Transport and Telecommunication, 2019, volume 20, no. 1, 22–39
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia
DOI 10.2478/ttj-2019-0003

MODELLING OF NOISE POLLUTION DUE TO HETEROGENEOUS HIGHWAY TRAFFIC IN INDIA

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Compared to homogeneous traffic flow, traffic speed variation is drastic with the involvement of heterogeneity. With an intent of studying the negative upshot of fluctuating speeds of heterogeneous traffic on the environment, the current paper is the outcome of the research done on various highways located in the states of Andhra Pradesh and Telangana in India, with an objective of developing a comprehensive noise prediction model by taking into account the traffic and roadway factors. Quantified noise levels [Leq (dBA) and L10 (dBA)] revealed that for the traffic speed variation of 10 to 95 kmph, the traffic noise levels were significantly affected by the variations in the proportion of the vehicle. On a specific note, the proposed model can be effectively used for the highway traffic noise prediction especially for the heterogeneous traffic, as the difference between the measured and predicted noise levels are within 1 to 10 dB (A).

Keywords: heterogeneous traffic, noise prediction, traffic speed, vehicle volume

1. Introduction

A recent study conducted by World Health Organisation (2011) reported that "*one million people are losing their lives every year due to traffic noise in western Europe alone*." This proves the severity and necessity of mitigating the traffic noise from every delicate corner possible. This inevitable requirement led to the need for taking up traffic noise studies by researchers globally including India, to study the core factors leading to road noise levels. Compared to most of the countries across the world, the unique phenomena that worries the road planners and traffic engineers in India is the heterogeneity in traffic flow on most of the roads. Accordingly, one of the significant agonizing factors affecting the road noise levels in India being the vehicle itself. Moreover, a drastic increase in different vehicle classes hitting the Indian roads are dreadful, as they grew at the Compound Annual Growth Rate (CAGR) of 10.5% between 2002 and 2012 (Guite, 2017; Hindu business line, 2009). This rise in different classes of vehicles in the traffic stream has made the nature of heterogeneity of Indian traffic into more complex phenomena (Bhavatharathan and Mallikarjuna, 2012; Kulkarni, 2014). Thus, there is a need for better traffic noise prediction models especially for the mixed traffic conditions. This is because, with the presence of different vehicle sizes, different engine characteristics and manoeuvring abilities, the road traffic movements results in the spectrum of noise levels (Jain *et al*., 2006; Wei *et al*., 2016). This is because, vehicle speeds holds a direct logarithmic relation with the tyre/road noise, and is dominant at speeds exceeding 50 kmph (Kumar *et al*., 2011). On the contrary, propulsion noise is the dominant noise source at lower vehicle speeds (Boodihal *et al*., 2014). Thus, the road traffic noise from the vehicle fleet is defined as the combination of aerodynamic noise, propulsion noise, and tyre/road noise levels (Adams *et al*., 2006; Cong *et al*., 2013). As aerodynamic noise effect is very less on overall noise emission, and is experienced only by the person sitting in the vehicle, the concentration of the noise levels due to tyre/road interaction and propulsion noise sources were majorly considered in traffic noise quantification (Sandberg and Ejsmont, 2002; Van Blokland and Peeters, 2009). As both of these sources are highly dependent on the vehicular speeds, it can be said that tyre/road interaction and engine propulsion are the most contributing noise sources on the Indian roads. Thus, it is inevitable to consider the speed spectrum along with the possible vehicle classes for developing the noise prediction model for Indian conditions to use as a design aid for future.

In earlier years, researchers (Gupta *et al*., 1984; Raghavachari and Narsimhamurthy, 1986; Rao, 1997) reported that, along with the vehicular characteristics, traffic and roadway parameters will affect the traffic noise levels. By considering the effect of these parameters, few studies (Parida *et al*., 2003; Shukla *et al*., 2009) focussed on comparing the geographical transferability of three different models (Federal Highway Administration (FHWA) Model, Calculation of Road Traffic Noise (CORTN) Model and stop-and-go Model) to predict the noise levels in New Delhi and Lucknow cities in India. Both FHWA and CORTN Models gave the acceptable result with a deviation of 1 dB (A) 7 dB (A) for FHWA, and 1 dB (A) 4 dB (A) for CORTN model. Besides, there is a definite limitation of not considering the acceleration and deceleration lane approach for interrupted traffic flow in FHWA model. To overcome this limitation, Rajkumara and Gowda (2008) developed an empirical traffic noise prediction model under interrupted traffic flow conditions using the acceleration and deceleration approach in the urban road network of Bangalore city in India. Along with the collection of traffic noise levels, traffic composition, traffic volume and the vehicle spot speed, effect of the distance of a sound level meter from the nearest traffic lane was considered. It was observed that variation in distance of the sound level meter to the noise source had a significant effect on the captured noise levels. Govind and Soni (2012) suggested the applicability of FHWA model in Indian conditions, and concluded that minimizing the speed limits on highways can be a constructive means of reducing the traffic noise at urban units. Research works (Sharma, 2008; Jamatia *et al*., 2009) were also focussed on capturing the traffic noise levels in the commercial zones of the urban areas of Agartala city in India where, a regression model was developed to represent the Leq (dB) from traffic volume and traffic speed. Average traffic speed variation was observed between 25 to 41 kmph and noise level variation between 41 dB (A) to 101 dB (A) that exceeded the local noise limits. On the other hand, Nelson and Piner (1977) observed that congested urban traffic would experience the speed of around 20 kmph and free flow traffic speed on the highway will exceed the 100 kmph in most cases. Thus, proposing the compact model for the noise prediction near urban agglomeration should include the wide speed range as it will differ from time to time, and is hugely varied by traffic and roadway parameters. Accordingly, the current study considers the highways near the urban agglomeration, and an attempt has been made in order to develop the traffic noise prediction models for the wider spectrum of vehicle speeds in the heterogenic traffic. Previously studies in India measured noise levels in the cities with main focus on the identification of traffic factors affecting the traffic noise levels.

Mahesh and Anu (2010) measured the prevailing noise levels at the major locations in Thiruvananthapuram city in India, to identify the traffic noise concentrated areas. Both traffic volume and traffic speed were considered from the near and far sides of the sound level meter in assessing the noise levels. Contribution from the heavy vehicles on the measured noise levels was observed to be significant in their study. Bakowski *et al*. (2017) proposed a new parameter for assessing the equivalent sound pressure level from the road traffic studies, with the intent of analysing the relationship between the traffic volume and the traffic noise. It was observed that fluctuations in measured noise values over a year would not fall under the normal distribution, and the chance of imprecise determination is maximum with standard ISO procedures. Apart from traffic and vehicular parameters, the effect of surface type and the texture of the pavement have shown a significant effect on the generation of traffic noise levels on the highways (Neithalath *et al*., 2005). McNerney *et al*. (1998) measured the sound pressure levels of individual passes of the test vehicles on different pavement types. A significant difference of 7 dB (A) to 10 dB (A) was observed with change in the noise characteristics of pavement surface types and recommended the consideration of the respective surface types prior to the selection of highway. Moreover, each vehicle class was generating different noise levels at the same vehicle speeds (Kamineni and Chowdary, 2016). This shows the necessity of considering the proportion of the vehicles in order to develop the traffic noise prediction models for any road. Moreover, each vehicle will have a different manoeuvring ability and its movement differs for each type of road, as the driving pattern involves a sudden change in acceleration and deceleration depending upon the geometrics of the roads. Accordingly, roadway geometrics need to be considered in order to formulate policies related to the road traffic noise.

On the whole, the mixed traffic will affect the noise levels from both the corners of volume and speeds, which in turn can be affected by the roadway geometrics and pavement characteristics. As each type of vehicle can generate different noise levels at the same speeds, consideration of independent proportion of vehicles in quantifying the noise levels is necessary while considering the broad range of speeds occurring on highways, which is found lacking in the most of the previous studies. Thus, the main objective of this study is to develop a comprehensive noise prediction model for heterogeneous highway traffic covering the whole possible spectrum of speeds including the selection of governing parameters affecting the noise levels such as traffic speed, traffic volume, and carriageway width.

2. Study Area and Data Collection

The study area selected for the current study covers the important highways in the states of Andhra Pradesh and Telangana in India, that are grouped in Table 1.

