Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Environmental noise mapping study for heterogeneous traffic conditions

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PACS: 43.50.LJ, 43.50.RQ.

ABSTRACT

Traffic noise characteristics in cities belonging to a developing country like India are varied slightly by virtue of the fact that the composition of the traffic is heterogeneous associated with variance in road geometrical features, surface characteristics, honking conditions and varying density of the building on the either side of the road. To study the propagation and spread of the traffic noise in some of the areas a noise mapping study has been attempted along with field measurements of L_{10}, L_{50}, L_{90} and L_{eq}. In the noise mapping parameters such as L_d, L_N, L_{den} have been arrived at by taking into consideration the geometrical features of the roads and varying heights of the buildings. In this study noise mapping through computer simulation model (soundplan software) is used by considering several noise sources and propagation of noise to the receiver point. Some of the prediction models such as U.K's CRTN, U.S's TNM and their modified versions have a limited applicability for heterogeneity. Therefore a separate multiple regression model is discussed to suit the heterogeneous traffic conditions for noise mapping purposes.

INTRODUCTION

Generally large cities in India are loaded with heavy traffic associated with large groups of new buildings extending beyond the original city zones. Prediction of impact of noise pollution associated with such larger cities is interesting. It enables one to see the growth of any city and associated environmental impact problems. Noise due to transportation infrastructure poses a formidable challenge to the environmentalist. Some issues relating to this with respect to Indian environments are described in ref [1]. In last few years the Indian cites has experienced significant structural changes due to the rapid growth in the number of motor vehicles, expansions of road network, industrialization and urbanization. These modifications lead to a change in the noise levels associated with the city [2]. From the sustainability point it is very important to see the noise levels are contained. Noise mapping of urban environment is very useful technique in terms of urban noise control and sustainability. In a developing country such as India the metropolitan environments exhibit varying characteristics as compared to a developed country. Initially the noise mapping has been attempted through soundplan software which shows a difference of 7 to 10dB(A) of Lden values from the measured values. Hence in this context a multiple regression model has been developed taking into consideration the actual traffic composition, speed, horn noise contribution, road width, gradient and local metrological conditions. This model can be integrated into any open sources GIS software such as QGIS and GRASS for noise mapping purposes.

NOISE MAPPING PROCESS

The area selected for noise mapping is Chennai city (A typical Indian city for heterogeneous traffic conditions) the city covers an extent of 1172 sq.kms of which the city municipal administration area extends to 172 sq.km. The road network is based on 5 major radial roads, and an inner ring road that connects all the major radial roads. Since the total area of the city is very large to map a small portion an urban arterial road stretch is taken and mapped.

The road traffic noise model is a three dimensional digital representation of noise levels associated with generation, propagation and reception of road traffic noise. The model requires three important features such as the noise source, the path of propagation and the receiver. The noise source data includes the vehicle flow rate, Percentage of heavy vehicles (vehicles with un-laden weight > 1525Kg), mean vehicle speed, gradient of road and the road characteristics. The propagation path includes the perpendicular distance of receiver from source, average height of propagation above ground surface, the acoustical characteristics of the ground surface, angle of view of source from receptor and reflecting surface close to the source.

The receptor data includes the location, height and angle of view of the receptor and also the reflecting surfaces close to receptor. The methodology adopted in the calculation is shown through flowchart of figure1. The layout of the houses and other important buildings, road widths, side slope location and widths, areas of acoustically hard ground (water bodies, etc) are taken from Chennai survey map. The Local topography of the study area is built into the model by creating a Three-dimensional representation of the city. Buildings are built into the ground model the heights are estimated with the help of aerial photographs (Google earth) as specified in toolkit 15.2 [3]. Wherever information is not available all buildings are assumed to be 8m high [3]. The area of the buildings and receptors located are identified and located as industrial area, business district, inner city, mixed area and others. The road traffic data is obtained by site studies for traffic and composition heavy vehicle counts. The vehicle speeds are considered between 30-50 kmph. A further assumption in the computation is that all road and motorway surfaces are constructed of impervious bitumen with a texture depth of 0.98 millimeters.

