Development of in-vehicle noise prediction models for Mumbai Metropolitan Region, India

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ABSTRACT

Traffic noise is one of the major sources of noise pollution and has very critical effects on human health. In this study, prediction models of noise, which can measure the noise level experienced by the commuters while driving or travelling by motorized vehicles in the Mumbai Metropolitan Region, India, were developed. The models were developed by conducting a comprehensive study of various factors (e.g., speed of the vehicle, traffic volume and road characteristics etc.) affecting the levels of concentration of noise. A widespread data collection was done by conducting road trips of total length of 484.6 km via different modes of transport like air-conditioned (A/C) car, non A/C car, bus and intermediate public transport (i.e., traditional 3-wheeler Autos). Multiple regression analysis was performed to develop functional relation between noise exposure by passengers while travelling (which was considered as a dependent variable) and explanatory variables such as traffic characteristics, vehicle class, speed of the vehicle, various other location characteristics etc. Noise levels are generally high near intersections and signalized junctions. Independent data sets (for each mode of transport) were used to validate the developed models. It was identified that maximum differences between observed and estimated values from the model were within the range of ±7.8%.

Key Words: Traffic Noise, Volume, Speed, Decibel, Mumbai.

INTRODUCTION

Due to increasing urbanization and growing traffic levels, Indian metro cities are more confronted with the need to deal with the impact of noise in day-to-day life *(1, 2).* In a survey conducted by the Central Pollution Control Board (CPCB), India, found that noise levels in all Indian metro cities are more than permissible limit. Also, with the increase in economic trends and change in lifestyle, noise pollution is expected to increase in most of the metropolitan cities in the future. Exposure to environmental noise due to transport affects public health *(3).*

Road traffic is the most widespread source of noise pollution in most of the metro cities (particularly in developing countries) and the most prevalent cause of annoyance and interference *(4).* As per the ministry of Environment and Forest, Government of India, noise standard levels (ambient noise level experienced due to vehicle at running stage) recommended (day time) for automobiles are- 75dB in industrial area, 65dB in commercial area, 55 dB in residential area and 50dB in silence zone. In Indian metro cities like Mumbai, day-to-day travel and commuting could be considered as a predominant daily activity which leads to exposure to very high noise levels. According to a recent survey, 1 in 4 workers in India commute over 90 minutes/day; and Mumbai being the business hub of India, even larger duration can be predicted *(5).* Another survey conducted in Mumbai articulates that the average one way commute is 41 minutes, although 41 percent of Mumbai commuters have to travel over three quarters of an hour each way *(6).* Since the time spent by people in Mumbai in commuting is high compared to other cities; therefore, it became imperative to calculate the in-vehicle noise exposure to the people commuting in Mumbai. Though a few researches has been carried out to calculate the ambient noise pollution *(7, 8, 1)* but there are not much research work available for calculating the noise exposure to commuter travelling inside a vehicle in Indian road condition particularly Mumbai.

Unlike most of the developed cities in the world, in India, in addition to vehicle engine noise and noise due to interaction between road surface and tyres, major source of noise is due to vehicle horn. Due to lack of proper traffic system and driver discipline, high traffic volumes and congestion, drivers use horn very often throughout the journey. Various research papers have proposed a range of models to quantify the traffic noise levels at different traffic volumes, locations and at different times (*9, 10, 11, 12*). However, as far as authors are aware, there is no model developed to estimates the traffic noise level exposure by a passenger inside a vehicle for Indian road conditions and for different modes of transport (air-conditioned (A/C) car, non A/C car, bus and intermediate public transport (i.e., traditional 3-wheeler Autos) etc).

In this research study, traffic noise (experienced by commuters) data was collected according to the vehicle type and type of road surface (Bitumen and concrete). Four different vehicles type considered for the study were Car with and without air conditioned facility, traditional three wheeler intermediate transport vehicle (auto) and bus. Multiple regression models were developed and validated.