Table 1. List of survey locations

Sl.No.	Road Stretch	Survey Location
1	Vijayawada- Kolkata Highway	Near Pottipadu Tollgate
2	Vijayawada-Chennai Highway	Near Nagarjuna University
3	Warangal- Khammam Highway	Near Mamnoor (Vaagdevi College)
4	Hyderabad- Nagpur Highway	Near Medchal
5	Hyderabad-Vijayawada Highway	Near Ramoji Film City
6	Hyderabad-Bengaluru Highway	Near Shamshabad Airport
7	Hyderabad- Pune Highway	Near IIT Hyderabad
8	Hyderabad- Warangal Highway	Near Ghatkesar

Usually, noise levels were measured through near field and far field measurements. Placing the microphones on the roadside and capturing the noise levels from the moving traffic is classified under far-field methodology and is adopted in the current study. A class 1 sound level meter was placed at a predefined distance of 1.5 meters from the adjacent traffic lane, at the height of 1.5 meters above the ground, and the continuous noise levels were measured with a data logging of 1-second interval using the time averaging method. Accordingly, SVAN 945A pocket sound level meter (SLM) was used to measure the noise levels and are analysed using SVAN PC suite by transferring the data to the computer. The measured noise indices in the current study are equivalent A-Weighed continuous sound level [Leq or Leq (dBA)], Sound Pressure Level [SPL], Sound Exposure Level [SEL] and the noise level exceeded for 10% of the measurement time [L10]. Along with these noise level measurements, traffic volume and spot speed studies were carried out simultaneously. Classified traffic volume on both the directions of the selected road was collected. In order to achieve this task, four trained enumerators were employed in each direction of the vehicle movement. Accordingly, vehicles are classified as Bus (B), Mini Bus (MB), Motor Cycle (MC), Scooter (SC), Bicycle (CY), Cycle Rickshaw (OT), Auto Rickshaw (A), Small Car (CS), Big Car (CB), TractorTrailer (TT), Light Commercial Vehicle (LT), Two-Axle Truck (HT) and Multi-axle Truck (MT). As consideration of these classes on the same roadway will lead to heterogenic traffic volume, classes of all vehicles were converted into Passenger Car Units (PCU's). Spot speeds of the vehicles were recorded using the RADAR speedgun. Along with these traffic parameters, geometric factors such as the width of the carriageway, the number of lanes and the shoulder width were recorded for each highway location. All the measurements were carried out from 10 am to 5 pm continuously.

3. Results and Discussion

Various vehicle types travelling on the highways would generate different noise levels with respect to the vehicle and roadway characteristics. To account for these variations over a continuous noise exposure level on the commuters, the captured noise levels were averaged for a data logging of 15 minutes and one-hour time intervals, and the governing Leq (dBA) and L10 (dBA) were analysed with respect to the vehicle volumes and speeds as shown in Figures 1(a) to 8 (c).

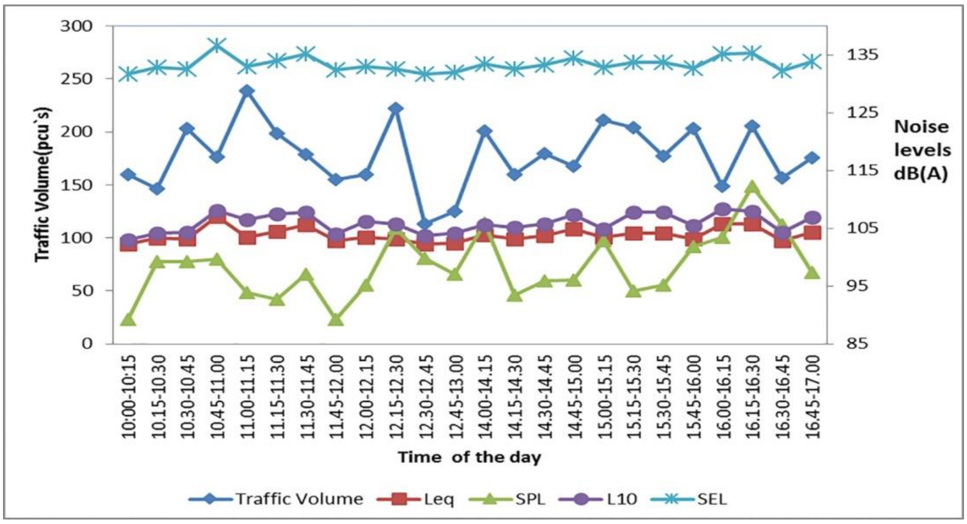

Figure 1(a). Traffic volume v/s Noise levels on Vijayawada-Kolkata highway

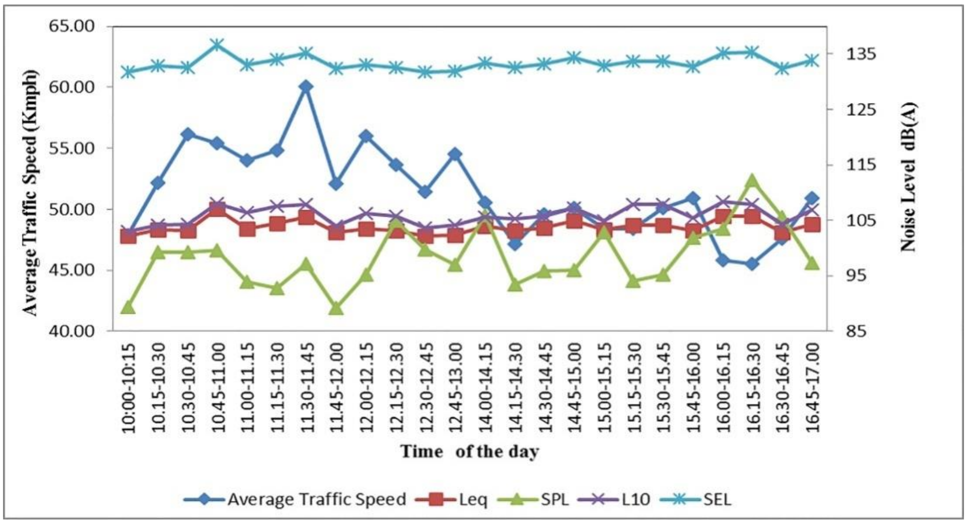

Figure 1(b). Average traffic speed v/s Noise levels on Vijayawada-Kolkata highway

