A Study of Transport Related Noise Pollution in Delhi

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In rapidly urbanishing country like India, the transportation sector is growing rapidly and the number of vehicles on Indian roads is increasing at a rate of more than 7% per annum. This has led to overcrowded roads and pollution. Transportation sector is one of the major contributors to noise in urban area, according for as much as 55 percent of the total noise on highway. In this study, three different models for noise prediction have been used, namely, FHWA Model, CORTN Model and Stop- and - Go Model. These models have been used to predict the noise level for an urban area. The data collected at eight different sites in Delhi has been analysed and compared with the values predicted by each of three different models. After comparision of the result, it was observed that both FHWA and CORTN Models could be satisfactorily applied for Indian condition as they give acceptable result with a deviation of 1dB(A)- 7dB(A) for FHWA and 1dB(A)- 4dB(A) for CORTN Model. In addition, statistical analysis has been done on the data between measured and predicted values and a good agreement was obtained. Also, a regression model for prediction of noise level was developed from the data collection in eight different location in Delhi.

Keywords : Noise pollution; Noise prediction model

INTRODUCTION

General

Sound is created when an object moves: the rustling of leaves as the wind blows, the air passing through vocal chords, the almost invisible movement of the speakers on a stereo. The movements cause vibrations of the molecules in air, in waves like ripples on water. When the vibrations reach ears, it is known as sound. Sound is quantified by a meter which measures units called decibels, dB(A). For highway traffic noise, an adjustment, or weighting, of the high and low- pitched sounds is made to approximate the way that an average person hears sounds. The adjusted sounds are called A- weighted levels dB(A). The A- weighted decibel scale begins at zero. This represents the faintest sound that can be heard by humans with very good hearing. The loudness of sounds varies from person to person, so there is no precise definition of loudness. However, based on many tests of larger numbers of people, a sound level of 70 is twice as loud to the listener as a level of 60[1].

Noise Level Descriptors

Most common traffic noise descriptors are L_{10}, L_{50}, L_{90}, and L_{eq}. L_{10} gives indications of the top end of the level range although it can substantially be less than the occasional peak. L_{90} correspond to the backward noise level in the absence of nearby noise sources. L_{eq} is the equivalent continuous sound level contains the same quantity of sound energy over a defined time period as the actual time varying sound level.

Equivalent Energy Level

The eqivalent energy level L_{eq} is the energy means of noise sample and is calculated from the expression:

$$L_{eq} = 10 \cap_i P_i 10^{\frac{L_i}{10}} \quad (1)$$

Where L_i is the median sound pressure level of the i th measuring interval of stoical analysis of sound; and P_i the probability of the sound level lying in the i th interval.

For a Gaussian distribution of noise level with a standard deviation of S the following relationship hold[2]

$$L_{eq} = L_{50} + \frac{\mathbf{S}^2}{8.68} \quad (2)$$

$$L_{eq} = L_{50} + \frac{(L_{10} - L_{90})^2}{56} \text{ dB}(A) \quad (3)$$

Ambient Noise Standards

With rapid urbanization and the corresponding increase in the number of vehicles on Indian roads, the pollution is increasing at an alarming rate in most of our Indian metropolitan cities. More than 55% of the total noise in our environment is due to vehicular noise. The noise levels are showing an alarming rise and in fact the levels exceed the prescribed levels in most of the areas. The ambient noise standards being followed in India for different types of areas are given in Table 1.

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Table 1 Ambient noise standards (India)[3]

Area	Leq dB(A)	
	Day Time	Night Time
Industrial area	75	70
Commercial area	65	55
Residential area	55	45
Silence zone	50	40

Factors Affecting Traffic Noise

The level of highway traffic noise depends mainly on the volume of the traffic, the speed of the traffic, and the number of heavy vehicles in the flow of the traffic.

Objectives

(i) To conduct field studies for interrupted traffic at eight selected locations in New Delhi which is representative of the entire urban area and to determine the ambient noise level at these locations.

(ii) To fit the collected data into various empirical models for noise prediction, *i e*, Federal Highway Administration (FHWA) Model, Calculation of Road Traffic Noise (CORTN) Model and Stop-and-Go Model and to determine the predicted noise levels from these models.

(iii) To compare the predicted noise level values with observed data and to evaluate the suitability of these models for Indian conditions.

(iv) To develop an analytical model for noise level prediction using regression analysis.

RESEARCH REVIEW

FHWA Model

Traffic noise levels in the vicinity of roadways can be predicted on the basis of individual vehicle noise levels, vehicle volume and speed, observer distance and other correlations[3].

The actual FHWA Model is in the form given below

$$L_{eq} = L_0 + A_{vs} + A_D + A_B + A_F + A_G + A_S \quad (4)$$

where L_{eq} is hourly equivalent sound level; L_0, the reference energy mean emission level; A_{vs}, volume and speed correction; A_D, distance correction; A_B, barrier correction; A_F, flow correction; A_G, gradient correction and A_S, ground cover correction.

CORTN Model

For calculation of L_{10}, based on CORTN Model, first of all the basic noise level is calculated at a reference distance of 10 m away from the nearside of the carriageway edge. Basic noise level is obtained from the traffic flow, speed of the traffic, composition of the traffic, gradient of the road and the type of road surface[3].

The basic L_{10} value is calculated

$$L_{10} = 42.2 + 10 \log_{10} \text{dB(A)} \quad (5)$$

where q is total flow of vehicles in veh/h.

The hourly L_{10} value is calculated as

$$L_{10} = L_0 + A_{HV} + A_D \quad (6)$$

where L_0 is basic noise level dB(A); A_{HV}, adjustment for mean traffic speed and percentage of heavy vehicles; and A_D, distance correction.

STOP and GO Model

There are two analytical approaches for uninterrupted traffic flow noise: single model analysis and the separated model or dual model analysis.