STATE-OF-THE ART LITERATURE AND RESEARCH MOTIVATION

Road traffic noise has an adverse effect on sleeping cycle of human-being of which commonly observed short-term effects are prolonged sleep latency, shallow sleep and reduction in sleep minutes (*13*). Long term exposure to noise acts as behavioral, psychological and physiological stressor (*14*). Irreversible hearing loss because of damage of sensory hair cells of the inner ear may occur due to prolonged exposure to high intensity noise (*15*). Sufficient evidence for a causal relationship between noise exposure and hearing impairment, hypertension, ischemic heart disease, annoyance and sleep disturbance has been established in a review article by Vermeer and Passchier (*16*). Exposure to noise has an undesirable effect on the health of children and those exposed for a long term road traffic noise exposure face an increased risk of chronic stress hormone regulation disturbances (*17*). Zhao et al (*18*) have established a logistic regression to indicate exposure to noise as a significant determinant of prevalence of hypertension. Significant findings have been established against the relation of noise and cardiovascular disease and extended noise exposure can contribute to the prevalence of cardiovascular disease (*19*).

Qudais and Alhiary (*20*) developed statistical models using 14,235 noise level measurements which established relation between equivalent noise level and traffic volume, traffic speed, distance, percentage of heavy vehicles and road roughness data obtained from (British Pendulum). Filho (*21*) developed empirical expressions with reasonably good correlation indexes to analyze the effect of traffic composition on the noise generated by typical Brazilian roads by plotting noise levels against the composition of the traffic. Ogle and Wayson (*22*) examined the influence of vehicle speed on the noise spectra produced by motor vehicles and developed a mathematical relationship to predict the shift in frequency spectra and subsequent change in dominant frequency. Samuels (*23*) developed a method for the prediction of traffic noise around relatively simple signalized intersections. The measured and predicted traffic noise levels were compared at selected intersections in Australia and New Zealand. Qudais and Alhiary (*24*) evaluated the major factors affecting traffic noise levels at signalized intersections by collecting traffic noise levels and the factors expected to affect noise at 40 signalized intersections. Equivalent noise levels were found to be mainly dependent on traffic volume, maximum noise levels on the number of heavy vehicles passing through the intersection and horn effect whereas minimum noise levels were dependent on pavement surface texture. Zuo (*25*) explored the temporal and spatial variability of traffic noise in Toronto and observed that noise variability was predominantly spatial in nature rather than temporal with variability accounting for 60% of the total observed variations in traffic noise. The independent variables such as traffic volume, length of arterial road, and industrial area explained the majority of the spatial variability of noise. Noise generated due to traffic is related to the parameters like pavement type, speed of vehicle and traffic composition etc. (*26*). Sound generated due to interaction between tyre and road type also contributes to traffic noise. Pavement surface characteristics are the major factors towards the noise generated due to tyre and pavement interactions (*27*). Passenger or driver spend most of their time inside the vehicle during their journey rather than outside vehicle or on-road atmosphere. Distinguished models have been generated over the last few years for the traffic noise prediction, some of them are explained in Table 1.

TABLE 1 Existing Models

Authors	Factors Considered	Remark
Kumar P. et al., (1)	• Average Vehicle Speed • Heavy Vehicle Percentage • Traffic Volume	• Ambient Environment Condition • Used Artificial Neural Networks • Receptor at 8.5m from the road
Qudais-Abo et al., (25)	• Average Vehicle Speed, • Heavy Vehicle Percentage • Traffic Volume • Use of Horn	• Ambient Environment Condition • At Signalized Intersection • Maximum and Minimum Noise level Equations
Banerjee et al., (7)	• Traffic Volume • Percent Heavy Vehicle • Road Width	• Ambient Environment Condition • Inclusion of Land Use Characteristics • Different models for day and night condition
FHWA model	• Traffic Volume • Speed of the vehicle • Ground effect	• Ambient Environment Condition • Inclusion of adjustment factors for every variable • Software package
CoRTN model	• Traffic Volume • Percentage of Heavy vehicles • Type of pavement • Receptor Distance • Shielding factor • Angle made be vehicle to rector along the line of road • Road Gradient	• Ambient Environment Condition • Inclusion of correction factors • Receptor at 8.5m from the road