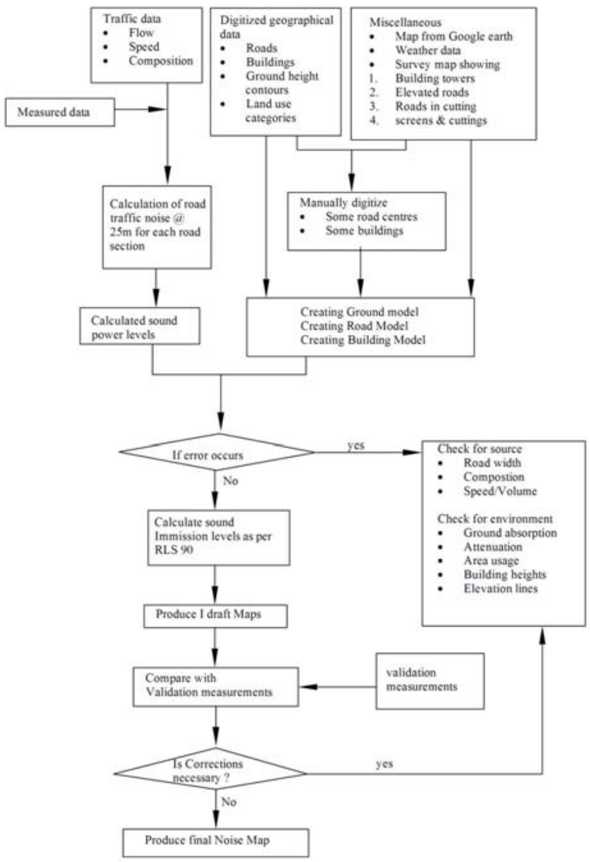

Figure 1. Flow chat for Noise mapping process

Initially the selected area is modeled in accordance with the methodology prescribed in RLS 90 [4]. The RLS 90 specifications rate (rating level) the sound level at the receiver location for the day (6.00 AM to 10PM) and night (10.00PM to 6.00AM) time ranges for the evaluation of the resulting sound impact. The RLS 90 uses the point source method and includes ground attenuation, screening and reflection. The standard is made up of two separate models. The source model uses the traffic data and results in the reference noise level at 25m distance from the road at 4m above the ground. The propagation model assumes average emission for day and night as an input and the noise levels at the receiver with respect to timings.

