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FHWA Model for Predicting Traffic Jam Noise in Varanasi City India

Kanakabandi Shalini and Brind Kumar

Department of Civil Engineering, Indian Institute of Technology (BHU), Varanasi, U.P., India

Correspondence should be addressed to Kanakabandi Shalini, kskanakabandishalini@gmail.com

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Abstract Industrial and transport activities are the two major sources of noise pollution in any city. Most of the cities in India are facing serious noise pollution problems due to the concentration of motor vehicles and human population within the limited urban areas. Varanasi is the spiritual capital of India on the banks of the Ganga in Uttar Pradesh has an area of 1,550. Km^2. The population of Varanasi city as per census 2011 is 1,201,815. Main source of noise was vehicular traffic. A study has been performed in Varanasi city to assess the noise levels at selected locations with heavy traffic. Equivalent noise levels were measured at ten different traffic jam locations. From the data it was found that noise levels at all selected locations were much higher (70–90 dB(A)) than the prescribed limits. Federal Highway Administration Agency (FHWA) model was used to predict noise levels and the calculated noise levels were compared with the observed levels for checking the suitability of this model. It was observed that the results obtained by FHWA model were very close to the observed noise levels.
Keywords *Noise Pollution; Heavy Traffic; FHWA Model; Ambient Noise Levels*

1. Introduction

In the context of urbanization process, the road traffic noise is increased due to the increasing urban transport demand and leads to destroy the quality of life of people. With deteriorating level of mass transport services and increased use of personalized motor vehicles, vehicular noise pollution is assuming serious dimensions in most of the cities in view of its associated health hazards [1]. Vehicular noise pollution is increasing at an alarming rate in cities with an increase in urbanization. Road traffic noise mainly caused due to a rapid increase in population, unplanned urbanization and the development of transportation projects without environmental impact assessment [2].

The main source of road traffic noise is motor vehicles. Motor vehicles noise is created by mainly from horn, friction between tyre and roadway, engine, and exhaust system of vehicles. Patil and Nagarale (2013) reported that India is exceeding the permissible noise limits in major cities. Increasing the vehicle population is directly proportional to noise pollution and associated health effects and can cause both short term as well as long term psychological and physiological disorders like hearing impairment, hypertension, and ischemic heart disease, annoyance, and sleep disturbance. Disturbances created by noise may cause hypertension, headache, allergy, asthma, emotional breakdown, insomnia, hypertension, gastrointestinal problems, heart diseases, high blood pressure [1; 2; 3].

Shukla et al. (2009) reported that noise levels in India cities have reached very high levels i.e., 76–80 dB(A). Due to a lack of enforcement and poor legislation, the traffic management technologies have been failed. Motor vehicles, which are significant part of this urban environment, and produce more than 55% of the total noise in our environment [2].

Koushki et al. (1993) monitored traffic noise at 42 locations in 13 districts in Riyadh, Saudi Arabia. They found the perceived impact of noise on their welfare and health and maximum mean district equivalent noise levels by road type were presented. They found that extent and degree of annoyance with traffic noise varied with the change in the functional classification of urban roadway. Reported that traffic noise caused headaches, and nearly one in four stated nervousness as a result of exposure to noise, only in 10 indicated awareness concerning the loss of hearing from long term exposure to traffic noise. Annoyance levels with traffic noise also increased with a change in the functional classification of roadways.

Koushki et al. (1999) presented the measurements of traffic noise at the edge of traffic lanes and at distances equivalent to residence locations, and traffic flow variables for nine freeway/ arterial/collector roadway locations in Kuwait. They reported that 50% of the time during the daily peak periods the noise from roadway traffic ranged between 67 and 87 dB(A), at the local street; between 71 and 92 dB(A), at the arterial roadway, and between 83 and 94 dB(A) at the freeway section. The L50 noise levels were 69, 74, and 76 dB(A) at the local, arterial, and freeway sections, respectively. Li et al. (2002) studied the traffic noise levels in the roads of the Beijing city, China. They found that traffic flow conditions on the main city roads in Beijing are significant, exceeding national standards by 5.2 dB(A).

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. Pandya et al. (2003) states that road transportation plays a major role in the economic and social development of a country. They proposed a method to reduce the noise levels; one approach is to utilize education, persuasion and the tools of public relations to emphasize the need to control unreasonably loud, disturbing or unnecessary noise. Another approach is to controlling the impact of traffic noise on communities is to reduce the noise at the source by designing quieter vehicles and quieter road surfaces.