Many research studies have been done on noise level experienced outside the vehicle due to traffic (*7*, *8*, *1*) but not inside the vehicle. Since the time spent by people in commuting in Mumbai is high compared to other cities so it became imperative to calculate the noise exposure to the people commuting inside vehicles in Mumbai. In this study authors have tried to find out how different types of pavement, vehicle speeds and traffic density affect noise level exposure to a commuter traveling inside a vehicle. In this study, to lodge this attribute in prediction of noise, authors have considered two types of pavement surfaces: (a) concrete and (b) bitumen pavement.

DATA COLLECTION

Data was collected for various modes of transport like buses, car (with and without air conditioning facility) and intermediate public transport (i.e., traditional 3-wheeler Autos).

Site Selection

The routes have been selected such that most of the Mumbai Metropolitan area has been covered ranging from Powai in North East to Bandra in West, Kandivali in North West to Bandra in West, Bandra in West to Colaba in South, Colaba in South to Powai in North East (see Table 2 and Figure 1). Factors considered while deciding the routes were availability of bus services in the selected road network, inclusion of various types of road network, vehicle composition and activities in nearby area.

TABLE 2 Field Trips

Road Section (Part referred in Figure 1)	**Length**	**Mode of travel**
Bandra to Fort (*Part A)*	25.1 km	Bus, Car A/C, Car Non A/C
Fort to Chembur *(Part B)*	19.5 km	Bus, Car A/C, Car Non A/C
Chembur to IIT (Part C)	12.5 km	3 wheeler IPT, Bus, Car A/C, Car Non A/C
Kandivali to Bandra (Part D)	19.8 km	3 wheeler IPT, Bus, Car A/C, Car Non A/C
IIT to Kandivali (Part E)	15.1 km	3 wheeler IPT, Bus, Car A/C, Car Non A/C
Bandra to IIT (Part F)	20.1 km	3 wheeler IPT, Bus, Car A/C, Car Non A/C