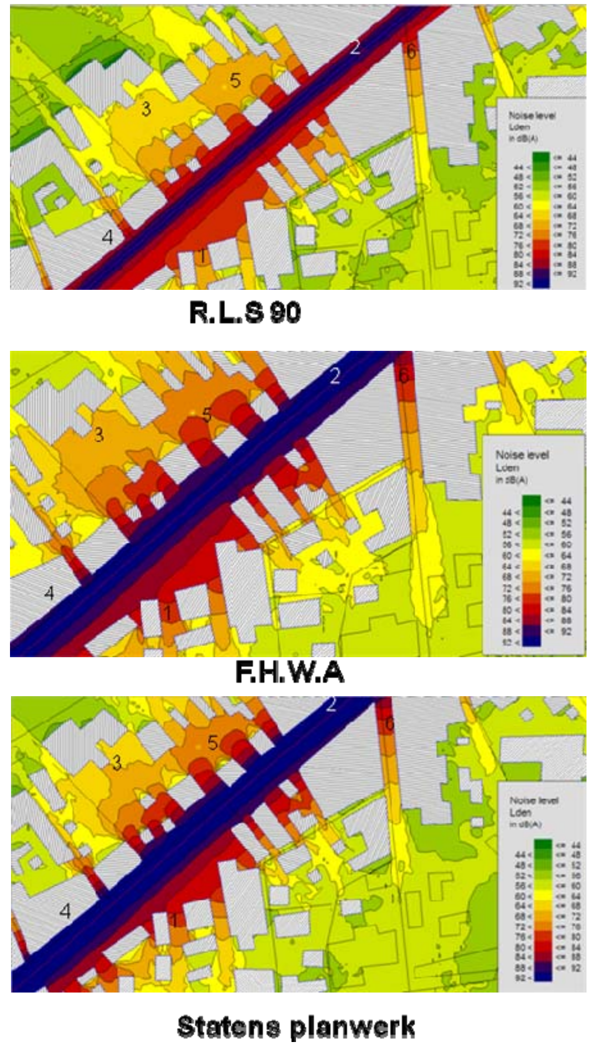

Figure 2. Noise map of study area using different standards

	CRTN L den	FHWA L den	RLS 90 L den	Statens planwerk L den	Measured L eq
1	67.3	75.7	69.6	74.4	78
2	82.6	86.2	79.3	87.4	87
3	56.4	64.3	60.5	61.7	71
4	81.7	85.5	78.7	86.4	88
5	69.6	76.6	71	76.2	81
6	83.2	86.7	79.8	87.9	89

Table 1. Mapped sound levels from different standards

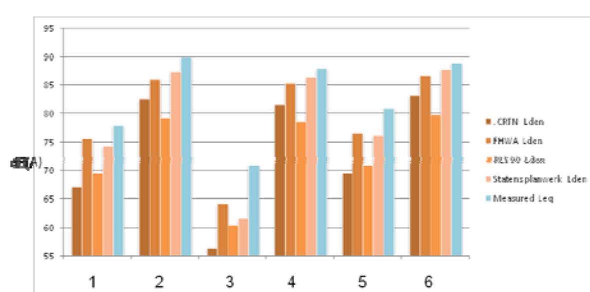

Figure 3. Chart showing comparison between different standards

The results (table 1) show a difference of upto 10 dB(A) when compared to measured data. Then to check the compatibility with other standards same area is modeled with other standards such as crtn, fhwa, and statens planwerk (e.g. Figure 2). The results show (e.g. Figure 3) a significant difference from the measured noise levels which are due to the fact that these standards inherently assume homogeneous traffic conditions with higher speeds, wider roads. Whereas Indian traffic conditions are heterogeneous. Due to the widely varying vehicular dimensions, speeds, lack of lane disciplines, in heterogeneous traffic conditions honking becomes inevitable. It changes the soundscape of the city considerably as compared to other cities of developed countries. Therefore a model is thought of considering the factors such as heterogeneity, horn honking conditions and multiple reflections

FIELD STUDY AND DATA COLLECTION

The city of chennai studied in this work will handle 15 lakhs of vehicles per day all over the city. Vehicular flow is principally connected by four important highways (NH4, NH 5, NH 45 & NH46 which connect the chennai city to other important cities) there are two ring roads and local urban roads connecting these high ways with the incoming and outgoing traffic of the city. Most of the roads in chennai are unplanned and they are not alike. Some of the roads in a traffic junction are narrow, while some others are wide. The sketches of six typical representative sites with the traffic center-line, microphone location, and the surrounding buildings have been shown in figure.4. The location 1, 3 & 4 are considered as urban locations and the locations 2,5 & 6 considered as highway locations.