Single Model Analysis

The single model approach was the first analysis applied to build a single stop-and-go traffic flow noise model. This can be applied to both sides of an urban roadway. The model developed in this study is given[4] in equation[6].

$$L_{eq}=71.05+0.10S_n+0.95 \log V_n+0.04S_f$$
$$+0.015 \log V_f - 0.111D_g \quad (7)$$

where L_{eq} is equivalent traffic noise level in 1 hour, dB(A); S_n, mean speed of traffic on near side of observer (both sides of roads), km/h; S_f, mean speed of traffic on far side of observer (both sides of roads), km/h; V_n, volume of traffic for near side of traffic (both side of road), veh/h; V_f, volume of traffic for far side of traffic (both sides of road), veh/h; D_g, geometric mean of road side section, m; $D_g = \sqrt{(D_f \times D_n)}$; D_f, distance from the observer to centre line of far side roadway, m; and D_n, distance from the observer to centre line of nearside roadway, m.

Seperate Lane Model Analysis

This analysis approach acknowledge the difference in traffic noise characteristics between acceleration lane and deceleration lane on both side of the urban road when vehicles leave an intersection on a green traffic light and come to a stop on a red traffic light. The acceleration lane model was build using data generated from the noise level meter placed on the sidewalk near the acceleration lane of the roadway when the traffic leaves the intersection. These models are given[4] in equations (8) and (9).

Acceleration Lane Interrupted Traffic Noise Model

$$L_{eq}=56.91+0.09S_n(a)+5.22 \log V_n(a)$$
$$+0.04S_f(a)+0.02 \log V_f(a)-0.061D_g(a) \quad (8)$$

Deceleration Lane Interrupted Traffic Noise Model

$$L_{eq}=71.12+0.07S_n(b)+0.42 \log V_n(b)$$
$$+0.08S_f(b)+0.44 \log V_f(b)-0.061D_g(b) \quad (9)$$

Efforts Made in India

In India the earliest noise surveys were carried out by Pancholy, *et al*, during the sixties. Gupta, Khanna and Gangil attempted to develop a relationship between the vehicular noise and stream flow parameters in 1979[5]. Gupta, *et al* analysed the traffic noise pollution for mixed traffic flow for various land use in 1986[6].

Srivastava, Gupta and Khanna evaluated the environmental noise pollution on SH-45 between Ghaziabad and Roorkee in continuation of their early study. Kumar Vimal carried out a study in Delhi to study urban noise scenario and has developed useful correlations between the various traffic parameters[7]. Siddiramalu has made an attempt to find the suitability of FHWA noise prediction for Indian conditions using limited data. P Kumar, carried out individual vehicle noise level study for proper categorization of vehicles and developed basic noise level equations for each vehicle category. N Gupta has developed a software package for design of highway noise barriers in VC++. Jain and Parida have completed a research project on Development of Comprehensive Highway Noise Barrier and Design of Noise Barriers in which they calibrated the FHWA model Indian conditions[2].

FIELD STUDY AND DATA COLLECTION

General

For the present study data was collected from eight sites in Delhi. The basic noise data was obtained using noise level meter placed 1.2 m above the ground vehicle were divided into six categorises like car, scooter, LCV, bus, truck and tractor trailor. A field data collection programme was chalked out to collect data regarding the following parameters: classified traffic volume; classified traffic speed; ambient noise level; geometric parameters like road width, number of lanes, lane width, shoulder width, presence of median and its width, presence of pedestrian side walk and its width and details of roadside developments, and miscellaneous information regarding type and condition of roadway, etc.

Table 2 Locations chosen for field studies

Type of Zone	Location
Residential zone	• Scientist's Apartments, Near Ashram Chowk • Sarita Vihar, Beyond Apollo Hospital
Commercial zone	• Connaught Place, Near Hotel Janpath • Nehru Place, Near Paras Talkies
Silence zone	• Delhi Public School, Mathura Road • Dr Ram Manohar Lohia Hospital, Near Gol Dhak Khana
Heavy traffic zone	• Noida Intersection • Moolchand Flyover, Lajpat Nagar

Identification of Study Locations

This study is mainly intended to measure the noise level in urban and semi-urban locations and hence the locations were so chosen as to represent the different zones within an urban

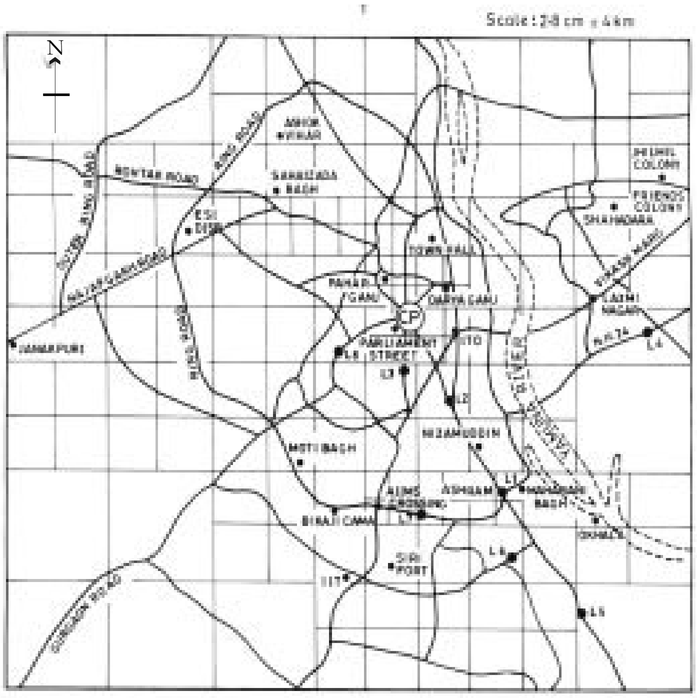

Figure 1 Map of Delhi showing identified field study locations

area like, residential zone, commercial zone, silence zone and heavy traffic zone. The locations chosen for this particular study are shown in Table 2 and Figure 1. The details of selected locations are shown in Table 3.