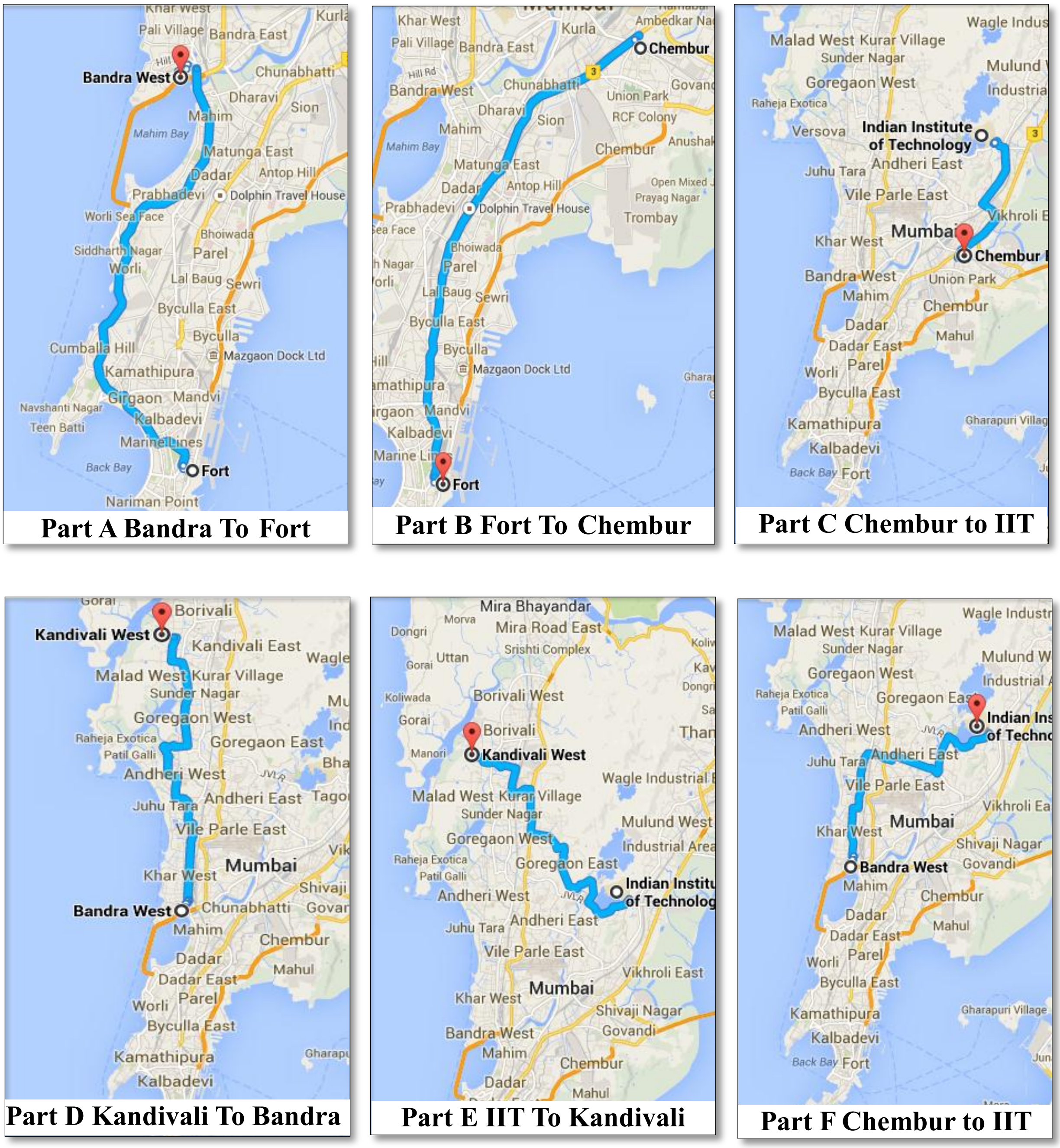


FIGURE 1 Field Trips

Instrumentation

Real time noise level meter-SL 1352 (manufactured by HTC instruments) was used to collect the noise level on second-by-second time interval in the field. Noise level meter instrument has data logger facility and it gives noise level absorbed with respect to the time of observation. Noise level meter was mounted on a tripod at a height corresponding to the ear-level of an average height person when they sit inside a vehicle to calculate the actual noise experienced by the commuter while travelling inside the vehicle. Trimble Juno SB-500 series, Hand-held GPS was carried throughout the experiments inside the test vehicle to give spatial reference and its time was synchronized with sound level meter. While processing the data, GIS software was used to extract all the required geographical parameters.

Field Trips

In total 26 trips were conducted through different types of vehicle equipped with GPS and noise level meter each designed to sample noise data. Characteristics like number of lanes and signal, type of road surface and intersection area were noted in a survey sheet as per the GPS time while travelling inside the vehicle. To neglect the effect of variation in self-vehicle parameters on data collection, same car was used for entire data collection inside car (both A/C and non A/C). While collecting data from non-air conditioned car, windows of the car were kept open. To collect noise level data inside buses, authors traveled as common passengers with sound level meter instrument and GPS device.

Intermediate public transport (i.e. traditional 3-wheeler Autos) (see Figure 2) are more susceptible to higher noise levels because of its comparatively open structure and low height, much closer to the ground than any other vehicle considered in the study. Sound level meter was mounted on the rear seat of the auto where passengers sit. To neglect the effect of variation in self-vehicle parameters on data collection, same auto was used for entire data collection of noise level.