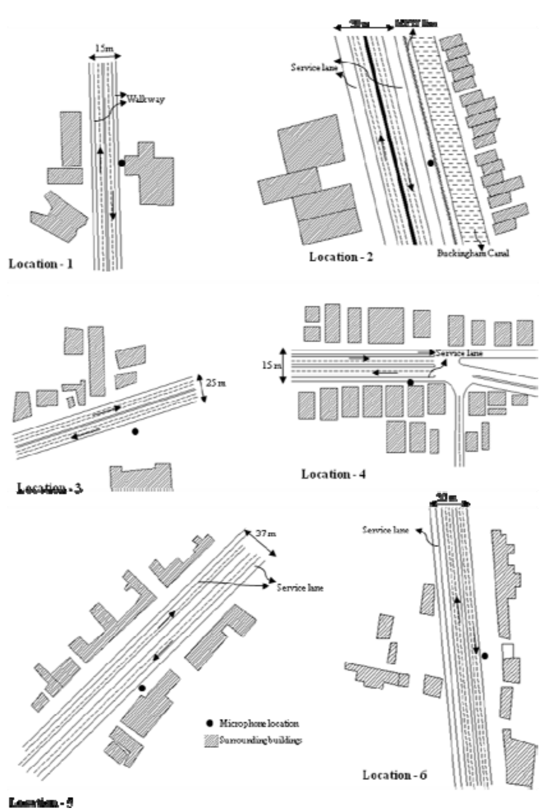

Figure 4: Geometry of the location studied.

For the present study data was collected from six sites of Chennai. Measurements are carried out during the working and non working days which represent peak & lean traffic flow. Field measurements have been taken by using the Norsonic sound level meter for 15 minutes duration. The sound level meter is calibrated prior to each measurement using a Norsonic sound calibrator type 1251. Sound level meter is mounted on a tripod at 1.2m above the floor level. Vehicle were divided into five categorizes like two wheelers, Three wheelers, car, bus and truck.

The distance of the microphone from the traffic center-line was different for different sites, depending on the width of footpath and road. The actual distance of microphone from the plying traffic center-line for each site has been given in Table 3b.

The counts of number of vehicles (Table 3a) that crossed the point of measurement from either direction on the road were recorded with the help of a video camera. The speeds were also monitored with a hand held radar gun along with the noise level. The average A-weighted noise emitted by the individual vehicles in the five categories traveling the roads of Chennai under actual conditions of the noise monitoring site was determined at six different measurement locations when a single vehicle in each category was passing at its free speed.

MODELING OF THE BASIC NOISE LEVEL

The data collected at the six selected locations have been analyzed 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. Table 3 shows the measured values of Leq, L10, L50 & L90 along with the vehicle count and average spot speeds of that particular location. The total number of horn events during the measurement duration are shown in table 3. A difference of 2 to 13 dB(A) in Leq levels is observed according to the number of horns, hence honking correction need to added to the basic noise level for heterogeneous traffic conditions where honking becomes inevitable. The honking correction for average number of horns per minute is given in the table 5.

The average noise levels *Lm* for different categories of vehicles on the roads of Chennai, and their passenger car noise unit in terms of the average noise emission levels, are given in Table 4. Utilizing these conversion factors the hourly traffic density at each location is converted to the equivalent number of light/heavy vehicles per hour. (Qi)

The basic noise equation is arrived in the form of multiple regression equation with the independent variables such as traffic volume (Qi) and speed (V). The basic equation is the standardized level for the following conditions.

- Road surface non-grooved asphalt
- Gradient < 5%
- Free field propagation.

$$Leq = L_{m(15)} + C_{horn} + C_{REF}$$

Where

$L_{m(15)}$ is the basic noise level, C is the correction factor for honking conditions and road width

For Urban areas:

$$L_{m(15)} = 76.21 + 3.44 \log Qi - 4.66 \log V$$

For Highways:

$$L_{m(15)} = 34.31 + 1.3 \log Qi + 9.2 \log V$$

Where Qi is the total number of vehicles/hr in terms of PCNU. V is the speed in km/hr.