Table 3 Details for the locations chosen for field studies

Location Code and Number	Name of the Place	Number of Lanes and Road Width	Details of Median	Type of Road	Type of Zone
L1	Scientists' Apartments, Ashram Chowk	Six Lanes	Present	Residential	Bituminous
L2	Delhi Public School, Mathura Road	Six Lanes	Present	Silence	Bituminous
L3	Hotel Janpath, Connaught Place	Six Lanes	Present	Commercial	Bituminous
L4	Noid International	Six Lanes	Present	Heavy Traffic	Bituminous
L5	Sarita Vihar, Beyond Apollo Hospital	Six Lanes	Present	Residential	Bituminous
L6	Paras Takies, Nehru Pace	Six Lanes	Present	Commercial	Bituminous
L7	Moolchand Flyover, Lajpat Nagar	Six Lanes	Present	Heavy traffic	Bituminous
L8	Dr Ram Manohar Hospital, Near Gol Dhak Khana	Six Lanes	Present	Silence	Bituminous

DATA ANALYSIS AND RESULTS

General

The data collected at the eight selected locations have been analysed and presented in this paper. The data analysis and presentation has been done to develop a better understanding of the various traffic parameters and the variation of noise during the different times of the day.

Passenger Car Noise Equivalents

Each vehicle in the stream having mixed traffic system has different noise generation characteristics than other vehicle and the fact makes the road traffic noise problem little complex. In order to understand the behaviour of road traffic noise, or to understand the various relationships, it is necessary to convert all vehicles into some equivalence based on the their noise generation characteristics. The passenger car noise equivalence (PCNE) of particular vehicles represents that, how many times the vehicle is noisier than car[3]. PCNE values can be used to quantify noise produced by different types of vehicles into a common unit and is used in modelling process.

The intensity I of sound corresponding to L, dB (A) is

$$I = 10^{\frac{L}{10}} \times I_0 \qquad (10)$$

where I_o is reference intensity.

Now corresponding to L_c dB(A) of sound level produced by

car intensity is given by $I_C = 10^{\frac{L_C}{10}} \times I_0$

Corresponding to L_T dB (A) of sound level produced by a

particular vehicle intensity is given by $I_T = 10^{\frac{L_T}{10}} \times I_0$

Also $I_T = \text{n} \times I_C$.

Considering total intensity due to n car is equal to intensity due to one particular vehicle

$$10^{\frac{L_T}{10}} \times I_0 = n \times 10^{\frac{L_C}{10}} \times I_0 \ \cap_i \text{P}_i\ 10$$

$$n = 10^{\frac{(L_T - L_C)}{10}} \qquad (11)$$

where n is PCNE of any particular type of vehicle whose noise level is L_T dB (A).

Calculation of Weighted Flow (Q_W)

To find out the weighted flow Q_W for each sample of one hour, the number of vehicle passing the section in the same time is multiplied by the corresponding passenger car noise equivalent (PCNEs) and summed up.

$$Q_W = N_C + 1.26N_{2-W} + 2N_{LCV} + 7.08N_B + 7.08N_T + 9N_{TT} + 6.5N_{3-W} \qquad (12)$$

where Q_W is weighted flow (PCNEper hour); N, number of vehicles per hour; and C, 2-W, LCV, B, T, TT/and 3-W denote, cars, 2-wheelers, light commercial vehicles, buses, truck/tractor/trailor and 3- wheelers, respectively.

Data Analysis

The traffic volume at all the locations have been summarised in the form of total traffic volume for both directions for every hour. The traffic volume has also been converted to passenger car noise equivalent (PCNE) which has been used for the model development. The traffic speeds have been summarised in the form of average traffic speed values calculated for every hour. The average has been calculated for both the directions for the complete eight hours. The traffic noise has been analysed and the values of L_{10}, L_{50}, L_{90}, and L_{eq} have been calculated.

MODEL DEVELOPMENT

General

In this study, three different models namely FHWA, CORTN and Stop - and - Go are utilized for the prediction of noise level. FHWA and CORTN models are part of empirical modelling strategy while the Stop - and - Go model can be classified as an analytical model. The predicted results are analyzed by comparing them with the observed noise level.

On the basis of analyzed results, a new analytical model based on the modelling approach of Single Lane Model Analysis is developed for Indian conditions.

FHWA Model

Traffic noise prediction algorithm is of the form given below.

$$L_{eq} = L_0 + \Delta L_i$$

where L_0 is basic noise level for a stream of vehicles; and ΔL_i, various adjustments taken into account.

In this model vehicles are classified into seven categories as car/ jeep/ van, scooters/ motorcycle, LCV, bus, truck, auto rickshaw and tractor trailor. This classification has been done on the basis of individual vehicle noise level study. In FHWA model, the reference energy equations for each vehicles category are calculated and are of the form $Y = A + B \log S$; where S is speed of the vehicle category in kmph.

Following equations are calculated based on the individual vehicle noise study. These equations are core element of a traffic noise prediction model.

The hourly L_{eq} value for each category is calculated using the following equation

$$L_{eqi} = L_0 + A_{rs} + A_D + A_S \qquad (14)$$

where, L_{eqi} is hourly equivalent sound level; L_0, the reference energy mean emission level; A_{vs}, volume and speed correction; A_D, distance correction; and A_S, ground cover correction.