FIGURE 2 Intermediate public transport (Auto)
(*source: www.rickshawchallenge.com)*

During data collection, it was observed that more than 50% of the total travel time, noise levels were more than 70dB. That means, a normal passenger exposes to more than 70dB of noise for at least 50% of his/her total journey time. At some cases, abrupt increase in noise levels (above 90dB) were observed due to vehicle horn. Generally in congested traffic condition in India, vehicles will be very close proximity to each other, further noise due to horn lead to more noise levels to commuters. Average noise level observed inside a non-air conditioned car and air conditioned car were 70.8dB and 65.64 dB respectively.

METHODOLOGY

Based on the literature review conducted, various factors affecting commuter daily exposure to noise pollution during travel were identified. Noise experienced by a passenger inside a vehicle depends upon traffic parameters like vehicle composition, speed distribution, traffic volume and congestion on the road (*21*, *28*).

In this study authors have tried to find out how different types of pavement, vehicle speeds and traffic density affect noise level exposure to a commuter traveling inside a vehicle. For this study, noise level is measured during both peak hour and non-peak hour flow. On-road traffic volume and speed of the test vehicle were considered in traffic parameters. Number of lanes and road surface type (bitumen or concrete) are considered in road infrastructure parameter.

Areas near the intersections are having more noise pollution mainly because of congestion and vehicle horn. While doing the data collection it was found that this effective area depends upon the widespread geographical area of the intersection. Here author considered the area under the radius of five times the number of lanes combining both ways of the widest approach of intersection from the center point as the intersection area. Further, data was being extracted and matched according to the synchronization of GPS time and sound instrument time. Geographical information of the trips made were necessary to get the number of lanes and intersection area details. This Geographical information was obtained from the data collected through GPS device and later on processed in a GIS software. KML files obtained from GPS were processed through Google earth to obtain Geographical information. Traffic volume was obtained with the help of transportation planning software-*CUBE*. A network file for the CUBE software was created by the Transportation System Engineering group, IIT Bombay, Mumbai. Traffic volume count obtained from the software was verified for all the road links and corridors inside the study area. Traffic volume obtained from CUBE is the total volume combining both the directions. Width of roads was noted in the form of number of lanes. Overall methodology is shown in Figure 3.