Phan et al. (2008) collected data on community response to road traffic noise, from the cities. Hanoi and Ho Chi Minh, in order to investigate the characteristics of road traffic noise and to establish dose-response relationships for road traffic noise in Ho Chi Minh's. They reported that road traffic noise in Hanoi and Ho Chi Minh City was characterized by a large number of motorbikes emitting frequent horn sounds. Pathak et al. (2008) to evaluate the noise pollution problem in the Varanasi city and its effect on the exposed people. They reported that most of the sampling sites were badly affected with traffic noise as these noise levels were higher then compared to the standards of the Central Pollution Control Board.

Road traffic noise has become serious problems to many authorities. Anti-noise laws, major highway control regulations, ordinances, and other governmental laws that concern environmental noise cannot be decreased without a priori empirical considerations. Therefore, it is the needed to prevent noise before it reaches a dangerous level.

In this paper attempt has been made to study the noise levels due to traffic in selected areas of Varanasi city and to predict noise levels using Federal Highway Administration Agency (FHWA) model and compared the calculated valued with observed levels for checking the suitability of this model.

2. Back Ground of Varanasi City

Varanasi is one of the oldest cities in continuous habitation in the world, with a history dating back to more than 3000 years. It is a major religious, cultural and educational centre of India. Varanasi town lies between the 25°15'N to 25°22' N latitudes and 82°57'E to 83°01'E longitudes. The river Ganga only here flows in a south-to-north direction, having the world famous Ghats on the left bank of the river. The environment of the town is tropical with temperature ranging from 5°C in winter to 45°C in summer. The mean annual rainfall lies between 680 mm to 1500 mm with a large proportion of its occurring during the months of July to September. Varanasi heavily populated city. According to 2011 census Varanasi has a population of 1,201,815. Its population growth rate over the decade 2001 to 2011 was 17.32%. Increase in living standards due to exponential economic growth the number of vehicles has also having the significant contribution in vehicular traffic there by leading to noise pollution. Varanasi is unable to support the exponentially growing traffic because its ancient buildings and old roads have stood since ages. Traffic congestion is a common scene in the entire city [11].

3. Methodology

A progressive development in predicting the traffic noise levels has made from past decades. Most of the early work concentrated on forecasting noise level from freely flowing traffic. 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.

Traffic noise prediction models are used in the design of highways and other roads and sometimes in the assessment of existing or envisaged changes in traffic noise conditions. These models are generally needed to predict sound pressure levels, specified in terms of L_{eq}, L_{10}, etc. The prediction models represent national responses to the noise pollution concerns, and also from the current interest in environmental matters generally [12].

FHWA (Federal Highway Administration Agency) Model

FHWA (Federal Highway Administration Agency) model, like several other traffic noise prediction models, arrived at a prediction noise levels through a series of adjustment to a reference sound level. In FHWA model, the reference level is the energy mean emission level. Adjustment are then made to the reference energy mean emission level to account for traffic flows, for varying distance from the roadway, for finite length roadways, and for shielding.

$$L_{eq} = L_o + \Delta Li$$

Where: L_o – basic noise level of a stream of vehicles; ΔLi – adjustment applied.

FHWA model calculations were depend on a series of adjustments to the reference sound level measured through field measurements. L_{eq} in this paper was calculated using the following formula [13].

$$L_{eq}(h)_i = (L_o)E_i + 10\,log\left(\frac{N_i D_o}{S_i}\right) + 10\log\left[\frac{D_o}{R_n} - \frac{D_o}{R_f}\right] - 30$$

Where

$L_{eq}(h)_i$ = is the hourlly equivalent sound level of the ith class of vehicle

$(L_o)E_i$ = is the reference energy mean emission level of ith class of vehicle

N_i = is the no of vehicles in the ith class passing a specified point during some specified time

D_o= is the refernce distance at which the emission levels are measured. In FHWA model, D_o is 15 meters

S_i = is the average speed of ith class vehicle and is measured in kilometers/ hour

T = is the time period over which the equivalent sound level computed

R_n = is the distance in meters between the centerline of the near end of the roadway segment and the observer

R_f = is the distance in meters between the centerline of the far end of the roadway segment and the observer

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 Leq.
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 de-acceleration is considered [2].

4. Field Studies

Noise levels were measured at different locations in order to study the impacts on the environment with a possibility of a further expansion of the Varanasi city. Ambient noise levels were measured at different locations selected on the basis of traffic jams. Details of study locations in the Varanasi city covered during the survey are shown in Table 1.