Model definition   Y = a + b*log(x1) + c*log(x2)

Urban areas

Regression Variable Results

Variable	Value	Standard Error	t-ratio	Prob(t)
a	76.21	5.59	13.62	0.00001
b	3.44	0.74	4.61	0.00364
c	-4.66	0.98	-4.73	0.00322

Table (2 a) Regression variable results for urban areas

R^2 = 0.85 (figure 5a)

Prob(F) = 0.00259

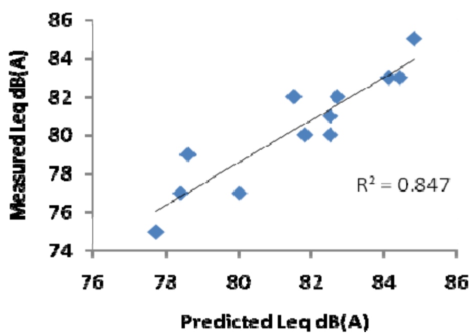

Figure 5a. Measured VS Predicted correlation chart for urban areas

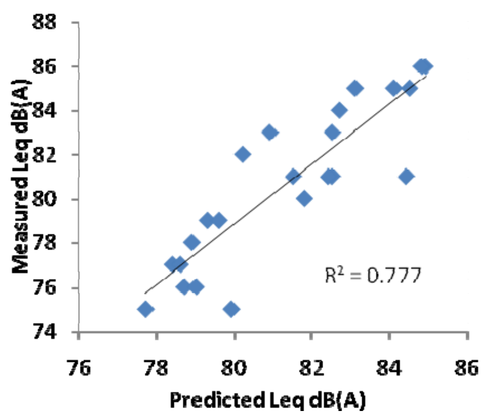

Figure 5b. Measured VS Predicted correlation chart highways.

Highways

Regression Variable Results

Variable	Value	Standard Error	t-ratio	Prob(t)
a	34.31	13.78	2.49	0.04157
b	1.39	0.37	3.77	0.00697
c	9.32	3.03	3.07	0.01786

Table (2 b) Regression variable results for highways

R^2 = 0.85 (figure 5b)

Prob(F) = 0.00259

Location	Composition of vehicles					Total vehicles
	Two wheeler	Auto	Car/ van	Trucks	Buses	
Location 1	219	38	156	2	7	422
Location 1	283	56	207	8	22	576
Location 2	375	55	259	11	30	730
Location 3	646	159	501	33	83	1422
Location 6	56	3	53	40	11	163
Location 6	41	4	34	65	14	158
Location 4	266	76	205	7	22	576
Location 2	418	67	255	20	33	793
Location 6	42	5	59	23	7	136
Location 6	87	6	72	31	6	202
Location 5	112	8	165	31	38	354
Location 5	115	6	127	33	29	310
Location 4	281	63	199	6	25	574
Location 2	420	57	271	9	34	791
Location 3	751	111	345	24	60	1291
Location 1	428	47	222	2	10	709
Location 6	50	3	50	24	8	135
Location 6	54	3	56	23	7	143
Location 5	227	13	128	50	44	462
Location 4	292	58	213	6	35	604
Location 2	298	47	222	4	8	579
Location 3	572	120	453	18	44	1207

Table 3a. Composition of vehicles

Location	Total vehicles	Qi	No of horns	Distance (m)	speed		Sound level
					Mean	S.D	Leq
Location 1	422	443		15	34	6.6	81.8
Location 1	576	711		15	36.8	6.79	77.7
Location 2	730	912		20	51.24	9.72	80
Location 3	1422	2013		25	35.19	5.6	84.4
Location 6	163	350	16	10	65.1	19.35	78.7
Location 6	158	444	18	10	54.98	16.71	80.2
Location 4	576	717	172	18	25.99	8.34	82.5
Location 2	793	1017	103	20	52.05	13	84.1
Location 6	136	247	27	10	65.94	18.01	80.9
Location 6	202	321	30	10	61.76	16.65	82.4
Location 5	354	693	68	30	57.46	16.07	79.6
Location 5	310	591	62	30	56.91	15.33	79.9
Location 4	574	727	240	10	26.45	5.53	82.7
Location 2	791	986	97	20	54.4	10.96	81.5
Location 3	1291	1661	220	25	35.67	4.61	84.8
Location 1	709	711	125	15	40.52	7.22	78.4
Location 6	135	254	14	10	71.43	24.97	78.9
Location 6	143	251	17	10	59.61	17.68	79
Location 5	462	878	63	30	54.57	11.73	84.5
Location 4	604	823	190	18	27.48	6.21	82.5
Location 2	579	599	78	20	54.05	15.15	78.6
Location 3	1207	1485	158	25	37.94	4.84	83.1