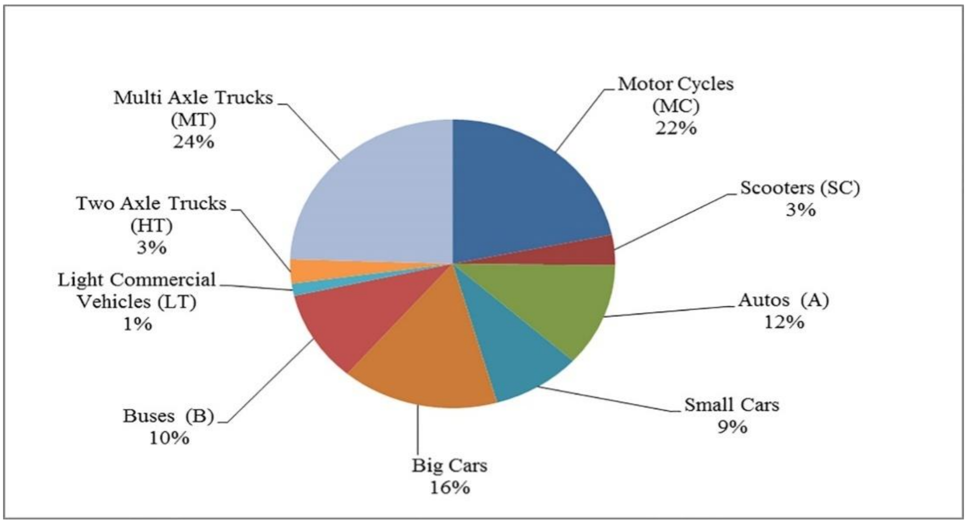

Figure 1(c). Mode share on Vijayawada-Kolkata highway

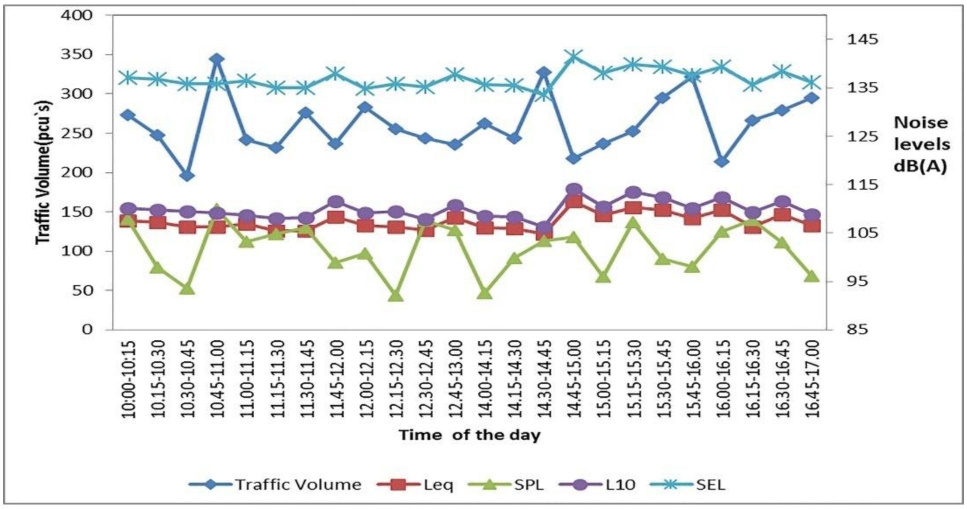

Figure 2(a). Traffic volume v/s Noise levels on Vijayawada-Chennai highway

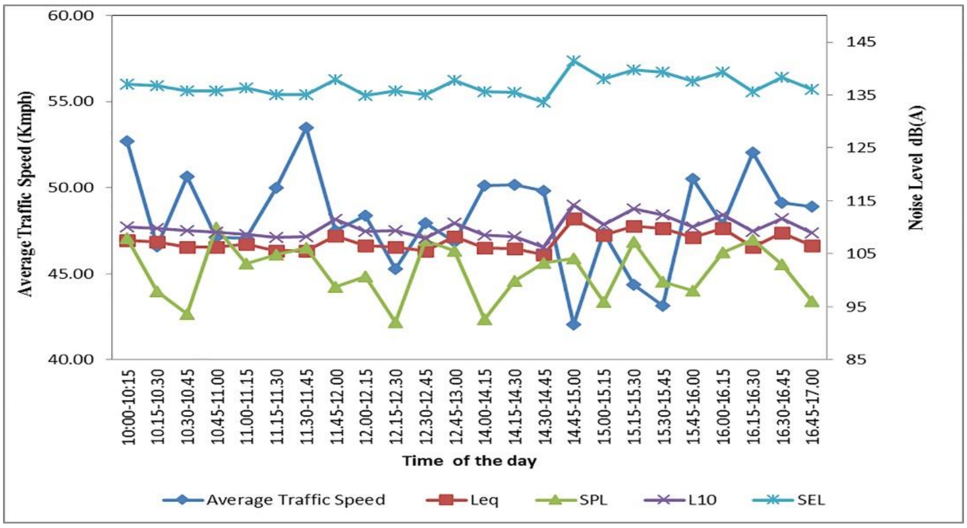

Figure 2(b). Average traffic speed v/s Noise levels on Vijayawada-Chennai highway