Table 4 Individual vehicle noise emission equations

Category	Model
Car/ Jeep/ Van	$Y= 15.891+ 32.372 \text{ Log}_{10}(S)$
Scooter/ Motorcycle	$Y= 8.979+ 35.871 \text{ Log}_{10}(S)$
LCV/ Mini bus	$Y= 23.26+ 31.212 \text{ Log}_{10}(S)$
Bus	$Y= 8.873+ 41.378 \text{ Log}_{10}(S)$
Truck	$Y= 6.597+ 43.248 \text{ Log}_{10}(S)$
Auto rickshaw	$Y= 61.51+ 0.2202 \text{ Log}_{10}(S)$
Tractor trailor	$Y= 73.065+ 6.411 \text{ Log}_{10}(S)$

Volume and Speed Correction

The correction is given as

$$A_{vs} = 10 \log_{10} D_0 V/S - 25 \quad (15)$$

where, V is volume for the category in veh/h; S is speed in kmph; and D_0, reference distance.

Distance Correction

While calculating distance adjustment the type of intervening ground cover between the highway and reception point is also considered a is the coefficient which accept the value of ground cover.

$$A_D = 10 \log_{10} (D_0/D)^{1+\alpha} \quad (16)$$

where, D_0 is reference distance given as 10 m; D, distance of measurement from centre of each lane; and α, ground cover coefficient.

The value of α is different for different locations because it depends upon the amount of absorption at each location which in turn depends upon the type of ground cover. Ground cover absorption coefficient (α) is assigned a value ranging from 0 to 0.75 depending upon the type and extent of ground cover.

Table 5 Ground cover coefficient

Hard site	$\alpha=0$
Moderately reflective	$\alpha=0.25$
Absorptive ground	$\alpha=0.50$
Vary absorptive	$\alpha=0.75$

Noise level for each carriageway is evaluated and then combined logarithmically to get the total L_{eq} value and the combined hourly L_{eq} value is calculated by the logarithmic summation of hourly L_{eq} values for each category

$$L_{eq} = 10 log \sum_{i=1}^{n} 10^{L_{eqi}/10} \quad (17)$$

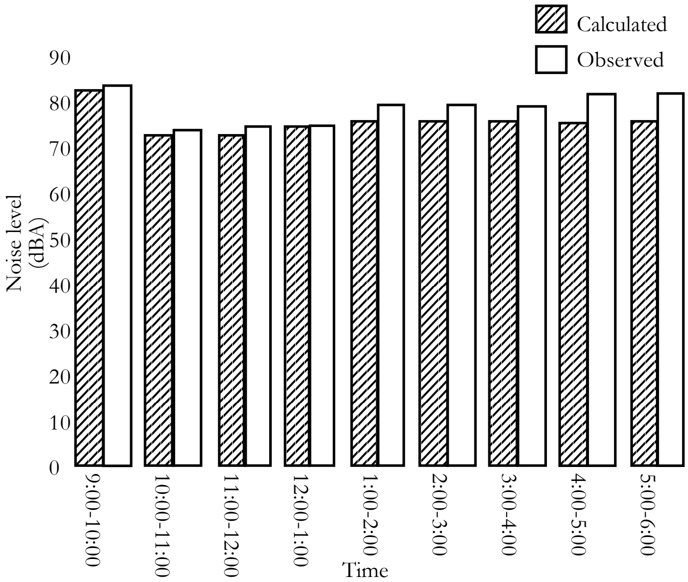

Figure 2 Graph between observed L_{eq} against calculated L_{eq} location 1 scientist apartments (FHWA model)

Model Interpretation

The hourly observed and estimated L_{eq} values for all the identified eight locations are compared and bar graphs are also generated to show the hourly variation between observed and estimated L_{eq} values. A sample bar graph for location 1 (scientist apartments) is presented in Figure 2 showing the hourly variation between observed and estimated L_{eq} values. The final scatter plot for FHWA model is presented in Figure 3.

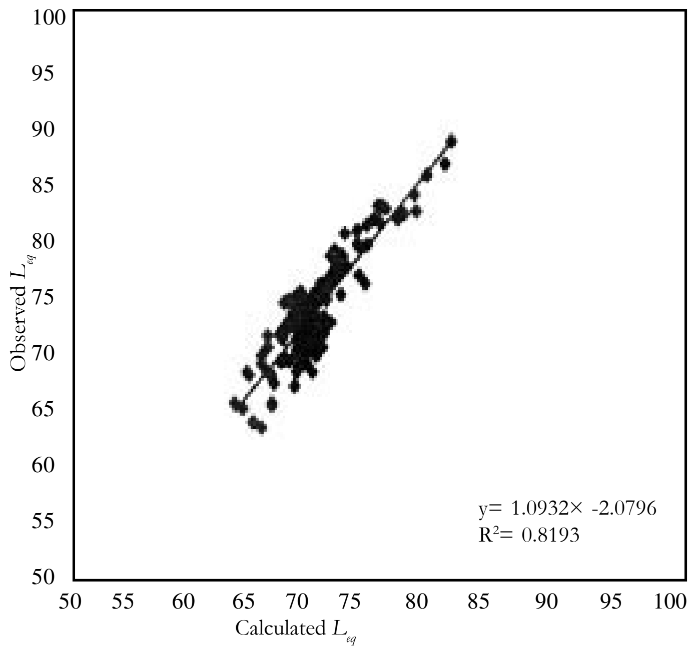

Figure 3 Observed L_{eq} against calculated L_{eq} (FHWA model)

There can be a number of model acceptability criteria, *ie*, (i) difference between observed and estimated noise level;

(ii) correlation coefficient between L_{eq} (obs) and L_{eq} (est); (iii) using 't' test. No single criteria is good enough to ensure the soundness of model prediction. Usually a series of criteria are used for deciding the acceptability of a model. In the present case:

(i) the difference between observed and estimated noise level lies in the range of 1-7 dB(A), which is definitely in the acceptable range,

(ii) the best fit line generated between L_{eq}(obs) and L_{eq}(est) gives an R^2 value of 0.8193 which is also acceptable. An R^2 value of 1 is considered to be the best whereas any value above 0.7 is considered to be good,

(iii) the paired t test carried out between L_{eq} (obs) and L_{eq} (est) gives a value of t = 4.60 which is higher than the tabulated value of t at 5% level of significance and 128 degrees of freedom.

