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PERFORMANCE OF FHWA MODEL FOR PREDICTING TRAFFIC NOISE: A CASE STUDY OF METROPOLITAN CITY, LUCKNOW (INDIA)

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Abstract. Industrial and transport activities are the two major sources of noise pollution in any metropolitan city. Lucknow city, the capital of the largest populated state Uttar Pradesh in India has an area of 310 sq. km and is rapidly growing as a commercial, industrial and trading centre of northern India. The population of Lucknow city as per census 2001 is 22.45 Lacs. It is expected that by the year 2021 it will make 45 Lacs. The total vehicle population in Lucknow city on 31 March 2008, was nearly 1 million with almost 80% two wheelers, 12% cars, 1.36% three wheelers, 0.45% buses etc. A study was carried out to assess the existing status of noise levels and its impacts on the environment with a possibility of further expansion of the city. Ambient noise levels were measured at different locations selected on the basis of land use such as silence, heavy traffic and residential and commercial zones. It was found that noise levels at all selected locations were much higher (75–90 dB) than the prescribed limits. The observed traffic volume and data on road geometry were used to predict noise levels using Federal Highway Administration Agency (FHWA) model and the calculated noise levels were compared with the observed levels for checking the suitability of this model for predicting the future levels. It was established that the results obtained by FHWA model were very close to the observed noise levels and that the model was suitable to be used for other similar metropolitan cities in India.

Keywords: buffer zones, equivalent noise level, noise barriers, FHWA model, ambient noise pollution.

1. Introduction

Vehicular noise pollution is increasing at an alarming rate in metropolitan cities with an increase in urbanization.

A rapid increase in population, unplanned urbanization and the development of transportation projects without environmental impact assessment may be listed as the main reason behind traffic noise (Abdel Alim *et al.* 1983; Ayvaz 1994; Morillas *et al.* 2002; Homburger *et al.* 1992).

In India, noise levels in metropolitan cities have reached very high levels making 76–80 dB(A) and traffic management technologies have failed due to a lack of enforcement and poor legislation. More than 55% of the total noise in our environment is due to vehicular movements. All India Institute of Medical Sciences New Delhi (AIIMS) has revealed that noise enlarges blood vessels of the brain thereby causing severe headaches. Even mild noise is enough to dilate the pupil of the eye. Repeated dilation makes it necessary to change the eyes' focus immediately, thus adversely affecting the ability to do delicate work. The aggravation of allergy, asthma, emotional breakdown, insomnia, hypertension, gastrointestinal problems, heart diseases, high blood pressure and malformation in foetal nervous system are only a few diseases caused by noise.

Li *et al.* (2002) performed a study to analyze traffic noise levels along three main roads in Beijing, China. They discovered that the selected roads were overloaded by traffic flow during daytime. Due to road traffic, noise levels were above relevant environmental standards by 5 dB(A).

Ali and Tamura (2003) conducted a traffic noise study in Greater Cairo, Egypt and carried out an extensive measurement in 21 sites. They measured the degree of annoyance by questionnaire. The received results revealed that there was a strong relationship between road traffic noise levels and the percentage of highly annoyed respondents.

Morrilas *et al.* (2002) carried out noise studies in Caceres, Spain and found out that noise levels were quite high with 90% of values higher than 65 dB(A) and the results were in coincidence with the results of other researchers.

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Koushki *et al.* (1999) conducted noise studies in Kuwait on the arterial roadway and observed that there was a strong correlation between traffic volume and noise level.

Bazaras (2006) performed studies of internal noise modelling problems of transport power equipment.

Kliučininkas and Šaliūnas (2006) investigated problems of noise mapping for the management of urban traffic flows.

Gupta *et al.* (1986) studied problems of traffic noise for various land uses for mixed traffic flow.

Rao (1991) carried out studies on prediction of road traffic noise.

Baltrėnas *et al.* (2007a) carried out efficiency evaluation of a noise barrier.

Baltrėnas *et al.* (2007b) performed a study to investigation of noise dispersion from seaport equipment on the enterprise territory and residential environment.

Bazaras *et al.* (2008) performed studies in Lithuania at intersections and established interdependency between noise levels and traffic flow.