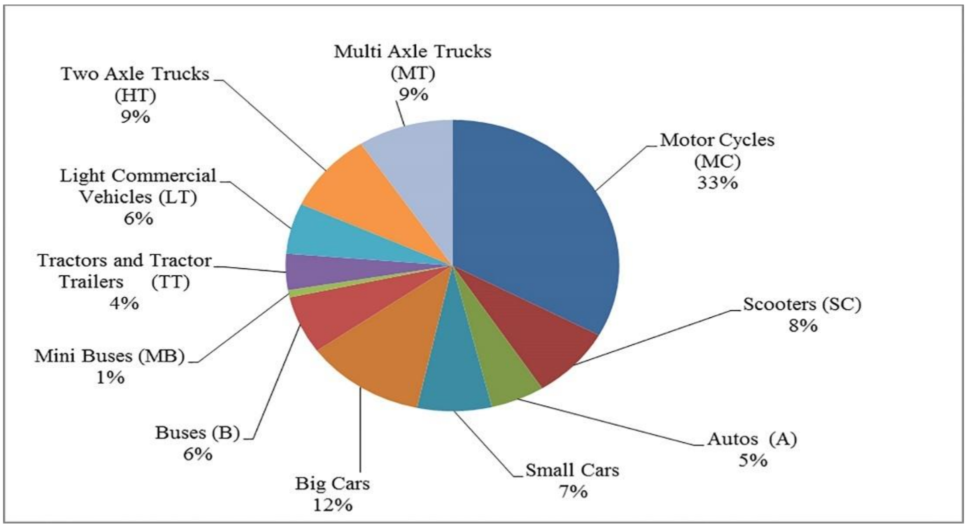

Figure 2(c). Mode share on Vijayawada-Chennai highway

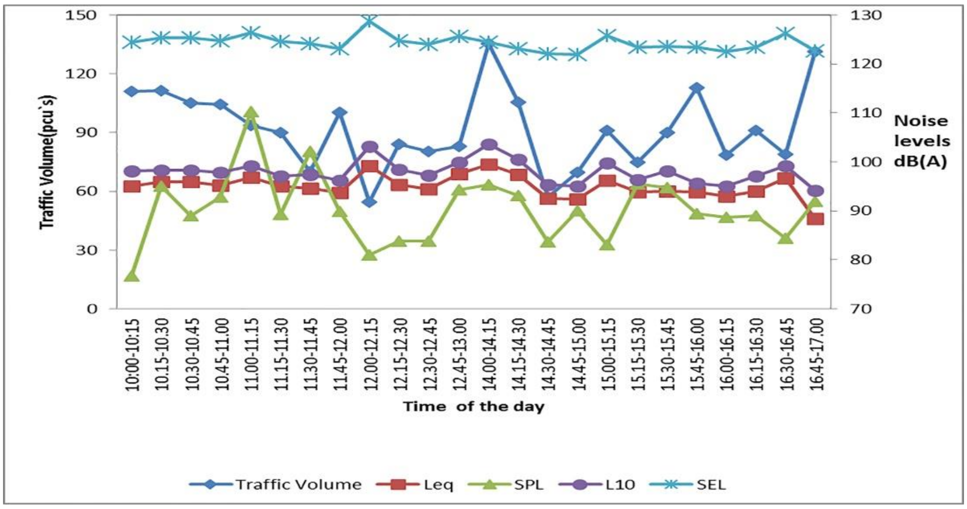

Figure 3(a). Traffic volume v/s Noise levels on Warangal-Khammam highway

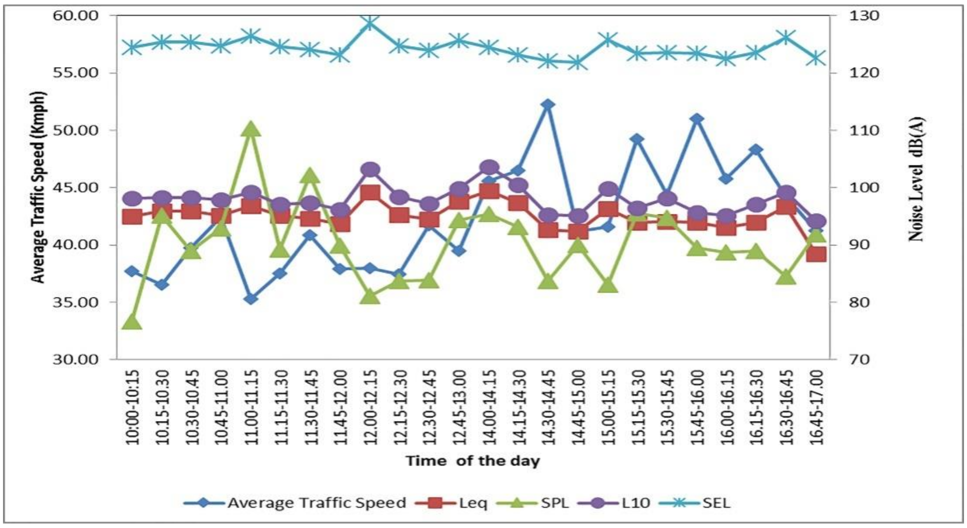

Figure 3(b). Average traffic speed v/s Noise levels on Warangal-Khammam highway

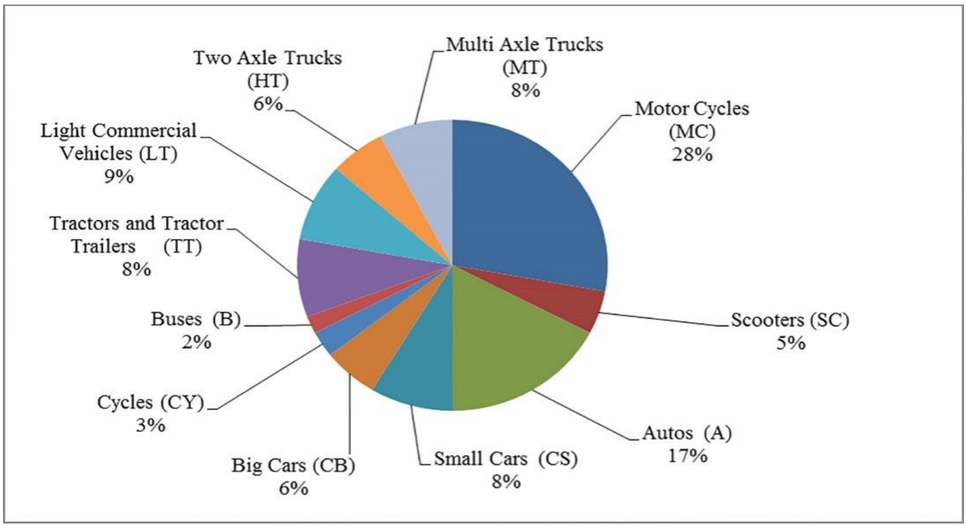

Figure 3(c). Mode share on Warangal-Khammam highway

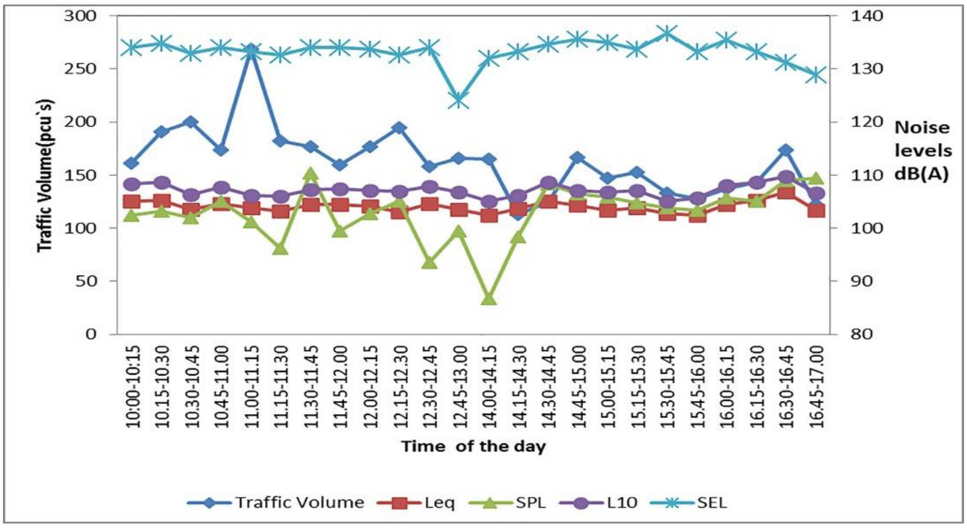

Figure 4(a). Traffic volume v/s Noise levels on Hyderabad-Nagpur highway

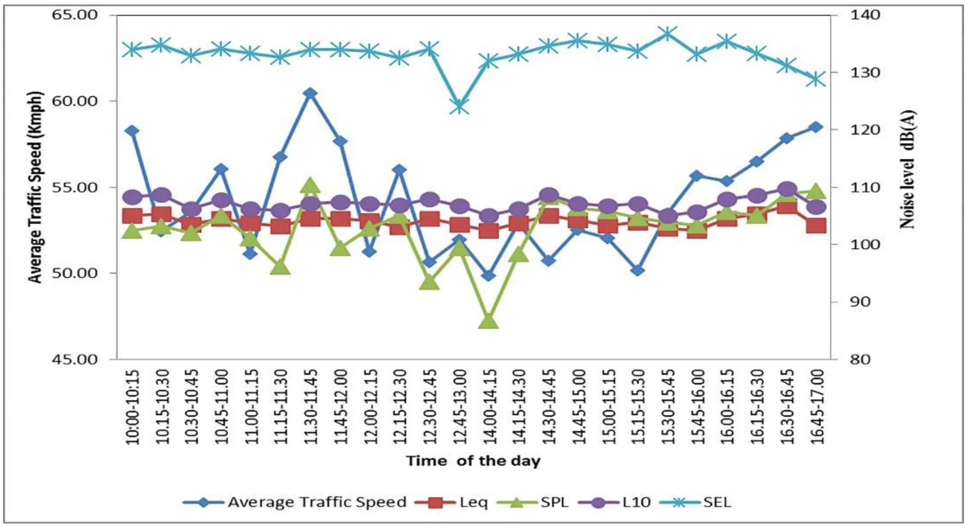

Figure 4(b). Average traffic speed v/s Noise levels on Hyderabad-Nagpur highway

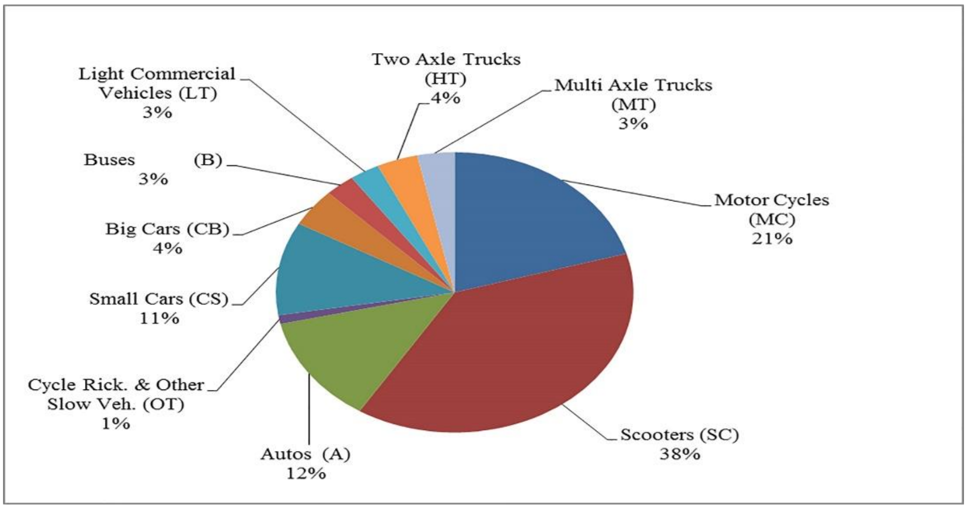

Figure 4(c). Mode share on Hyderabad-Nagpur highway

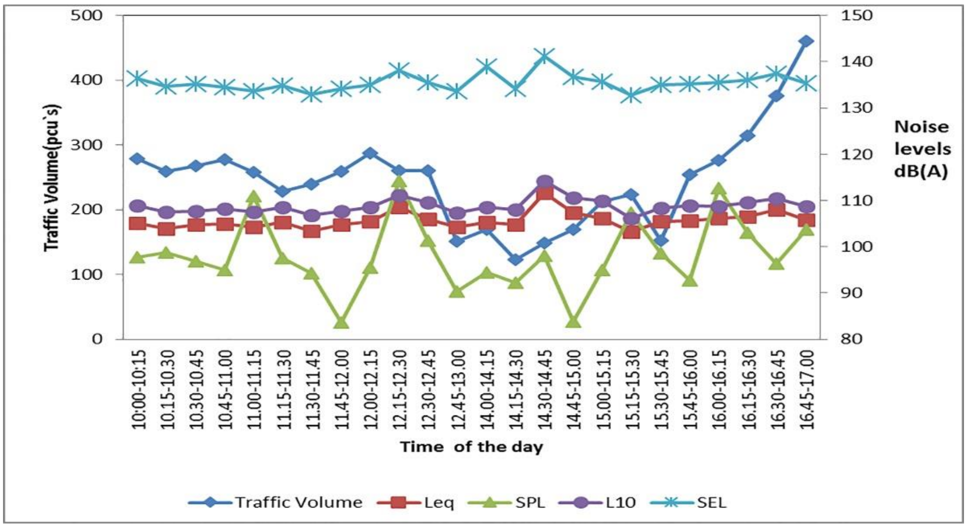

Figure 5(a). Traffic volume v/s Noise levels on Hyderabad-Vijayawada highway

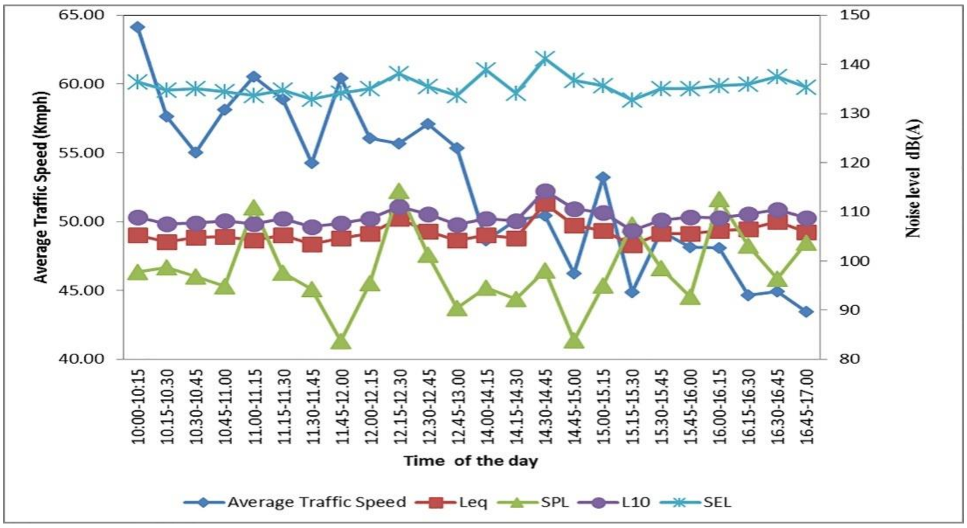

Figure 5(b). Average traffic speed v/s Noise levels on Hyderabad-Vijayawada highway