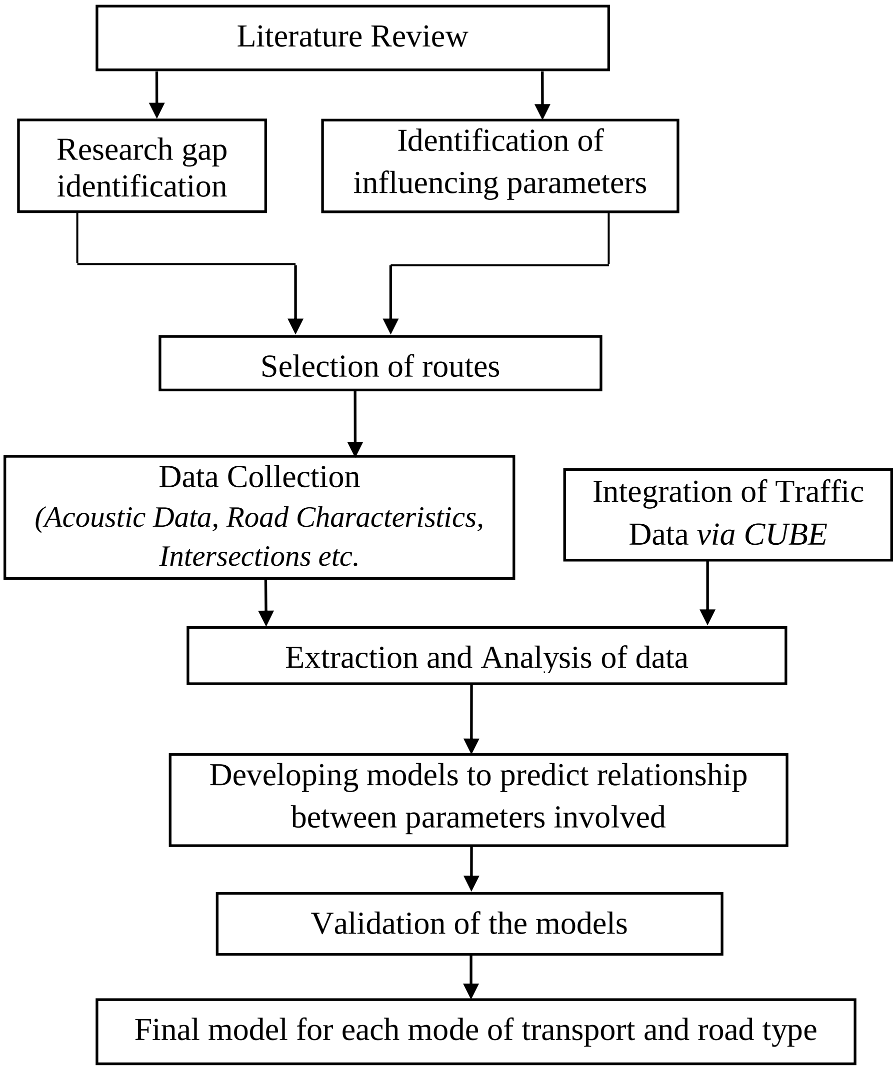


FIGURE 3 Methodology

Mathematical formulations were developed by multiple regression of all the traffic and road infrastructure parameter as independent variables and noise level experienced by a commuter, while travelling inside the vehicle through traffic, is considered as dependent variable. Separate models were developed for each mode of transport for the study area and for different types of roads (Bituminous and Concrete).

MODEL

In this study, linear regression modelling was considered to build functional relationship between Noise and other independent parameters. For developing the models, initially authors considered all the independent variables for the regression analysis. Further, a step-by-step independent variable drop-off method (based on t-statistics and R-square values) was adopted to arrive the final model. Eight different models were developed for each type of road surface and vehicle. These models are shown in Table 3.

TABLE 3 Models

Type of Vehicle	Type of Road	Model	R square Value	Model No.
CAR with Air-conditioning	Concrete Road	$N_{cAC}^{C} = 61.993 + 0.067N + 7.311I + 0.001732V + 1.9924S$	0.78	1
	Bitumen Road	$N_{cAC}^{B} = 61.611 + 0.211N + 7.14I + 0.0007621V + 0.1404S$	0.72	2
CAR without Air-conditioning	Concrete Road	$N_{cNAC}^{C} = 69.624 + 0.0876N + 2.675I + 0.0019V$	0.78	3
	Bitumen Road	$N_{cNAC}^{B} = 69.611 + 0.0875N + 2.678I + 0.0022V$	0.75	4
3 Wheeler IPT	Concrete Road	$N_{Auto}^{C} = 7.5783N + 24.4503I + 0.00153V + 0.823S$	0.82	5
	Bitumen Road	$N_{Auto}^{B} = 7.394N + 15.4195I + 0.00027V + 0.82S$	0.76	6
BUS	Concrete Road	$N_{Bus}^{C} = 76.0896 + 0.2242N + 8.3834I + 0.00214V + 21.7632S$	0.82	7
	Bitumen Road	$N_{Bus}^{C} = 74.021 + 0.22362N + 8.410I + 0.002V + 20.9894S$	0.84	8

Where,
N_{cAC}^{C} is the noise level in decibel inside a car with air condition facility for concrete pavement,
N_{cAC}^{B} is the noise level in decibel inside a car with air condition facility for bitumen pavement
N_{cNAC}^{C} is the noise level in decibel inside a car without air condition for concrete pavement
N_{cNAC}^{B} is the noise level in decibel inside a car without air condition for bitumen pavement
N_{Auto}^{C} is the noise level in decibel inside an auto for concrete pavement
N_{Auto}^{B} is the noise level in decibel inside an auto for bitumen pavement
N_{Bus}^{C} is the noise level in decibel inside a bus for concrete pavement
N_{Bus}^{B} is the noise level in decibel inside a bus for bitumen pavement
N is the number of lanes on the road,
I is the intersection area (I= 1 for intersection area and zero for other sections of road),
V is the traffic volume in PCU in both the direction and
S is the speed of the vehicle in meter per second