Since out of the three model acceptability criteria two of them are satisfied for this model so it can be concluded that FHWA model gives acceptable results for Indian conditions.

CORTN Model

This model has potential for use in strategic planning to produce noise level estimates. A simple, user- friendly format was produced for the model for ease of application to large projects. This new modelling procedure could have a dramatic impact on the planning of projects such as construction of a new freeway.

The CORTN model was developed by the UK Department of Transport in 1988. It predicts noise at a reception point located at a certain distance from a road based on many factors including basic noise level based on vehicles composition, road surface, grade, etc; propagation effects such as distance attenuation and ground absorption capacity, and site layout features, *eg,* screening effects and reflections from surfaces.

It generally gives an uncertainty of 1-2 decibels, however obviously relies on the accuracy of input data. The CORTN model assumes a source of height 0.5 m, and distance of 3.5 m from the edge of the road. Noise is estimated one meter in front of the most exposed part of an external window or door. Moderate wind velocities and directions are assumed. The model does not take background noise into account such as trains, aeroplanes, industry etc, therefore it must be used with caution in particular applications.

CORTN model in turn has not classified vehicles category. For its calculation it combines the flow of all vehicles in veh/ h and considers hourly flow of all vehicles (q) and hourly flow of heavy vehicles (f). Based on CORTN model, for the calculation of Indian sites, bus, truck, TT are considered as heavy vehicles. Therefore, the hourly flow of all vehicles combined and the hourly flow of these three categories combine is used.

CORTN model does not take into account vehicle categories; therefore basic noise level is obtained from traffic flow, traffic speed, traffic composition, gradient and road surface. The standard equation for L_{10} (18 h) and L_{10} (hourly) are used for calculations.

The basic L_{10} is calculated:

$$L_{10} = 42.2 + 10 \log_{10} q \text{ dB (A)} \qquad (18)$$

where., Q is hourly flow of vehicles in veh/h.

For the 18 h L_{10} it is :

$$L_{10} (18h) = 29.1 + 10 \log_{10} Q \; dB \; (A) \qquad (19)$$

where, q is the number of passenger cars for an h; and Q, the number of cars for the 18 h period.

The hourly L_{10} value for each category is calculated using the following equation

$$L_{10} = L_0 + A_{hv} + A_D \qquad (20)$$

where, L_{10} is hourly equivalent sound level; L_0, the reference energy mean emission level; A_{hv}, correction for mean traffic speed and percentage of heavy vehicles; and A_D, distance correction.

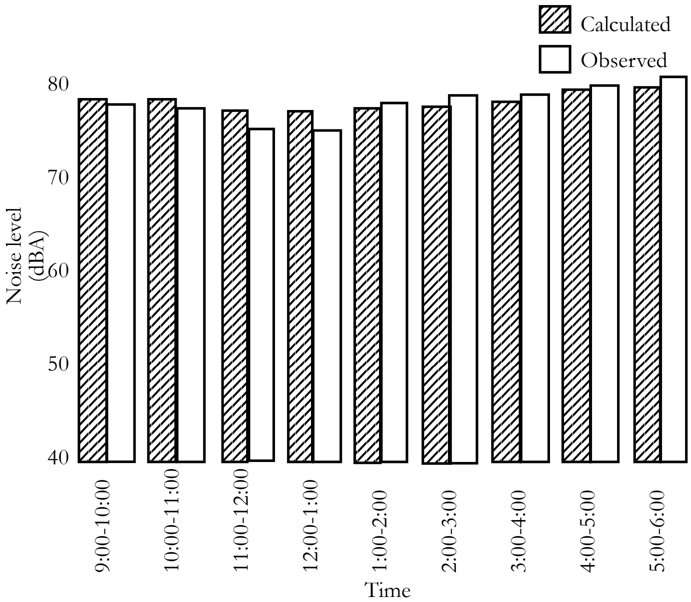

Figure 4 Graph between observed L_{10} against calculated L_{10} location 1 scientist apartments (CORTN model)

Model Interpretation

The hourly observed and estimated L_{10} values for all the identified eight locations are compared and bar graphs are also generated to show the hourly variation between observed and estimated L_{10} values. A sample bar graph for location 1 (scientist apartments) is presented in Figure.4 showing the hourly variation between observed and estimated L_{10} values . The final scatter plot for CORTN model is presented in Figure 5

Application of the usual acceptability criteria in this case speaks for the validity of the model.

(i) The difference between observed and estimated noise level

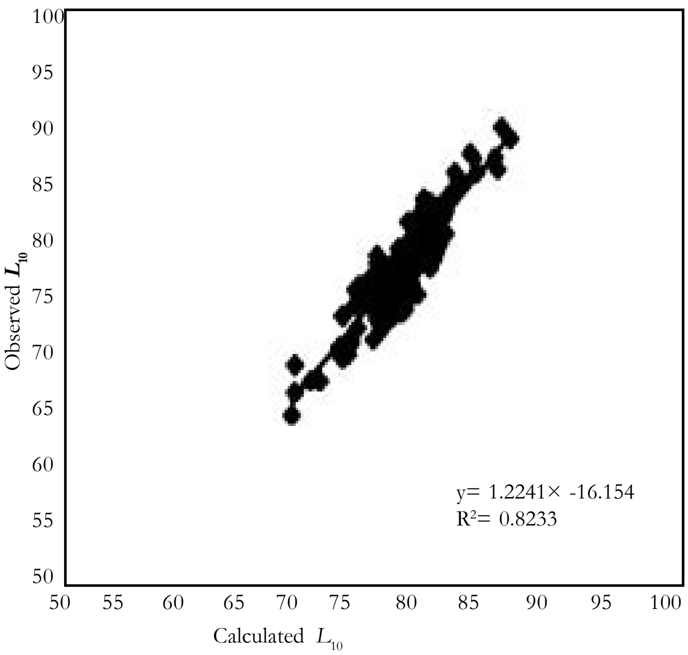

Figure 5 Observed L_{10} against calculated L_{10} (CORTN model)

lies in the range of 1-4 dB(A) which is definitely in the acceptable range.