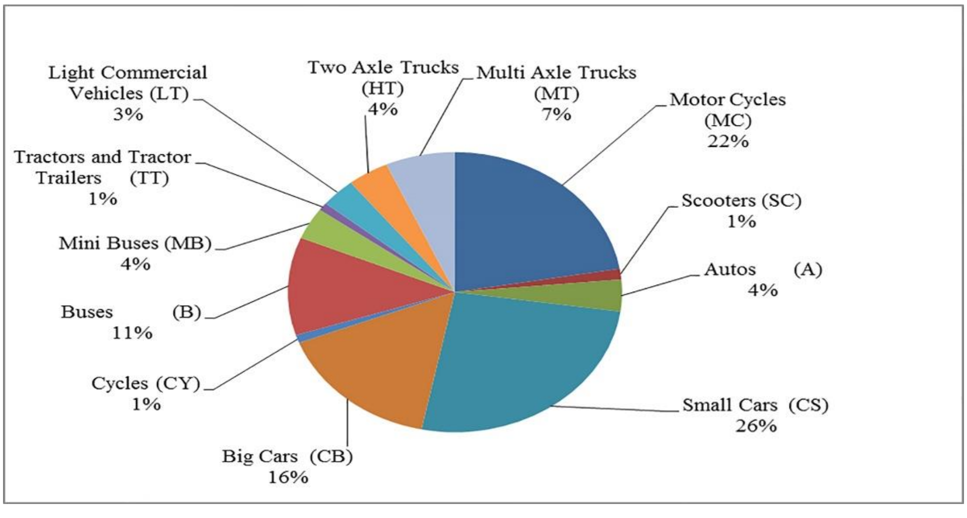

Figure 5(c). Mode share on Hyderabad-Vijayawada highway

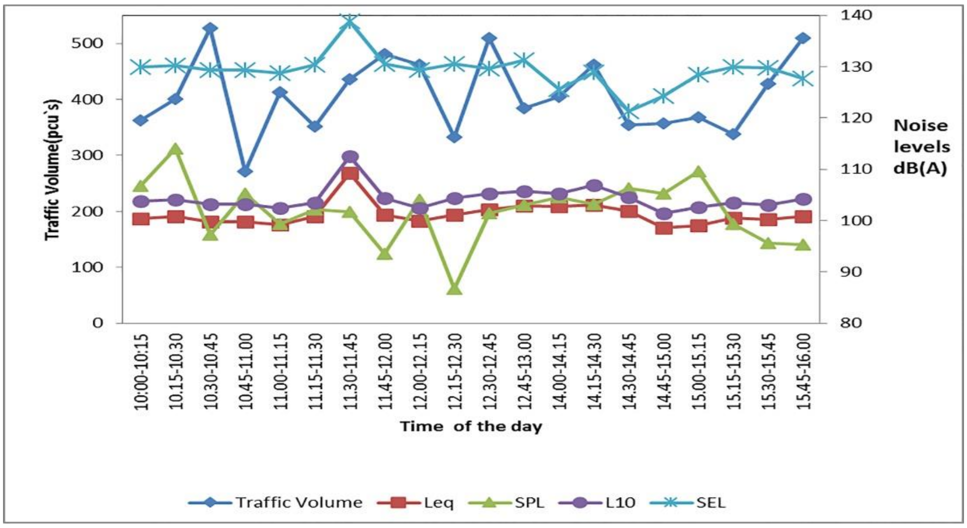

Figure 6(a). Traffic volume v/s Noise levels on Hyderabad-Bangalore highway

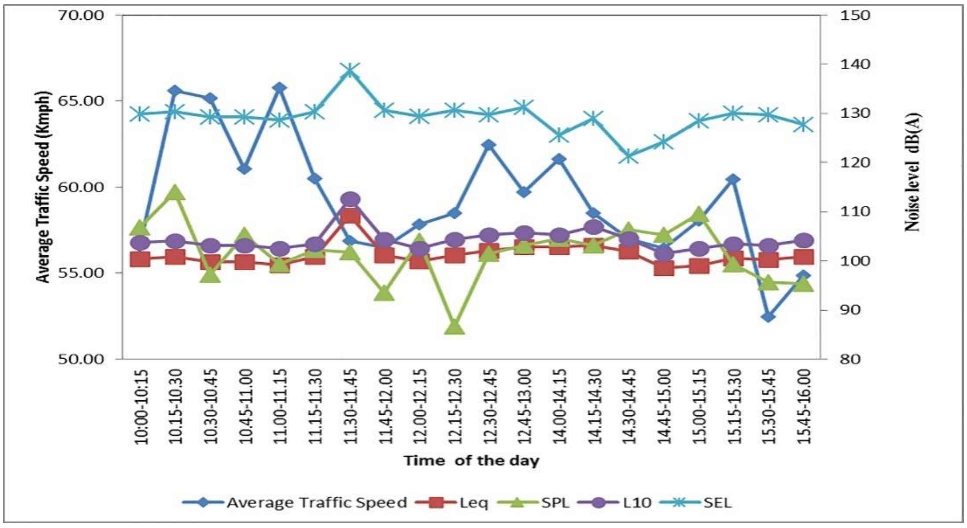

Figure 6(b). Average traffic speed v/s Noise levels on Hyderabad-Bangalore highway