Table 3b. Measured values of volume, equivalent volume and equivalent speed, total no of horns in the measurement duration, Leq and statistical levels at the study locations

PASSENGER CAR NOISE UNIT (PCNU)

Since the noise levels emitting from different types of vehicles are different according to their engine's capacity and weight. To understand the characteristics and various relationships of road traffic noise it is important to convert all vehicles into one common unit. The most accepted such unit in transportation is that of passenger car unit (PCU) it is used to find the density of roadway under mixed traffic conditions. Similarly for road traffic noise it will be more meaningful if passenger car noise unit is arrived (PCNU). Passenger car noise unit of a particular vehicle represents that, how many times the vehicle is noisier than that of a car. PCNU values can be used to calculate noise produced by different types of vehicles in a heterogeneous traffic conditions into a common unit.

To find the PCNU the pass by noise of vehicles moving at constant speed were measured for all five categories. The average noise emission levels for individual vehicles of different categories of the city, is given the table 4. These measurements have been taken during the early hours where the individual noise emission can be accurately estimated without the presence of any other category of vehicle. The space can be considered as an acoustically free space which is reasonably free of reflections from surrounding buildings.

The L, dB (A) of sound corresponding to intensity I is
$L_{car} = 10 \log_{10} (I_{car} / I_0)$ where I_0 is ref intensity
Similarly $L_{truck} = 10 \log_{10} (I_{truck} / I_0)$
(When converting to exponential form)
$I_{car} / I_0 = 10^{(L car /10)}$ &
$I_{truck} / I_0 = 10^{(L truck /10)}$
By definition we have I truck = n x I car
By substituting eqn 2 in 3 we will get

$n = 10^{(Ltruck – Lcar)/10}$

Category of vehicle	Max permissible Noise Lvl - dB (A)	Mean SPL dB(A)	S.D SPL dB(A)	PCNU n
Two wheelers	80	78.95	5.71	0.8
passenger cars,	82	80.29	4.31	1
LMV up to 4000kg.	85	81.29	6.42	1.25
HV up to 12000kg.	89	86.08	4.23	4
HV above 12000kg.	91	89.05	3.91	8

Table 4. Mean noise emission level of five different categories of vehicles in heterogeneous traffic condition with the conversion factors for equivalent number of cars

Qi = 0.8 * (Two wheelers) + 1* (Car) + 1.25 *(Three wheelers) + 4* (Light trucks) + 8 * (Heavy trucks or busses)

EFFECT OF HORN SOUND ON NOISE EXPOSURE (C_{HORN})

From the field measurements it is clear that traffic noise characteristics of Chennai city has an impulsive percussive character that result out of frequent horn sounds. In few locations, horn sound occupies more than 25% of the measurement duration (table 3b) to study the effect of horn sound on Leq, the horn sounds were removed from the obtained Leq by noise dose method as prescribed in OSHA standards by using a nomogram. To investigate the extent of noise pollution that the air horns can cause on the roads, a test have been conducted on air horns fitted to a heavy vehicle. The instruments used for the test purpose are HP real time frequency analyzer (type 3569) and B&K sound level meter (type 2230).

S.No	Description	At 2 m straight	At 7 m straight	At 7 m Kerb side
1	Air pressure horn	116	107`	103
2	Elec. Horn	118	111	98
3	Vehicle Idling	96		
4	Softone air horn	105	96	95

Table 5. The results of measured Air pressure, electric and softone air horn.