Note that in model 1, for car with air conditioning and concrete road, R square value obtained was 0.78 with higher t-distribution values than regression model without constant. Higher value of coefficient I indicates that intersection area has more effect on the noise level experienced by a passenger inside an air conditioned car. Very low value of coefficient V indicates that it has very less significant effect on noise level exposed by passenger. A constant value 61.693 may be because of car engine noise which is significant in non-air conditioning car. R square value obtained in Model 2, for car with air conditioning and bitumen road type was 0.72. Slight changes in the coefficient indicate that there is no significant change due to road type. The model has a constant value of 61.611 which indicates the residual value of noise even if the car is running alone on the road.

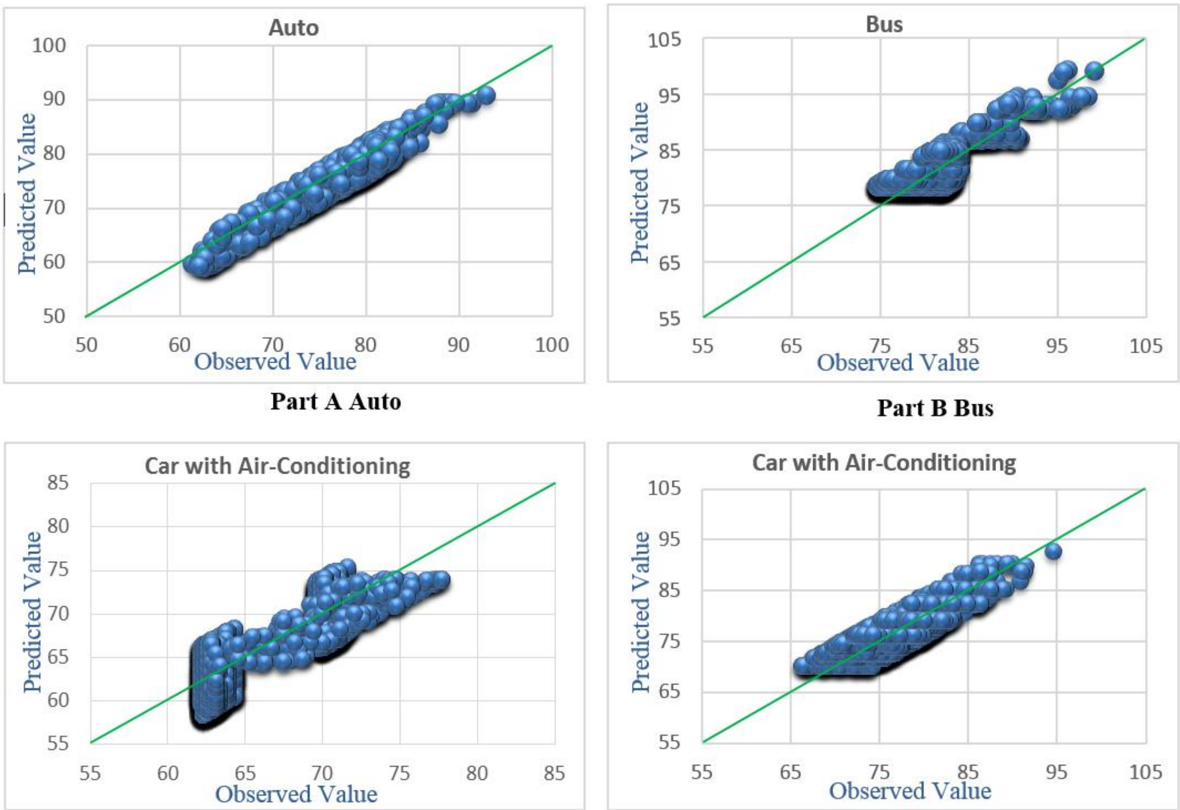
Model 3 and 4 are for car without air conditioning and road type of concrete and bitumen respectively. R-square value obtained for model 3 was 0.78. Zero value of coefficient of vehicle speed indicates that it has no significance in air condition car. But it has larger constant value which might be due to open ventilation in non A/C car. R-square value obtained for the model 4 was 0.72. In this case, value of coefficient for speed is zero indicating that speed has no significance in air condition car for concrete for bitumen pavement type also. There is very small change in coefficient values in model 4 and model 3, this indicates that type of road pavement has very less effect on noise levels experience by a commuter inside a car (air conditioned).