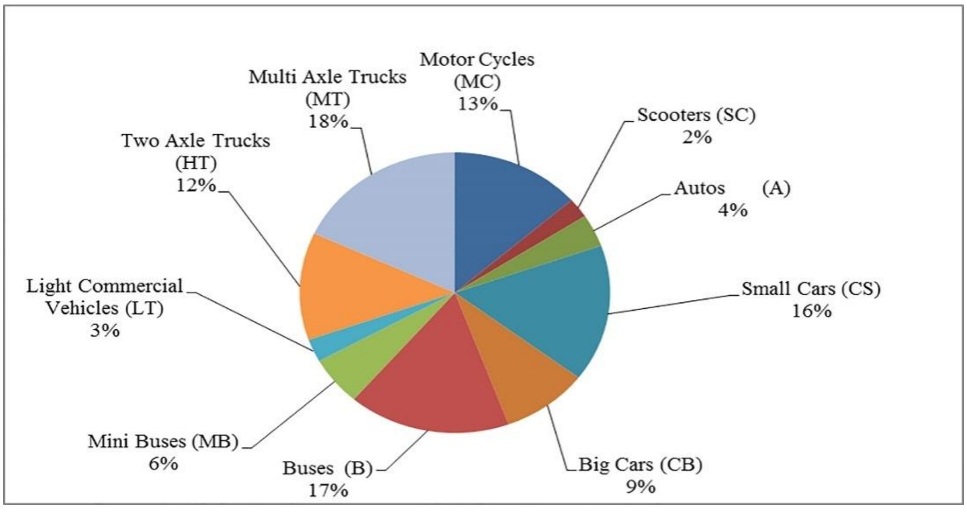

Figure 6(c). Mode share on Hyderabad-Bangalore highway

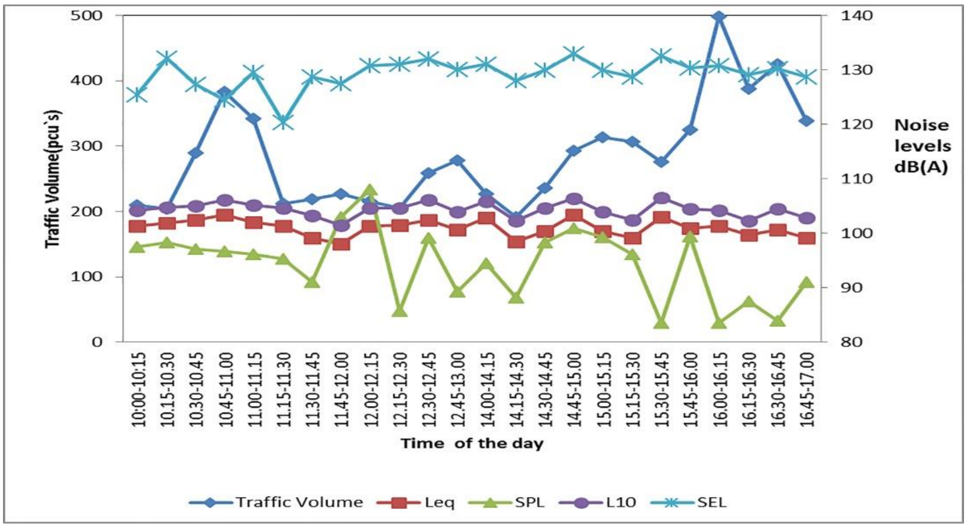

Figure 7(a). Traffic volume v/s Noise levels on Hyderabad-Pune highway

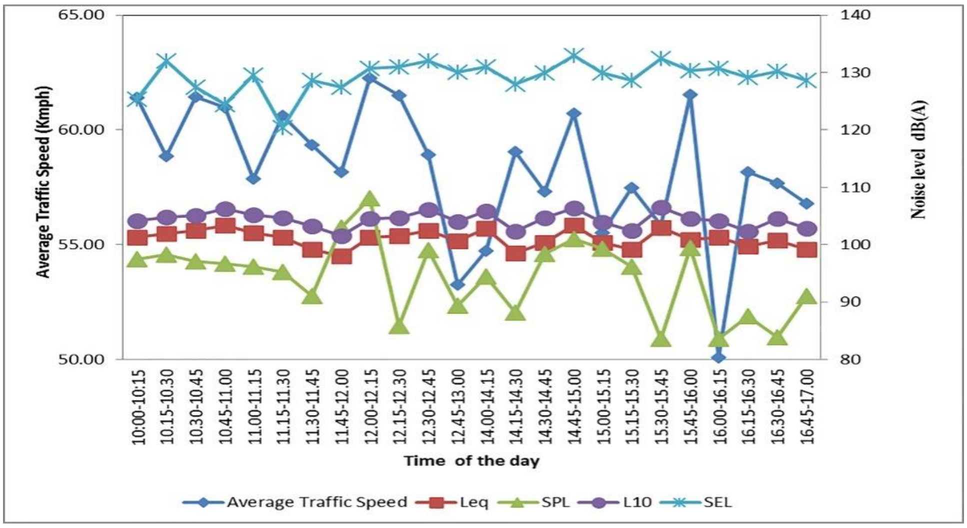

Figure 7(b). Average traffic speed v/s Noise levels on Hyderabad-Pune highway

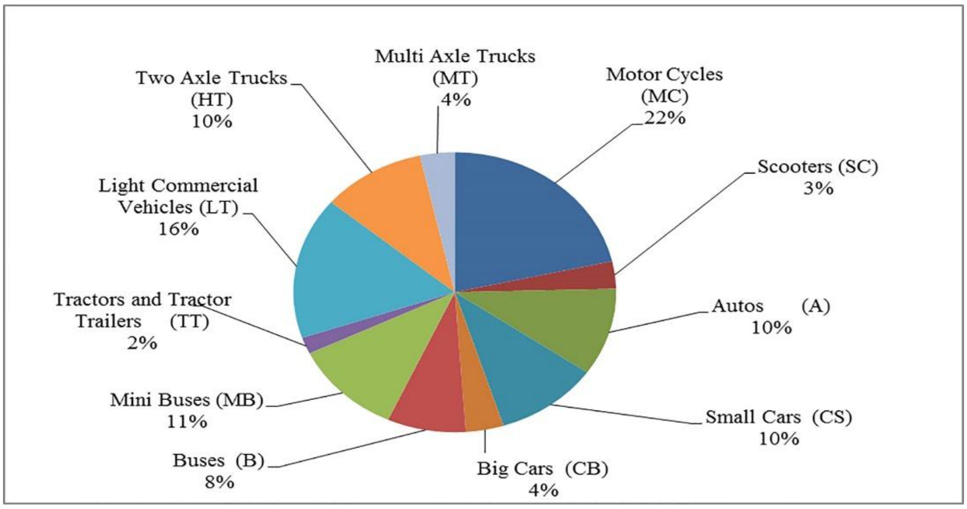

Figure 7(c). Mode share on Hyderabad-Pune highway

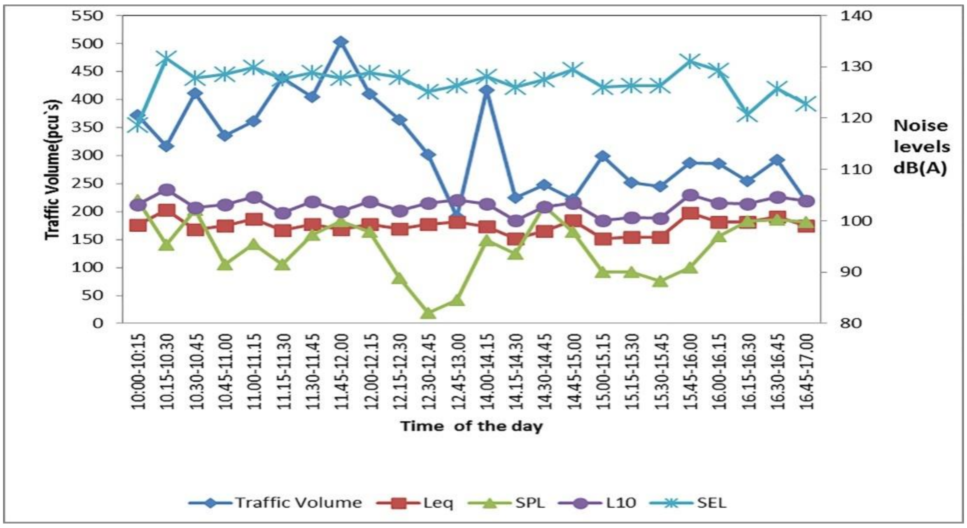

Figure 8(a). Traffic volume v/s Noise levels on Hyderabad-Warangal highway

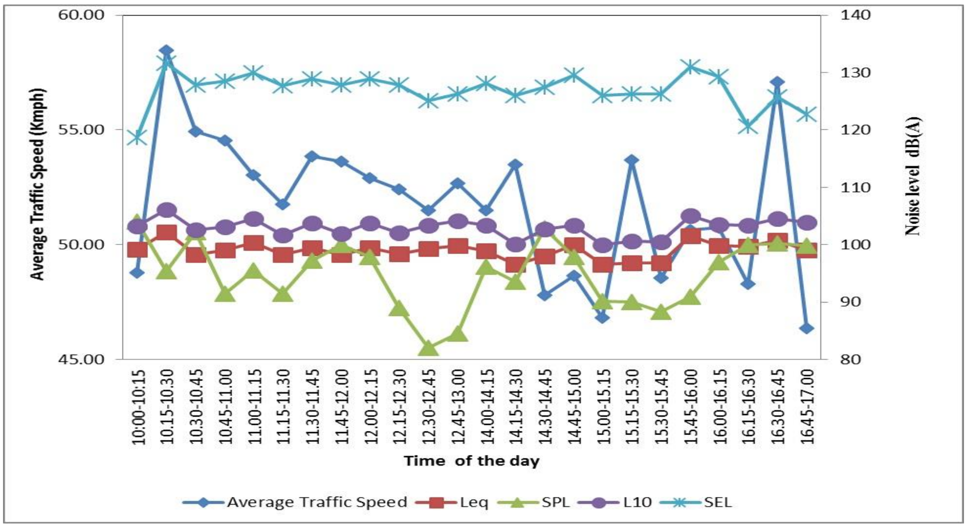

Figure 8(b). Average traffic speed v/s Noise levels on Hyderabad-Warangal highway

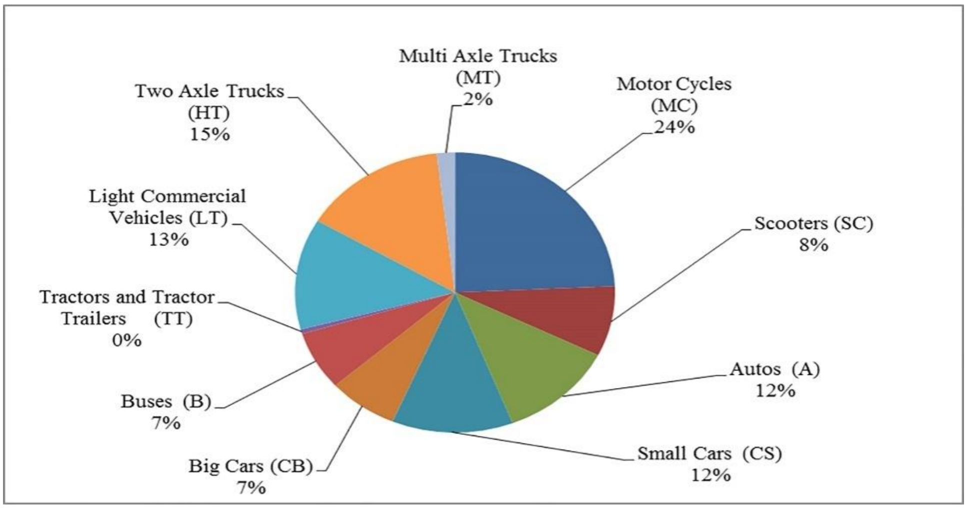

Figure 8(c). Mode share on Hyderabad-Warangal highway

It was observed that motorcycles have a dominant share in traffic flow among most of the selected sections. Figure 1(a) shows that maximum Leq (15 minutes) of 107.1 dB (A) was observed for the vehicle volume of 176 (pcu's). On the same section, for the highest volume (pcu's) of 238.5, the Leq (15 minutes) was observed to be 103.5 dB (A) between 11:00 to 11:15 am. This shows that maximum Leq (15 minutes) need not necessarily corresponds to the maximum traffic volume, and vice-versa. Whereas, on Warangal-Khammam highway, maximum Leq (15 minutes) of 99.5 dB (A) was observed for the highest 15-minute volume of 136 (pcu's) shown in Figure 3(a). Thus, the variation of the proportion of the vehicle type can play a significant role in the generation of traffic noise levels, irrespective of the traffic volumes. Similar results were observed on other highways, as shown in Figures 2(a), 4(a), 5(a), 6(a), 7(a) and 8(a).