(ii) The best fit line generated between L_{eq}(obs) and L_{eq}(est) gives an R^2 value of 0.8233 which is also acceptable. An R^2 value of 1 is considered to be the best whereas any value 0.7 is considered to be good.

(iii) The paired *t* test carried out between L_{eq}(obs) and L_{eq}(est) gives a value of t = 5.30 which is higher than the tabulated value of t at 5% level of significance and 128 degrees of freedom.

Since out of the three model acceptability criteria two of them are acceptable for this model so it can be concluded that CORTN model gives acceptable results for Indian conditions.

Stop and Go Model

This model is developed in Bangkok. Data collection include measurement of traffic characteristics, traffic noise levels, geometrical dimensions of road cross section which were used at 60 uniformly distributed locations within study area.

Traffic Noise Measurement

Traffic noise data were collected simultaneously with that of traffic characteristic traffic volume, and speed using integrated precision sound level. Traffic noise was measured in L_{eq} index with an A- weighted scale of decibel unit for a *i*-hour period at each selected location.

Traffic Volume Computation

Traffic volume is computed using equation (21)

$$\text{Volume} = (AU) + 1.04(LT) + 1.12(MT+TT) + 1.14(HT) + 1.09\,(MC+BU+MB) \qquad (21)$$

where AU= automobile, HT= heavy track, LT= light truck, MC=motorcycle, MT=medium truck, BU=bus, MB=minibus, TT=tractor trailor.

Single Model Analysis

The single model approach was the first analysis applied to build a single stop and go traffic flow noise model. This model can be applied to both sides of an urban roadway. The model developed in this study is given in equation (22).

$$L_{eq} = 71.05 + 0.10S_n + 0.95\log V_n + 0.04\,S_f + 0.015\log V_f - 0.111\,D_g \qquad (22)$$

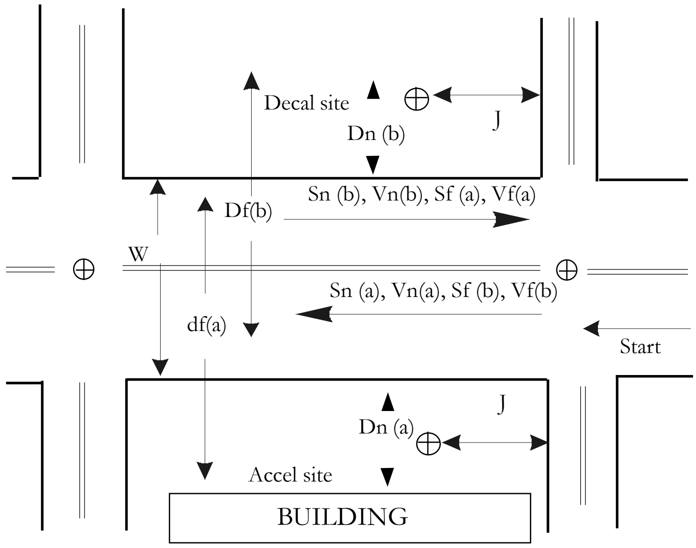

Figure 6 Road section and parameter layout of single model approach

L_{eq}, equivalent traffic noise level in 1 hour, dB(A); S_n , mean speed of traffic on near side of observer (both side of roads), km/h; S_f , mean speed of traffic on far side of observer (both side of roads), km/h; V_n ,volume of traffic for near side of traffic (both side of road), veh/h; V_f , volume of traffic for far side of traffic (both side of road), veh/h; D_g ,geometric mean of road side section, m; and, $D_g = (D_f \times D_n)$.

Model Interpretation

The hourly observed and estimated L_{eq} values for all the identified eight locations are compared and bar graphs are also generated to show the hourly variation between observed and estimated L_{eq} values. A sample bar graph for location 1 (scientist apartments) is presented in Figure 7 showing the hourly variation between observed and estimated L_{eq} values. The final scatter plot for Stop-and-Go Model is presented in Figure 8.

The values for the various acceptability criteria for this model are

(i) the difference between observed and estimated noise level lies in the range of 1-10 dB (A) which is definitely in the acceptable range,

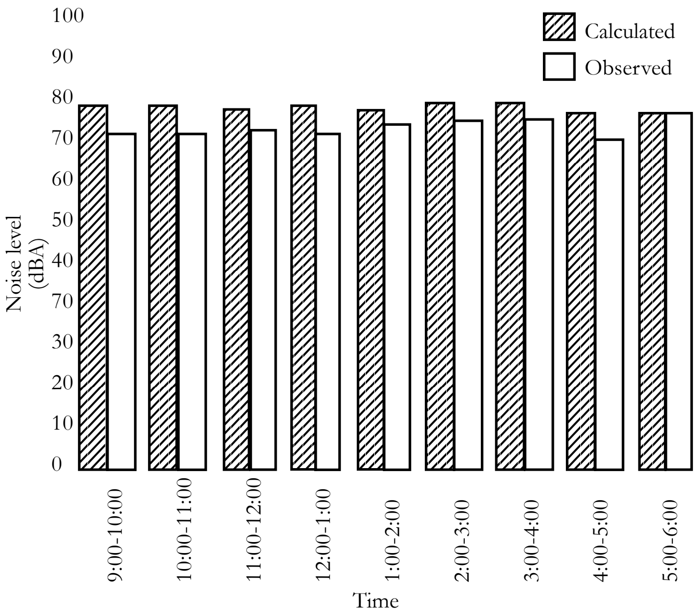

Figure 7 Graph between observed L_{10} against calculated L_{10} location 1 scientist apartments (Stop-and Go model)