Vaisis *et al.* (2008) carried out noise prediction modeling nearby Siauliai railway station (Lithuania).

Akgüngör and Demirel (2008) iinvestigated urban traffic based noise pollution in the city of Kirikkale (Turkey).

Paslawski (2009) investigated flexibility in highway noise management.

Therefore, it is the need of the hour to prevent noise before it reaches a dangerous level. Different types of vehicles cause different noise levels. Heavy vehicles, trucks in particular, are the most noise producing vehicles because of axle loads. If the axle load of a truck is reduced from nearly 2000 kg to 500 kg, a 15 dB(A) decrease in noise level is obtained. Vehicle speed is another major factor generating traffic based noise. The faster a vehicle travels the more noise it generates because of the friction between tires and pavement. Actually, as the speed increases the friction noise surpasses the motor noise (Homburger *et al.* 1992). Apart from the type of a vehicle and its speed, the other factors are:

- the volume of traffic;
- the number of heavy vehicles in the flow of traffic.

In addition, the following factors influence the noise level at a reception point at a reference distance from the highway:

- distance between the source and the receiver;
- ground absorption;
- obstruction due to noise barriers;
- obstruction due to a restricted angle of view;
- reflection effect.

Generally, the loudness of traffic noise is increased by heavier traffic volume, higher speeds and larger numbers of trucks. Vehicle noise is a combination of the noises produced by the engine, exhaust and tyres. The loudness of traffic noise can also be increased by defective mufflers or other faulty systems of vehicles. Other condition (such as a steep slope) that causes heavy labouring of motor vehicle engines will also increase traffic noise levels influenced by distance, terrain, vegetation and natural or manmade obstacles. Traffic noise is not usually a serious problem for people who live more than 150 m away from heavily travelled freeways or more than 30 to 60m from lightly travelled roads.

2. Methods of Reducing Highway Noise

Road traffic noise in most of the urban areas is increasing at an alarming rate which is a cause of concern for the residents living along the highways. Noise levels must be controlled in order to reduce its societal impacts. Reducing noise levels may be produced following Harris (1979) who suggested some noise control measures like:

- motor vehicle control;
- land use control;
- highway planning and design;
- buffer zones;
- noise barriers;
- using dead end streets for residential complexes;
- depressing freeways and arterial roads below the ground level;
- creating more gap between road and buildings;
- constructing high rise buildings along the roads providing barrier for low rise buildings;
- making external and internal sound insulated walls;
- making double glazed windows.

3. Noise Reduction on New Roads

All of the above described measures can be employed on both existing and new roads. However, the following additional measures may be introduced on new roads:

- A new road can be located away from noise sensitive areas, such as schools or hospitals and placed near less-sensitive areas such as business centres or industrial areas. New roads can also be located in developed areas.
- New roads can be constructed below ground level. A large amount of noise from vehicles travelling on a similar type of the road is deflected into the air by embankments on the side of the road. Therefore, these embankments function as noise barriers.
- A new road can be designed and constructed as level as possible. The elimination of steep slopes helps with reducing traffic noise. Although there are a huge number of noise reduction measures possible, however all of those have certain limitations. At the same time, there are many situations where none of these noise reduction measures can be employed successfully. In such situation, the only option left with the local authorities is to provide adequate muffler devices for the vehicles producing louder noise.

4. Traffic Noise and Traffic Variables

Noise from interrupted flow traffic in urban areas has different characteristics from traffic noise generated by free flow on rural highway. Noise levels in urban areas depend on surrounding conditions such as:

- carriageway width;
- building on road side;
- road intersection.

The noise generated by traffic under interrupted flow condition may also be regarded as the aggregation of individual vehicle noise. Vehicle operation under such condition is predominately due to acceleration and braking. The interrupted flow condition occurs at intersection, congested roads and other road geometrics where common acceleration and braking manoeuvres exist.

5. About FHWA (Federal Highway Administration Agency) model

Over the past decade, considerable progress has been made in developing techniques for predicting noise level for road traffic. Much of early work concentrated on forecasting noise level from freely flowing traffic and the result of these studies has been used to calculate noise emanating from the highway and a similar type of a new road carrying traffic travelling at moderate and high speed.