As the continuous noise exposure over time is more fatal than the instantaneous noise source for commuter's health, along with traffic volumes, average speeds were taken for each 15-minute time interval. It was observed that individual speeds of vehicles on all the highways were ranging between 10 to 95 kmph, with an average 15-minute speed of 30- 65 kmph. With the variation being drastic, the effect of speed on the noise level will be significant too. This is because, crossover speed between the engine propulsion and tyre/road interaction for highway traffic vary between 30-50 kmph (Sandberg and Ejsmont, 2002). Moreover, literature concluded that noise levels from the vehicles will vary linearly with speed. On a contradicting tone, for a highest 15-minute average traffic speed of 60.06 kmph in Figure 1(b), Leq (15 minutes) and L10 (15 minutes) appeared as 105.8 dB (A) and 107.8 dB (A). On the same section, for an average speed of 55.44 kmph during 10:45 am to 11:00 am, highest Leq (dB) of 107.1 dB (a) was observed. Similar results were observed in Figure 2(b), 3(b), 4(b), 5(b), 6(b), and 7(b). On another side, for a maximum 15 minutes, average traffic speed of 58.46 kmph, highest Leq (15 minutes) and L10 (15 minutes) indices of 102.2 dB (a) and 106.1 dB (A) was observed as shown in Figure 8(b). This clearly shows the fact that, unlike the individual traffic speeds and noise levels, average noise levels over the time frame will strongly depend upon the combination of vehicle proportion, size, and speeds, that are shown in Figures 1(c), 2(c), 3(c), 4(c), 5(c), 6(c), 7(c) and 8(c). This is because, a weight of the vehicle can be a judgemental factor in the noise generation. This concludes that the proportion of vehicle volumes and road speed combination will play a major role in generating the continuous highway noise levels. Moreover, the carriageway width of the selected highways was different, which may affect the driving pattern apart from the volume and speeds. Accordingly, the consideration of all these independent variables can be vital for analysing the noise levels for the development of the prediction model for the highway. In order to confirm it, scatter plots are developed between the captured noise levels and these independent parameters, to observe the relationship between them. The developed scatter diagrams for both Leq (dBA) and L10 (dBA) are shown in Figures 9 to 10.

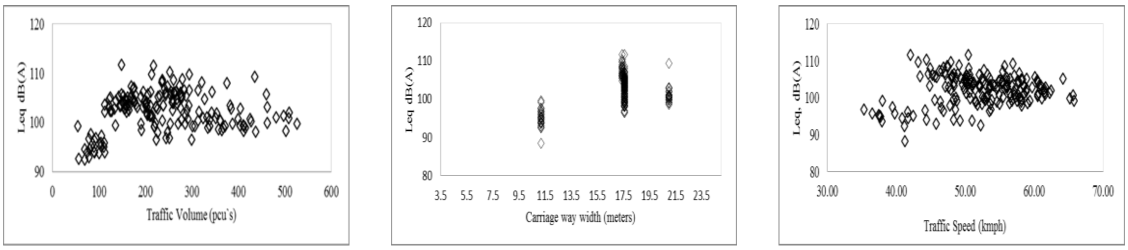

Figure 9. Scatter diagrams: (a) Leq Vs. Traffic volume, (b) Leq Vs. Carriageway width, (c) Leq Vs. Traffic speed

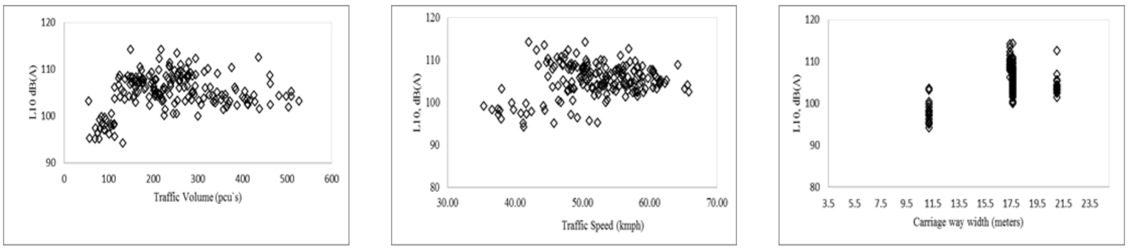

Figure 10. Scatter diagrams: (a) L10 Vs. Traffic volume, (b) L10 Vs. Carriageway width, (c) L10 Vs. Traffic speed

From Figures 9 and 10, it can be observed that the noise levels have shown a significant relation with speed and volumes whereas the relationship with carriageway width is questionable. Accordingly, data collected at all the study locations were taken and averaged for 15 minutes and 1-hour intervals, and datasets were prepared for both Leq and L10, that were processed using SPSS package to develop the linear noise models for all the highways selected in this study. For obtaining hourly Leq from the 15-minutes Leq data, the following equations are employed.

$$Leq(hr) = 10*\log [10^{(L_1/10)*t_1} + 10^{(L_2/10)*t_2} + 10^{(L_3/10)*t_3} + 10^{(L_4/10)*t_4}], \quad (1)$$

$$L10(hr) = 10*\log [10^{(L_1/10)*t_1} + 10^{(L_2/10)*t_2} + 10^{(L_3/10)*t_3} + 10^{(L_4/10)*t_4}], \quad (2)$$

where,

Leq(hr) = A - Weighed equivalent sound pressure level for one hour,

L10(hr) = A - Weighed noise level exceeded for the 10% of the total observations for one hour, and

L_1,L_2,L_3 and L_4 are fluctuating noise levels for an interval of t_1, t_2,t_3 and t_4.

Models are developed for the prediction of the noise levels, and these models are tested for the logical sign for every coefficient. Student t-test values are compared with the table values to know their significance of contribution to explain the variation in noise levels. Table 2 presents the best form of regression equations obtained for each highway location for both Leq (dBA) and L10 (dBA) noise descriptors, with the highest R^2 value. Data corresponding to each highway passing through a particular city was combined and the models are developed accordingly.

Table 2. Models developed for all the highway locations

Highway	R^2	Regression equation
Vijayawada- Kolkata Highway Vijayawada-Chennai Highway	0.646	Leq [15 min] (dBA)= 54.37+ 0.0166*Traffic Volume + 0.0167*Average Traffic Speed+ 0.451* % of Heavy Vehicles + 0.704 *% of Cars + 0.420* % of Buses +0.309*% of 2W +0.655*% of 3W
	0.636	L10 [15 min] (dBA)= 57.66+ 0.0271*Traffic Volume + 0.0168*Average Traffic Speed+ 0.381* % of Heavy Vehicles + 0.633*% of Cars + 0.353* % of Buses +0.388*% of 2W +0.675*% of 3W
	0.901	Leq [hr] (dBA) = 57.11 + 0.0235*Traffic Volume + 0.482*Average Traffic Speed+ 0.434 *% of Cars+ 0.515* % of 3W
	0.891	L10[hr] (dBA) = 56.55+ 0.0159*Traffic Volume + 0.456*Average Traffic Speed+ 0.381* % of Heavy Vehicles +0.056 *% of Cars
Hyderabad-Vijayawada Highway Hyderabad-Pune Highway	0.723	Leq [15 min] (dBA)= 54.71+ 0.0232*Traffic Volume + 0.119*Average Traffic Speed+ 0.518* % of Heavy Vehicles + 0.218 *% of Cars + 0.448* % of Buses +0.156*% of 2W +0.754*% of 3W
	0.684	L10 [15 min] (dBA)= 59.83+ 0.0032*Traffic Volume + 0.137*Average Traffic Speed+ 0.415* % of Heavy Vehicles + 0.359*% of Cars + 0.401* % of Buses +0.0309*% of 2W +0.915*% of 3W
	0.901	Leq [hr] (dBA) = 53.22+ 0.0089*Traffic Volume + 0.0049*Average Traffic Speed+ 0.625 *% of Cars + 0.926* % of Cars
	0.893	L10 [hr] (dBA) = 53.30+ 0.0101*Traffic Volume + 0.146*Average Traffic Speed+ 0.525* % of Heavy Vehicles +0.857*% of Cars
Hyderabad - Warangal Highway	0.683	Leq [15 min] (dBA)= 55.44+ 0.00102*Traffic Volume + 0.195*Average Traffic Speed+ 0.283* % of Heavy Vehicles + 0.162 *% of Cars + 0.420* % of Buses +0.539*% of 2W +0.270*% of 3W
	0.653	L10 [15 min] (dBA)= 54.88+ 0.0007*Traffic Volume + 0.262*Average Traffic Speed+ 0.295* % of HeavyVehicles + 0.226*% of Cars + 0.442* % of Buses +0.484*% of 2W +0.310*% of 3W
	0.914	Leq [hr] (dBA) = 57.40+ 0.00215*Traffic Volume + 0.735*Average Traffic Speed+ 0.0373 *% of Cars + 0.287* % of 3W
	0.887	L10 [hr] (dBA) = 56.14+ 0.0017*Traffic Volume + 0.793*Average Traffic Speed+ 0.0195* % ofHeavy Vehicles +0.513 *% of Cars
Hyderabad-Nagpur Highway Hyderabad-Bengaluru	0.626	Leq [15 min] (dBA)= 55.09+ 0.0133*Traffic Volume + 0.0603*Average Traffic Speed+ 0.408* % of Heavy Vehicles + 0.394 *% of Cars + 0.351* % of Buses +0.521*% of 2W +0.521*% of 3W
	0.656	L10 [15 min] (dBA)= 53.48+ 0.0178*Traffic Volume + 0.102*Average Traffic Speed+ 0.411* % of Heavy Vehicles + 0.453 *% of Cars + 0.389* % of Buses +0.586*% of 2W +0.502*% of 3W
	0.935	Leq [hr] (dBA) = 59.43+ 0.0019*Traffic Volume + 0.739*Average Traffic Speed + 0.179 *% of Cars + 0.128*% of 3W
	0.909	L10 [hr] (dBA) = 60.87+ 0.0027*Traffic Volume + 0.750*Average Traffic Speed + 0.119 *% of Cars + 0.121*% of 3W
Warangal - Khammam Highway	0.626	Leq [15 min] (dBA)= 55.25+ 0.026*Traffic Volume + 0.0201*Average Traffic Speed+ 0.384* % of Heavy Vehicles + 0.204 *% of Cars + 0.206* % of Buses +0.341*% of 2W +0.543*% of 3W
	0.592	L10 [15 min] (dBA)= 58.12+ 0.0269*Traffic Volume + 0.0196*Average Traffic Speed+ 0.422* % of Heavy Vehicles + 0.182 *% of Cars+ 0.227* % of Buses +0.425*% of 2W +0.334*% of 3W

Highway	**R^2**	**Regression equation**
	0.872	Leq [hr] (dBA) = 58.24+ 0.0321*Traffic Volume + 0.352*Average Traffic Speed+ 0.319* % of Heavy Vehicles + 0.179 *% of Cars
	0.844	L10 [hr] (dBA) = 58.14+ 0.0364*Traffic Volume + 0.350*Average Traffic Speed+ 0.385* % ofHeavy Vehicles + 0.0429* % of Cars

With the data pertaining to the two major highway locations near Vijayawada city, the models have been proposed as in Table 2. On a similar note, data collected at five important national highways covering the Hyderabad-Nagpur, Hyderabad-Vijayawada, Hyderabad-Pune, Hyderabad-Bengaluru, and Hyderabad-Warangal Highways was averaged for 15 minutes and one hour, and the respective calibrated models are shown in Table 3.