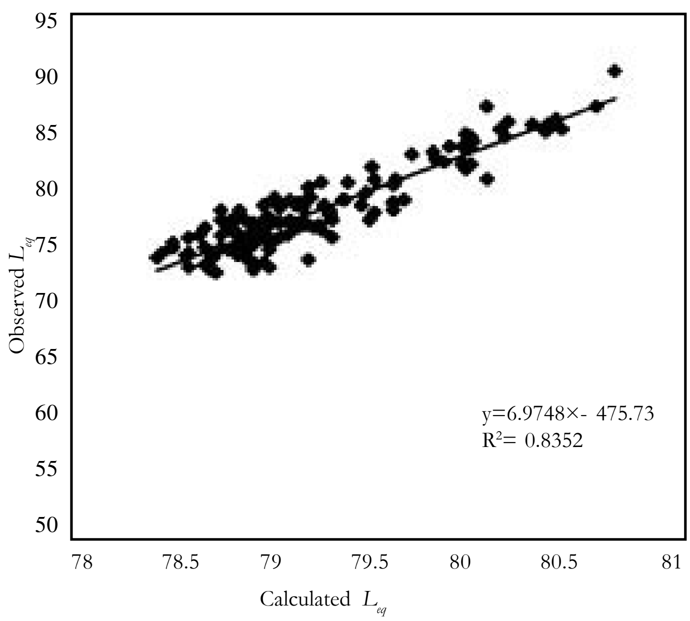

Figure 8 Observed L_{eq} against calculated L_{eq} (Stop-and-Go model)

(ii) the best fit line generated L_{eq}(obs) and L_{eq} (est) gives an R^2 value of 0.8352 which is also acceptable. An R^2 value of 1 is considered to be the best whereas any value above 0.7 is considered to be good,

(iii) the paired t test carried out between L_{eq}(obs) and L_{eq}(est) gives a value of t =4.63 which is higher than the tabulated value of t at 5% level of significance and 128 degrees of-freedom.

(iv) the paired t test carried out between L_{eq}(obs) andL_{eq}(est) gives a value of t =4.63 which is higher than the tabulated value of t at 5% level of signifcance and 128 degrees of-freedom.

Since out of the three model acceptability criteria only one of them is acceptable for this model so it can be concluded that Stop-and-Go Model does not give very good results for Indian conditions.

The Regression Model

Often, in practice the relationship is found to exist between two or more variables, when this relationship is to be expressed in mathematical form by determining an equation connecting the variables, the following steps may be adopted:

(i) identify and list the various possible variables which could be considered for the development of predictive models;

(ii) establish the independent and dependent variables.

Though, there are a number of independent variables which may affect the traffic noise parameters, in the present study the important parameters like hourly traffic volume (EPCNE/h), average traffic flow speed (kmph), distance of observer from the edge of pavement (meter) in both direction were taken as independent variables.

A common form mathematical model for traffic noise predic - tion is as follows

$$Y= a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + \text{---------------} + a_n X_n$$

Where, Y is traffic noise parameter *ie,* L_{eq}, a_0 is constant.

X_1, X_2, X_3 ----------X_n are the variables affecting the road traffic noise like, volume, speed, noise receptor distance on both side and road cross section parameters etc.

a_1, a_2 , a_3 ----------a_n are the coefficients to be determined adopting multiple linear regression method.

Basic Assumption

While discussing the strategies of traffic noise pollution modelling some basic assumptions are required to be made within the practical limit without any loss of generality.

For the present work the following assumption have been made.

(i) The traffic volume V_n, V_f is a positive number which is never less than 1 (V_n , V_f , ≥1)

(ii) The model is developed for a traffic flow condition or average traffic flow speed is always greater than zero (S_n,S_f ≥1).

(iii) The highway stretch should be straight and the level road with a reasonably good road surface condition and therefore influence of variation in road interface is excluded.

(iv) The model is applied under normal weather/ meteorological conditions.

(v) There is no noise barrier either natural or artificial between the observer and the noise source, *ie*, traffic flow.

(vi) Based on literature review it has been found that in most of the countries higher L_{10} or L_{eq} noise parameter is mostly referred as traffic noise parameters, of course, in India the permissible standards are available for L_{eq}. Keeping this in view, the model for mathematical predicting L_{eq} has been tried in present work.

Predictive Model

Using the survey data a new model for Indian condition has been developed in MS-Excel.The developed mathematical equation is

$$L_{eq}=81.715+0.361\ S_n+2.412\ \log\ V_n -0.189\ S_f -0.015\log\ V_f - 1.532\ D_g \quad (23)$$

Where, L_{eq}, equivalent traffic noise level in 1 h, (dB(A); S_n, mean speed of traffic on near side of observer (both side of roads), km/h; S_f mean speed of traffic on far side of observer (both side of roads) km/h; V_n ,volume of traffic for near side of traffic (both side of roads) veh/h; V_f, volume of traffic for far side of traffic (both side of roads), veh/h; and D_g, geometric mean of road side section, m.

$$D_g=\sqrt{(D_f \times D_n)}$$

D_f, distance from the observer to centre line of far side roadway, m; D_n, distance from the observer to centre line of nearside roadway, m.

To check the adequacy of the mode, the observed L_{eq} values are plotted against the predictive L_{eq} values which are shown in Figure 9.

Acceptability of the model is examined below in the light of the usual but of criteria.

(i) The difference between observed and estimated noise level lies in the range of 1dB(A)- 11 dB(A) which is definitely in the acceptable range.

(ii) The best fit line generated between L_{eq}(obs.)and L_{eq}(est) gives an R^2 value of 0.8094 which is also acceptable. An R^2 value of 1 is considered to be the best whereas any value above 0.7 is considered to be good.

