - 20.06Ln(d)	8.62
Motorcycle	y = 56.42 + 0.4476s - 15.48Ln(d)	6.42
Three-wheeler	y = 60.64 + 0.4692s - 17.04Ln(d)	8.27
Van	y = 73.98 + 0.0447s - 14.80Ln(d)	8.47

4. VALIDITY OF THE MODEL

4.1 Paired *t*-Test

The paired *t*-test was used for testing of the model for goodness-of-fit. First, *t*-test was carried out for each type of vehicles individually. Paired *t*-test yields that *t*-statistic values are less than the 5% significant for all types of vehicles. That means, the predicted noise levels fit well with the measured traffic noise data for individual vehicles.

Next, *t*-test was carried out for all the 650 data pairs together and a *t*-statistic value less than 5% significant level was observed. This implies that the noise levels fit well with the measured traffic noise data.

4.2 Dimensional Test

A dimensional test was also applied to test the model results (see figure 5). This graphical method tests the deviation of data from the predicted and measured values of traffic noise is on a 45 degree line. When the standard deviation of all 650 data pairs were taken, the model gives ±10.91 dB as the prediction error.

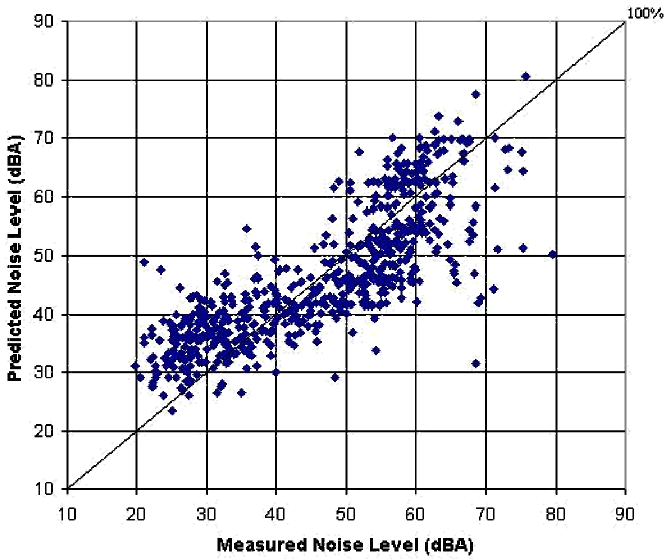

Figure 5: Dimensional test of the model

4.3. Simulation

Using the developed model results, a software simulator was implemented to use as a tool to predict noise levels near traffic routes. The developed simulator software is capable of simulating any number of vehicles in any of the vehicle types discussed earlier with different speeds. The simulation calculates the real time noise levels of measuring points L_1, L_2, L_3...L_6 and indicates the maximum noise levels observed for those points. The simulator is also capable of generating the noise contour maps in the vicinity of the traffic route and make predictions. Microsoft C#.Net® platform was used as the development environment for the simulation software.

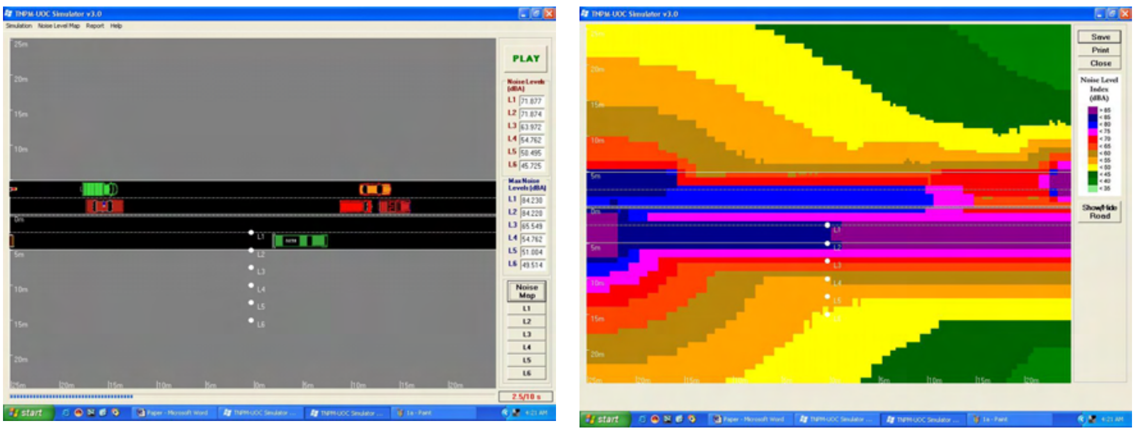

Figure 6: Traffic simulator main screen and noise contour map

5. SUMMARY AND CONCLUSIONS

In this work, the vehicular traffic noise behavior with distance and spot speed was analyzed and presented for eight types of vehicles. The development of a model capable of predicting noise levels in the vicinity of vehicular routes for a given traffic volume was discussed. The work shows that the model is capable of predicting the combined traffic noise with a varying traffic volume, speed and distance with an accuracy of better than ±11 dB.

6. REFERENCES

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