Pamanikabud and Vivitjinda (2002) formulated a model of highway traffic noise based on vehicle types with free-flow traffic conditions in Thailand. They developed a reference energy mean emission level for each type of vehicles based on direct measurement of L_{eq} from the real running condition of each type of vehicles.

Empirical model. An empirical model is developed based on the observation made over a period of time on an entity. Based on observation and past experience with a similar type of the problem, an equation is developed including parameters that vary with time for that particular entity. Empirical models include:

- FHWA model (Federal Highway Administration Agency model);
- CoRTN model;
- Gilbert model;
- STOP & GO model.

FHWA model. Traffic noise levels near roadways can be predicted based on individual vehicle noise levels, vehicle volume and speed, observer distance and other correlations. Traffic noise prediction algorithm is of the form given below:

$$L_{eq} = L_o + \Delta L_i, \tag{1}$$

where: L_o – basic noise level of a stream of vehicles; ΔL_i – adjustment applied.

The basic noise level is the noise emitted by a particular class of the vehicle at a distance of 15 m from the centre of the inner lane at the given speed and for the given road surface. FHWA model calculates noise level through a series of adjustments to the reference sound level measured through field measurements. The actual FHWA model is in the form given below:

$$L_{eq} = L_o + A_{vs} + A_D + A_B + A_F + A_G + A, \tag{2}$$

where: L_{eq} – hourly equivalent sound level; L_o – 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; A_S – ground cover correction.

Volume and speed correction:

$$A_{vs} = 10 \cdot \log_{10}\left(\frac{D_o V}{S}\right) - 25, \tag{3}$$

where: V – volume for the category in veh/h; A_{vs} – volume and speed correction; S – speed in km/h; D_o – reference distance.

Distance correction:

$$A_D = 10 \cdot \log_{10}\left(\frac{D_o}{D}\right)^{1+\alpha}, \tag{4}$$

where: D_o – reference distance given as 10 m; D – distance of measurement from the centre of each lane; α – ground cover coefficient.

Barrier correction can be estimated using the expression:

$$A_B = 5 + 20 \cdot \log \frac{\sqrt{2\pi N_{oi} \cos\theta}}{Tanth\sqrt{2\pi N_o \cos\theta}}, \tag{5}$$

where: N_{oi} – Fresnel number for the specific category; $N_o = 2\delta\lambda$ (where: δ – path difference).

Traffic flow adjustment:

$$A_F = 10 \log_{10}\left|\left(V\pi\, D_o \frac{V}{S}\right) ST\right|, \tag{6}$$

where: V – volume for the category in veh/h; S – speed in km/h; D_o – reference distance.

Grade correction is taken as the percentage of grade.

Limitations on FHWA model:

1. In this model, vehicles are classified into three categories namely light commercial vehicles, medium trucks and heavy trucks.
2. Adjustments are applied for the calculation of hourly L_{eq}.
3. Reference distance for measurement is taken as 15 meters from the centre of the near site lane and the actual distance of measurement is recorded.
4. No separate lane concept for acceleration or deacceleration is considered.

Noise Standards. The ambient noise standards of different types of zones being followed in India are given in Table 1.

Table 1. Ambient Noise Standards (India)

Area	L_{eq} dB(A)	
	Day time	Night time
Industrial Area	75	70
Commercial Areas	65	55
Residential Area	55	45
Silence Zone	50	40

Source: CPCB 1991

6. Field Studies

A study was carried out to assess the existing status of noise levels and its impacts on the environment with a possibility of a further expansion of the city. Ambient noise levels were measured at different locations selected on the basis of land use such as silence, heavy traffic and residential and commercial zones. This study was mainly intended to measure the noise level in urban and semi-urban locations and hence the locations were chosen so as to represent different zones within an urban area like residential zone, commercial zone, silence zone and heavy traffic zone. The details of the selected location are given in Table 2.