(iii) The paired *t* test carried out between $L_{eq}= L_{eq}$ (obs) and L_{eq}(est) gives a value of t = 3.55 which is higher than the tabulated value of t at 5% level of significance and 68 degrees-of-freedom.

Since out of the three model acceptability criteria two of them are acceptable for this model so it can be concluded that Stop – and –Go model gives acceptable results for Indian conditions.

COMPARISON OF NOISE MODELS

Comparative statistical test were applied to compare the three models by using the paired *t* - test technique in order to see how good these three models could be fitted to the observed traffic noise data in an urban environment. In paired *t* test, the predicted traffic noise levels from each model were compared with the measured ones. The null hypothesis was tested using paired *t* test which stated that the mean value of difference between pair of measured traffic noise level and predicted ones is equal to zero. Therefore, the null hypothesis and formulation of this test were as follows.

Null hypothesis $H_0=0$

$$T = \frac{d_1}{SE\ /\sqrt{n}} \quad (24)$$

D_1, where difference between measured traffic noise value and predicted one at the *i* th pair (measured-predicted); *SE*, standard error of the difference values; and N, number of paired sample. Table 6 shows the comparative results of paired *t* test

Table 6 Comparison and validity of noise models on basis the of paired *t* test

Model Used	Samples (N)	*t* Test	*t* Critical
FHWA	131	4.60	2.04
CORTN	131	5.30	2.04
Stop and Go	131	4.63	2.04
Regression	68	3.55	1.66

Table 7 Comparison of Noise Prediction Models

S. No.	Parameter	FHWA	CORTN	Stop-and- Go	Regression
1	Descriptior	L_{eq}	L_{10}	L_{eq}	L_{eq}
2	Vehicle Categories	Three-Automobiles, Medium Trucks and Heavy Trucks	No separate classification. Only for calculation utilities flow of all vehicles and flow of heavy vehicles	Four-Automo-biles, Buses, trucks, Motorcycles	Four-Automobiles, Buses, Trucks, Two Wheelers.
3	Adjustments	Are applied for the calculation of hourly L_{eq}	Are applied for the calculation of hourly L_{10}	Does not take into account adjustments factors because it is an analytical model	No adjustments applied because it is based on the approach of an analytical model.
4	Hourly volume of Traffic	Is calculated in terms of vehicles/hr.	Is calculated in terms of vehicles/hr.	Is converted into PCNE and then calculated	Is converted into PCNE and then calculated
5	Geometric mean of Cross section	Not utilised, instead for distance correction reference distance is taken as 15m from the centre of nearside lane and the actual distance of measure-ment is recorded	Not utilised, instead for distance correction reference distance is taken as 10m from the nearside carriageway edge and the actual distance of measure-ment is recorded.	Is utilised and is given as $D_g= (D_f \times D_n)$ where D_f= Distance from observer to centreline of farside roadway (m) D_n = distance from observer to nearside roadway curb (m)	Is utilised and is given as $D_g=(D_f \times D_n)$ where D_f=Distance from observer to centreline of farside roadway (m) D_n = distance from observer to nearside roadway curb (m)
6.	Separate lane concept	No separate lane concept for accelera-tion or deceleration lane	No separate lane con-cept for acceleration or deceleration	Has separate models for Acceleration and Deceleration Lanes	Is based on the modelling approach of Single Model lane Analysis and is developed for Indian conditions

There is a basic difference between analytical and empirical models for noise prediction. Analytical models are data hungry and black box like tools. Barrier design is not possible through these models. Empirical models on the other hand simulate the physical process of noise generation, propagation and attenuation. Table 7 shows a theoretical comparison between the three models namely FHWA, CORTN and Stop - and - Go along with the developed model, *ie,* Regression Model.

CONCLUSIONS

Collected data on noise generating parameters was applied to calculate the predicted noise level from the three models, FHWA, CORTN and Stop and Go. The comparison tests were made in order to examine the goodness of fit, between the predicted and measured noise level from the collected field data and to suggest a suitable model for Indian conditions. From the present study following conclusions are drawn.

(i) The summarized details showing the variation between observed and estimated noise level for all the mentioned models namely FHWA, CORTN, stop – and –Go and the developed regression model are shown in Table 8.

Table 8 Summerised details of noise prediction models

Model	Range of Difference between Observed and Estimated Noise Level dB(A)	R^2 Value
FHWA	1-7	0.8193
CORTN	1-4	0.8233
Stop and Go	1-10	0.8352
Regression	1-11	0.8094

(ii) From the Table, the R^2 value for all the models lie in the acceptable range, as the R^2 value of 1 indicate a very good correlation between the observed and estimated data sets. As from the table, it can be seen that the variation between observed and estimated data sets for Stop–and–Go model is quite high, whereas for FHWA and CORTN model this variation is within the acceptable range.

Scrutinizing the analysed results it can be concluded that FHWA and CORTN models give better results for Indian conditions in comparison to other models.

(i) The paired t test was also carried out to provide the statistical test for the differences between the predicted results from the model and the measured result from the field. The null hypothesis was $\mu = 0$, that is the mean value of the difference between pairs of measured noise and predicted noise is equal to zero. The results from paired t -test at a significance level of 5% and 128 degree of freedom are shown in Table 6. The results clearly show, that since the calculated value of t at 5% level of significance and 128° is greater than the tabulated value of t, so the null hypothesis is rejected, i*e,* the mean value of difference between observed and estimated noise level is equal to zero. Out of the three models examined for Indian conditions, namely, FHWA, CORTN and Stop and Go, CORTN and FHWA models were observed to give acceptable results for Indian conditions.

(ii) Finally the Regression model for Indian conditions was developed to correlate the traffic parameters and geometric parameters with traffic noise. Statistical analysis of the regression model shows that the model is reliable for prediction of noise in urban areas at 95% confidence level because out of all the mentioned three models, the difference between the tabulated value of t and the calculated value of t is minimum. This model is superior on account of statistical test in comparison to other three models.

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