S.No	No of horns/min	% of time occupied by horn sound	Increase in Leq dB(A)
2	< 2	3 %	0
2	2-4	3 % – 6%	2
3	4-8	6% - 13%	6
4	8-16	13 % - 26 %	10
5	> 16	> 26 %	12

Table 6. Horn correction values

No of horns	% of time occupied by horn sound	Leq	Leq without horns	Difference in dB(A)
16	1.7	78.7	78.2	0.5
18	2	80.2	79.5	0.7
172	19	82.5	74	8.5
103	11.4	84.1	80	4.1
27	3	80.9	79	1.9
30	3.3	82.4	80.3	2.1
68	7.5	79.6	76	3.6
62	6.8	79.9	76.5	3.4
240	26.6	82.7	69	13.7
97	10.7	81.5	76	5.5
220	24.4	84.8	73	11.8
125	13.8	78.4	75	3.4
14	1.5	78.9	78.5	0.4
17	1.8	79	78.5	0.5
63	7	84.5	80.3	4.2
190	21.1	82.5	71.6	10.9
78	8.6	78.6	73.2	5.4
158	17.5	83.1	75.4	7.7

Table 7. Results showing Leq levels without horns

The site selected inside the campus for the test purpose was such that it has minimal background noise of the order of 43 dB(A) and free from any spurious reflections. Various horn devices such as Air pressure horn (APH), Electric horn (vibrosonic) and special horn (softone air horn) are tested. The results are shown in table.5. An average of 100 dB(A) is taken for air pressure horn after considering 3 dB attenuation by the surrounding environment at the 7m distance from the kerb side for calculation purpose. A set of correction values are arrived on the basis of measured individual horn noise levels and Leq levels of road traffic noise, It is shown in the table 6. The figure.6 shows the relationship between the number of horns/min to the increase in leq levels with the R^2 value of 0.921. The noise levels with and without horns are given in the table.7. On an average the traffic noise decreases by 1 to 12 dB after horn sounds are removed from Leq. Hence horn sounds contribute a relatively reasonable amount to the total noise exposure.

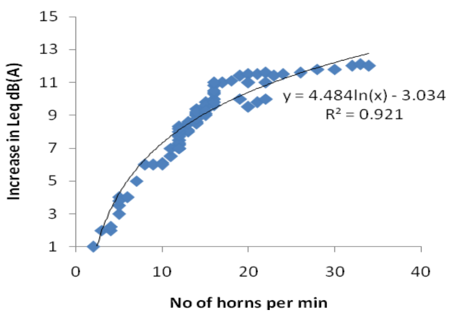

Figure 6. Relation between Increase in Leq dB(A) Vs No of horns per minute

EFFECT OF ROAD WIDTH AND MULTIPLE REFLECTIONS (C_{REF})

The evaluation of road traffic noise also involves the effects of the surroundings on the propagation of the noise. Two conditions are normally considered all over the world for surface on the same side of the road as the receiver, i.e. open conditions in which reflecting surfaces are sufficiently distant that their effect can be ignored and next is the configuration in which a building façade exists 1m behind the reception point. In this case a correction of upto 3 dB(A) is added depending upon the road width, however if the road width is more than 30m and building heights less than 6m then this effect can be considered to be negligible.

As per RLS 90 [4] it is given as

C_{REF} = 4 * (Building height) / (Road width)

For hard surfaces

C_{REF} = 2 * (Building height) / (Road width)

For absorbing surfaces

CONCLUSIONS

The present study has introduced a simple model for prediction of road traffic noise for heterogeneous traffic conditions. The regression model predicts Leq in terms of fundamental variables such as traffic flow and speed of the vehicle along with the correction factors such as honking effects and road width and building heights. In this study vehicles were divided into five categories and their equivalent noise emission were evolved in terms of PNCU. This will give some meaningful analysis for heterogeneous traffic conditions. Further horn noise is categorized separately according to the percentage of time occupied by horn sound during measurement duration and correction factor for different levels were given. The horn noise events can change the Leq in the studied environment by 2 to 13 dB(A). The developed multiple regression model can be used as a plug-in in any open source GIS softwares such as QGIS, GRASS etc for noise mapping purposes.

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