Table 2. Locations selected for sampling

Type of zone	Locations
Residential Zone	Engineering College, Govt Polytechnic, Thakurganj,
Commercial Zone	Nishatganj, Yahiaganj
Sensitive Zone	King George Medical College Hospital
Heavy Traffic Zone	Charbagh, Hussainganj, Alambagh, Quaiserbagh

Keeping in view the objective of the study, a field data collection programme was designed to collect data regarding the following parameters:

- classified traffic volume;
- classified traffic speed;
- ambient noise level;
- geometric parameters like road width, the number of lanes, lane width, shoulder width, the presence of median and its width, the presence of pedestrian sidewalk and its width and the details of roadside developments;
- longitudinal section parameters like the distance of a receptor point from the intersection;
- adjoining land use and the presence of bus stops etc. which would affect the continuous flow of traffic;
- miscellaneous information regarding the type and condition of roadway etc.

Traffic flow was generally uninterrupted in character. The basic noise data was taken by placing noise level meter 1.2 m above the ground level.

Classified traffic speed. The classified traffic speed was recorded for both directions at each of the selected locations. The classified traffic speed study was carried out for the same duration as the noise level study and the traffic volume study. The spot speed of vehicles was recorded using the traffic hand held radar. The identified vehicles categorized for spot speed study are listed below:

- car/jeep/van;
- scooter/motorcycle;
- light commercial vehicle;
- bus;
- truck;
- tractor trailer.

Ambient noise level. Ambient noise levels for the selected locations were collected using the Leutron make noise level meter. Ambient noise data was taken at varying distances from the pavement edge to incorporate the effect of distance in noise dissipation in the model development process. Ambient noise pollution data was collected continuously for a period of twelve hours for both directions at all identified locations. For data collection, each hour was divided into the intervals of 15 minutes and observations were taken at an interval of 15 seconds. Thus, a total of 240 observations were taken in an hour. The data is organized to calculate L_{10}, L_{50}, L_{90} and L_{eq}.

Geometric parameters. The parameters of road like road width, the number of lanes, lane width, shoulder width, the presence of median and its width, the presence of pedestrian sidewalk and its width and the details of roadside developments as well as miscellaneous information regarding the type and condition of roadway were also recorded etc. Adjoining land use and the presence of bus stops etc. would affect the continuous flow of traffic.

Traffic volume. As the directional classified traffic volume is the basic data requirement of this study, traffic volume studies were carried out at all locations identified for the detailed study. At all selected locations, traffic volume studies were conducted continuously for a period of 12 hours (8 am–8 pm). Directional classified traffic volume data was manually recorded in pre-designed, hourly traffic volume recording proforma subdivided into 15 minute intervals. Since the different classes of vehicles use the common roadway facilities without segregation on the highway, traffic flow becomes heterogeneous, and hence it is required to convert all the categories of vehicles into a single unit called Equivalent Passenger Car Units (EPCU).

Traffic volumes at all locations have been presented, both in the form of total vehicles per hour as well as converted into PCUs and expressed in terms of equivalent passenger car units. The conversion factors are given in Table 3. Traffic volume count in EPCU is given in Table 4.

7. Analysis, Results and Discussion

The noise levels recorded at each location were taken on an excel sheet and worked out.

The traffic volume and average traffic speed data of each location were also tabulated on an excel spreadsheet and from the equations given for each correction, the corresponding value for distance and speed corrections were worked out.

Table 3. Recommended EPCU values on urban roads

Type of vehicle	Equivalent Passenger Car Units (EPCU) factor	
	% composition of vehicle type in traffic stream	
	5%	10% and above
Two wheelers: motorcycle, scooter etc.	0.5	0.75
Passenger car, pickup van	1.0	1.0
Auto-rickshaws	1.2	2.0
Light commercial vehicle	1.4	2.0
Truck or bus	2.2	3.7
Agricultural tractor trailer	4.0	5.0

Table 4a. Total traffic volume at different locations

Time	Alambagh	Charbagh	Govt.Polytechnic	KGMC	Quaiserbagh
8:00–9:00 am	3173	3518	1854	2860	3473
9:00–10:00	3526	4954	1890	3211	3761
10:00–11:00	3663	4957	2165	3727	4586
11:00–12:00	3629	4603	1866	3702	3941
12:00–1:00 pm	3535	3881	1532	2683	4000
1:00–2:00	3100	3486	1555	2608	2650
2:00–3:00	3023	4351	1932	2359	2615
3:00–4:00	2907	3786	1847	3113	2830
4:00–5:00	2728	5385	2018	2773	3735
5:00–6:00	3036	5608	2324	3423	3425
6:00–7:00	3442	4765	1937	3421	2485
7:00–8:00	3212	4010	2040	4988	2560