Table 1: *Details of Study Locations*

Location	Location
Ravidas Gate	Cantt.
Rathyatra	Manduadi
Godowalia	Maidagin
Girijaghar	Andhra Pool
Saajan	Maldahiya

Keeping in view the objective of the study, a field data was collected. Geometric parameters like road width, the number of lanes, and lane width were measured. Longitudinal section parameter like the distance of a receptor point from the intersection was measured.

Classified traffic speed: The classified traffic speed was measured 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 speed was calculated using this formula.

$$q = KV_s$$

Where q = the average volume of vehicles passing a point during a specified period of time (vehicles/hour)

K = the average density or number of vehicles occupying a unit length of roadway at a given instant (vehicles/ km)
V_s = space mean speed of vehicles (kmph)

Ambient noise level: Ambient noise levels for the selected locations were collected using the noise level meter. Ambient noise pollution data was collected continuously for a period of 10 min at all identified locations.

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 10 min.

Here Passenger Car Equivalent (PCE) was used to convert a mixed vehicle traffic stream into an equivalent traffic stream. Srivastava *et al.*, (2003) had suggested an equation for determining the passenger car noise equivalence factor (PNCE).

Passenger Car Equivalent (PCE): Traffic volumes at all locations have been presented, both in the form of total vehicles per hour as well as converted into PCEs and expressed in terms of equivalent passenger car units [14]. Traffic volume count in PCE is given in Table 2.

Table 2: *PCE values of Different Vehicles at Ten Intersections*

Intersection	Cycle	Motor cycle	Auto	Rickshaw	Car	Bus	Truck	Others
Andhra pool	0.0401	1.5738	2.8894	0.0613	1	5.5970	7.2023	3.9812
Ravidas gate	0.0455	1.6304	3.0915	0.0649	1	4.8895	8.5354	3.8012
Godowalia	0.0451	1.2596	2.6384	0.0216	1	4.0033	6.6112	2.1345
Girijaghar	0.0444	1.3665	3.0846	0.0636	1	3.4543	7.1045	3.1645
Saajan	0.0409	1.4600	2.9469	0.0563	1	6.0217	8.1529	2.2901
Cantt	0.0395	1.2338	2.9589	0.0600	1	6.4929	7.3494	3.6314
Manduadi	0.0415	1.7703	3.2862	0.0607	1	6.6127	8.2684	5.4983
Maidagin	0.0406	1.7079	3.0898	0.0630	1	7.2991	8.3930	3.0957
Maldahiya	0.0416	1.0935	2.8218	0.0626	1	5.5184	7.4051	2.3987
Rathyatra	0.0393	1.1620	2.8232	0.0655	1	5.4187	7.0447	4.4632

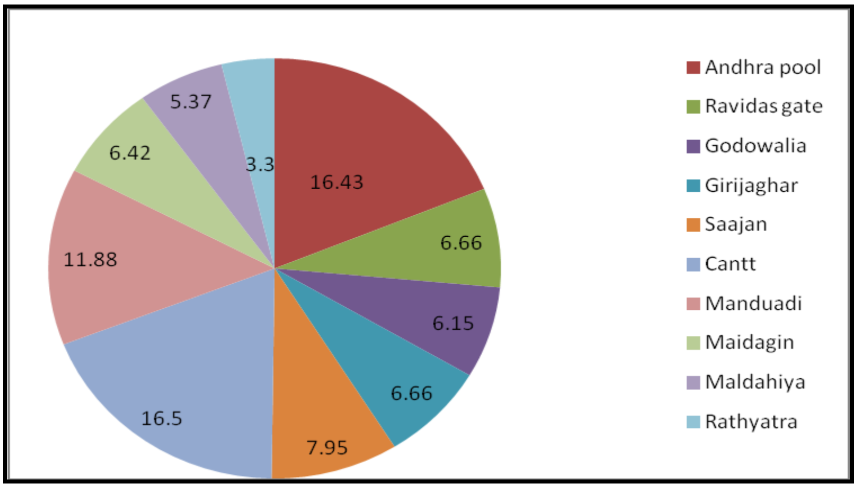

Figure 1: *Percentage of Heavy Vehicles at Different Intersections*

5. Analysis, Results and Discussion

From the observed data, we were calculated the traffic volume, speed of the vehicles, and Leq values at each location. The Leq obtained for near and far lanes were combined to get the final hourly Leq values for each location the calculation of which has been compared with the observed Leq values of each location. Leq values for different locations were tabulated in Table 3.