Note that model 5 for Intermediate Public Transport (IPT) (i.e., traditional 3-wheeler Auto mode) and concrete road, R-square value obtained was 0.82. Very large values of coefficient of speed indicated the high correlation with noise level inside the auto. Autos are open structure vehicle and person travelling inside an auto is susceptible to higher noise levels compared to any other vehicle considered in the study. R-square value obtained for the model-6, for IPT and bitumen road type pavement was 0.76 and it has higher t distribution value than model obtain considering constant. Here also high value of coefficient of speed indicates that it has high correlation with noise level inside the auto. Value of coefficient corresponding to ‘intersection area’ obtained in model 5 is higher than in model 6, because in the study area network, majority of the intersection with high capacity of traffic volume are of concrete pavement.

R-square value obtained for model 7, for vehicle type bus and concrete road type was 0.82. Very high constant value indicates that even in the steady condition a person inside a bus will have exposure to noise level of approximately 76dB. This is because of very high noise levels from the bus engine. The ventilation of bus is open (not air conditioned); this is also one of the reasons for high decibel noise level inside the bus. Note that in model 8, for vehicle type bus and bitumen road type, R-square value obtained for the above model was 0.84. In this case, very high value of constant indicates that even in the steady condition a person inside a bus will have exposure to noise level of approximately 74dB.

VALIDATION

A diagonal test was applied to test the model results (see Figure 4). This graphical method tests the deviation of data from the predicted and measured values of traffic noise on a 45 degree line. The data used for validation was not part of data considered for model development. Moreover, the validation is carried out for all the developed models. Observed noise values are found to be in 7.8% range bound of the values estimated from the models considering all types of roads and vehicle types. This signifies that models obtained from the multiple regression modeling are significant with good probability. The paired t-test was used for testing of the model for goodness-of-fit. First, t-test was carried out for each type of vehicles individually. Paired t-test yields that t-statistic values are less than the 5% significant for all types of vehicles.



Part D Car With A/C **Part C Car With Non A/C**

FIGURE 1 Validation

CONCLUSION

Road transportation is one of the major sources of noise pollution in urban area. From this study, it was observed that in-vehicle noise pollution is more than 70dB for 50% of the total journey. Due to lack of proper traffic system and driver discipline, high decibel noise is created while making a journey. Due to congestion and lack of enforcement, drivers use horn for significant part of their journey; this usually leads to high noise levels (above 90dB). Even if the vehicle is not moving, a person will be exposed to average noise level of more than 67 dB because of vehicle horn, vehicle engine noise, noise due to adjacent vehicles etc. Intersection area is prone to noise level more than 72 dB noise level in most of the peak hour traffic because of heavy traffic and noise due to vehicle horns. Average noise level experienced while traveling inside non A/C car was 71.8dB while that in A/C car was 65.64dB. The constant values obtained in models can be linked with the noise emitted by the test vehicle (i.e. noise generated by the engine, body interior noise etc). Most of the public transport buses in the study area are old and their engine make large noise during acceleration and gear change. It was identified that maximum differences between observed and estimated values from the model were within the range of $\pm$7.8%.

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