Table 4b. Total traffic volume at different locations

Time	Yahiyaganj	Thakurganj	Nishatganj	Hussainganj	Engineering College
8:00–9:00 am	1747	1595	2238	4014	1736
9:00–10:00	2034	1866	2618	6121	1927
10:00–11:00	2328	1724	2952	7492	1714
11:00–12:00	2041	2262	2463	7805	2409
12:00–1:00 pm`	1826	2223	1943	7159	2185
1:00–2:00	1939	2080	2241	5553	1765
2:00–3:00	1694	2026	1717	5832	1996
3:00–4:00	1705	1669	2046	5579	2064
4:00–5:00	1558	1614	2156	7933	1891
5:00–6:00	1843	2024	2599	8964	2016
6:00–7:00	1834	2021	3124	6338	2156
7:00–8:00	1768	1819	3159	6128	3048

The L_{eq} obtained for near and far lanes were combined to get the final hourly L_{eq} values for each location the calculation of which has been compared with the observed L_{eq} values of each location.

A regression equation between the observed and FHWA calculated L_{eq} values for each location has been drawn and the regression coefficient R^2 has also been worked out to assess the performance of the model.

The correlation equation obtained between observed and calculated L_{eg} values for each location has been given in Table 5.

To check the sensitivity of the model, *t*-test was conducted and good results were yielded.

Table 5. Correlation equation between observed and calculated L_{eq} values (Noise Prediction Models – FHWA)

Locations	Equation	R^2 value
Engineering College	$Y = 0.7585\ X + 12.573$	0.8894
Thakurganj	$Y = 0.6524\ X + 18.636$	0.8727
Government Polytechnic	$Y = 0.8129\ X + 7.917$	0.9478
Yahiyaganj	$Y = 0.5606\ X + 25.592$	0.8730
Nishatganj	$Y = 0.8535\ X + 4.6493$	0.8616
King George Medical University	$Y = 0.9838\ X – 5.4472$	0.7301
Charbagh	$Y = 0.8369\ X + 5.9769$	0.9319
Hussainganj	$Y = 1.0205\ X – 9.6552$	0.9297
Alambagh	$Y = 0.9220\ X – 0.5620$	0.7133
Quaiserbagh	$Y = 0.8875\ X + 0.479$	0.7179

8. Conclusions and Comments

A combined regression equation for all locations selected on the basis of land use is then combined together to validate FHWA (Federal Highway Administration Agency) noise prediction model for Lucknow city taking 120 observed L_{eq} and 120 calculated L_{eq} values. These are plotted on the Cartesian co-ordinates and a liner equation is developed between these two values as shown in Fig.

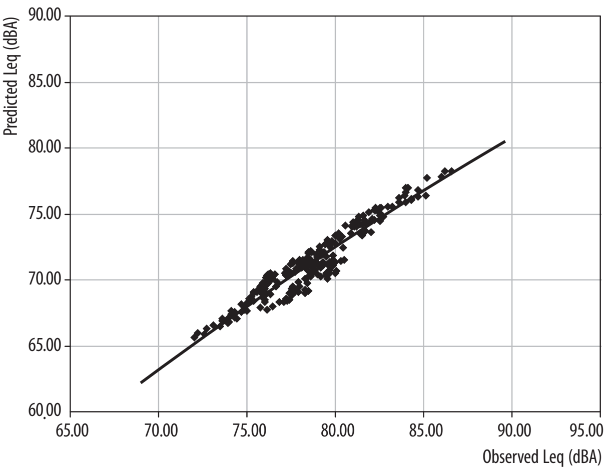

Fig. Correlation plot between observed and predicted L_{eq} values for Lucknow

The developed noise prediction model is:

$Y = 69.864 \cdot \ln(X) - 233.59$ and the model has $R^2 = 0.9075$,

where: Y – predicted L_{eq} noise level value; X – observed L_{eq} noise level value.

Hence, it can be concluded that FHWA model may be used for predicting noise pollution levels in metropolitan cities like Lucknow.

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