Table 3: *Leq Values for Different Locations Observed and Calculated*

S. No	Location	Leq Observed	Leq Calculated
1	Andhra pool towards Cantt 1	87	87.29269
2	Andhra pool towards Cantt 2	100	99.72478
3	Ravidas Gate 1	79	79.89382
4	Ravidas Gate 2	81	84.29473
5	Ravidas Gate 3	80.5	82.11419
6	Godowalia towards Bata Show Room 1	82	79.85732
7	Godowalia towards Bata Show Room 2	85	84.39069
8	Godowalia towards Titan Show Room	85	83.90565
9	Godowalia	83	82.23308
10	Girijaghar towards HP Petrol Bunk 1	86	80.02736
11	Girijaghar towards HP Petrol Bunk 2	86.5	84.26301
12	Girijaghar towards Dinshwas	86	81.21241
13	Girijaghar towards Ganga Opadi Kedhur	87	86.83675
14	Saajan towards Sigra 1	86	87.64154
15	Saajan towards Sigra 2	86	86.4983
16	Saajan towards Sigra 3	86	82.80811
17	Saajan towards Sigra 4	85	82.40663
18	Saajan towards IP Mall	91	92.68291
19	Saajan towards Sigra 5	92	90.00023
20	Cantt towards Lahartara	86	84.77389
21	Cantt towards Andhra Pool	85.5	84.84456
22	Cantt towards Lahartara 2	89.5	85.34415
23	Cantt towards Nadesar 1	92	90.98418
24	Cantt towards Lahurabir	84.5	81.33911
25	Cantt towards Nadesar 2	90	90.22529
26	Cantt towards fly over	90	89.43825
27	Manduadi 1	87	87.18489
28	Manduadi 2	87	88.22607
29	Maidagin towards Kabir Chaurah 1	87	81.53178
30	Maidagin towards Kabir Chaurah 2	93	94.17099
31	Maldahiya towards Teliyabaag 1	81.5	80.65819
32	Maldahiya towards Teliyabaag 2	93	91.89976
33	Rathyatra	87	85.90245

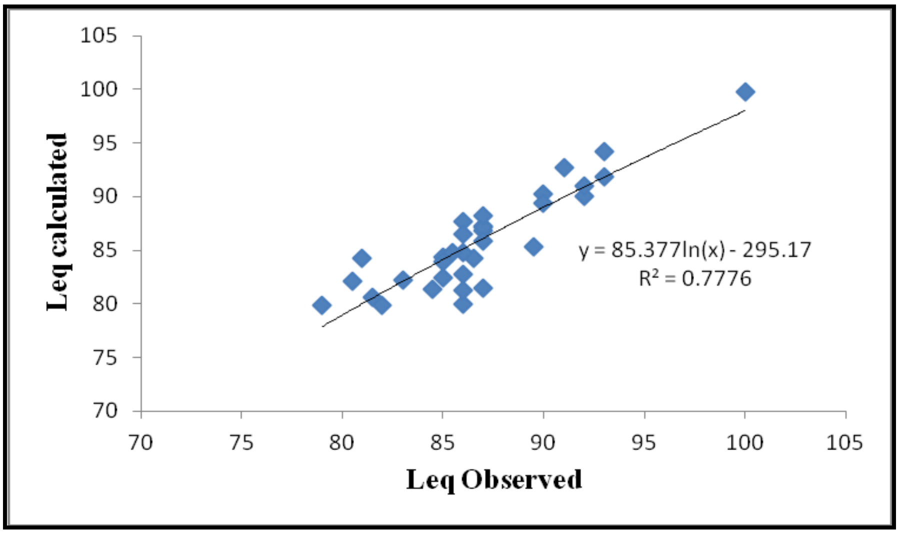

Figure 2: *Correlation Plot between Observed and Predicted Leq Values*

5. Conclusions

Leq values predicted from FHWA model were almost same to observed Leq values.

The developed noise prediction model is

$$\text{Predicted } Leq \text{ noise level value} = 85.3 \ln(\text{Observed Leq noise level value}) - 295.1$$

Hence, it can be concluded that FHWA model may be used for predicting noise pollution levels in Varanasi city. Vehicles, in fact, are forced to reduce their speed because of congestions, traffic jams and safety distance, resulting in a lower than expected equivalent level.

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