Table 3. Comprehensive noise prediction model for the highway locations near Hyderabad city

Hyderabad-Vijayawada Highway Hyderabad-Pune Highway Hyderabad -Warangal Highway Hyderabad-Nagpur Highway Hyderabad-Bengaluru Highway	0.705	Leq [15 min] (dBA)= 57.89+ 0.017*Traffic Volume + 0.0485*Average Traffic Speed+ 0.135* % of Heavy Vehicles + 0.557 *% of Cars + 0.201* % of Buses +0.423*% of 2W +0.764*% of 3W
	0.653	L10 [15 min] (dBA)= 55.96+ 0.0217*Traffic Volume + 0.0248*Average Traffic Speed+ 0.204* % of Heavy Vehicles + 0.397*% of Cars + 0.259* % of Buses +0.690*% of 2W +0.825*% of 3W
	0.907	Leq [hr] (dBA) = 52.99+ 0.0043*Traffic Volume + 0.638*Average Traffic Speed+ 0.281 *% of Cars +0.145* % of 3W
	0.907	L10 [hr] (dBA) = 55.53+ 0.00497*Traffic Volume + 0.574*Average Traffic Speed+ 0.329* % of Heavy Vehicles +0.207 *% of Cars

Finally, field data collected at all the study locations were taken and averaged for 15 minutes and 1-hour time intervals, and datasets were prepared for both Leq (dBA) and L10 (dBA), and the comprehensive noise prediction models are developed, that are shown in Tables 4 to 8.

Table 4. Comprehensive noise models for Leq [15min] (dBA)

Parameters	Beta weights						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Traffic Volume	0.0147 (2.335)	0.0168 (2.606)	0.009 (1.178)	0.008 (1.262)	-	0.0132 (1.667)	0.008 (1.114)
Average Traffic Speed	0.134 (1.653)	-	0.122 (1.140)	0.111 (1.229)	0.173 (1.943)	-	0.134 (1.229)
% of Heavy Vehicles	0.356 (4.543)	0.343 (4.191)	0.199 (2.272)	0.244 (3.449)	0.243 (3.511)	0.241 (3.356)	0.195 (2.452)
% of Cars	0.275 (3.402)	0.275 (3.241)	0.159 (1.609)	0.202 (2.393)	0.221 (2.539)	0.207 (2.421)	-
% of Buses	0.505 (5.071)	0.444 (4.101)	-	0.377 (3.983)	0.441 (4.101)	0.334 (3.745)	0.262 (2.965)
% of 2W	0.345 (3.721)	0.339 (3.487)	0.284 (2.682)	0.309 (2.988)	0.298 (2.930)	0.306 (2.923)	0.224 (2.051)
% of 3W	0.296 (2.381)	0.272 (2.10)	0.219 (1.349)	-	0.167 (1.334)	-	0.136 (0.929)
Intercept	55.23	61.74	65.11	64.37	65.38	66.37	66.23
Sample Size	188	188	188	188	188	188	188
R^2	0.641	0.579	0.574	0.518	0.518	0.470	0.381
R	0.800	0.761	0.730	0.720	0.720	0.686	0.617

Value in ( ) indicate t-value of the parameter

Table 5. Comprehensive noise models for L10 [15 min] (dBA)

Parameters	**Beta weights**						
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Traffic Volume	0.0116 (1.522)	-	0.0182 (2.22)	0.0113 (1.416)	-	0.0053 (0.625)	-
Average Traffic Speed	0.252 (2.519)	0.305 (3.123)	-	0.258 (2.463)	0.309 (3.057)	0.261 (2.198)	0.287 (2.627)
% of Heavy Vehicles	0.358 (4.415)	0.295 (4.070)	0.353 (3.804)	0.299 (3.938)	0.239 (3.685)	0.281 (3.111)	0.255 (3.226)
% of Cars	0.152 (1.626)	0.149 (1.532)	0.161 (1.498)	-	-	0.124 (1.039)	0.115 (1.07)
% of Buses	0.469 (4.469)	0.471 (4.329)	0.365 (3.301)	0.362 (4.229)	0.367 (4.173)	0.403 (3.332)	0.410 (3.458)

Parameters	Beta weights						
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
% of 2W	0.384 (3.045)	0.373 (2.851)	0.340 (2.385)	0.307 (2.506)	0.297 (2.367)	0.420 (2.822)	0.411 (2.824)
% of 3W	0.331 (2.799)	0.279 (2.372)	0.340 (2.507)	0.303 (2.472)	0.252 (2.096)	-	-
Intercept	55.07	58.29	64.12	61.49	63.40	61.43	62.37
Sample Size	188	188	188	188	188	188	188
R^2	0.654	0.604	0.517	0.597	0.549	0.484	0.473
R	0.809	0.777	0.719	0.772	0.741	0.696	0.687

Value in ( ) indicate t-value of the parameter

Table 6. Comprehensive noise models for Leq [hr] (dBA)

Parameters	Beta weights						
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Traffic Volume	0.0199 (1.297)	0.0328 (1.522)	0.033 (3.093)	0.0301 (0.786)	-	0.0241 (1.215)	-
Average Traffic Speed	0.292 (1.059)	0.041 (0.111)	-	0.171 (0.321)	0.708 (1.961)	0.181 (0.526)	0.579 (3.168)
% of Heavy Vehicles	-	-	-	0.0691 (0.316)	0.0181 (0.089)	-	-
% of Cars	0.311 (1.651)	-	-	0.328 (1.268)	0.458 (1.308)	-	0.406 (2.112)
% of Buses	-	-	-0.177 (-0.92)	-	0.254 (0.599)	-	-
% of 2W	-	-0.224 (-1.01)	-	-	-	-	-
% of 3W	-	0.084 (0.607)	0.093 (0.854)	-	-	0.116 (0.849)	-
Intercept	63.19	70.38	68.04	56.32	55.26	69.25	66.28
Sample Size	188	188	188	188	188	188	188
R^2	0.882	0.898	0.836	0.892	0.872	0.795	0.782
R	0.939	0.934	0.914	0.945	0.934	0.891	0.875

Value in ( ) indicate t-value of the parameter

Table 7. Comprehensive noise models for L10 [hr] (dBA)

Parameters	Beta weights						
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Traffic Volume	0.0345 (1.234)	-	0.0372 (2.750)	0.0385 (2.080)	0.0416 (2.253)	0.0366 (1.597)	0.039 (1.867)
Average Traffic Speed	0.133 (0.641)	0.700 (0.827)	0.147 (1.436)	-	-	0.0489 (0.311)	-
% of Heavy Vehicles	0.328 (0.984)	0.194 (0.406)	0.370 (2.094)	0.306 (1.239)	0.342 (1.575)	0.311 (1.049)	0.312 (1.117)
% of Cars	0.093 (0.766)	0.268 (0.876)	-	-	-	-	0.052 (0.597)
% of Buses	-	0.197 (0.614)	-	-	-	-	-
% of 2W	-	-	0.0592 (2.181)	-	-	-	-
% of 3W	-	-	-	-	.042 (1.394)	-	-
Intercept	55.27	57.79	51.01	60.69	55.66	59.84	58.98
Sample Size	188	188	188	188	188	188	188
R^2	0.906	0.811	0.934	0.843	0.920	0.850	0.867
R	0.952	0.901	0.987	0.918	0.959	0.922	0.931

Value in ( ) indicate t-value of the parameter

Table 8. Comprehensive noise prediction model for highway traffic

Comprehensive noise prediction model for highway traffic	0.641	Leq [15 min] (dBA)= 55.23+ 0.0147*Traffic Volume + 0.134*Average Traffic Speed+ 0.356* % of Heavy Vehicles + 0.275 *% of Cars + 0.505* % of Buses +0.345*% of 2W +0.296*% of 3W
	0.654	L10 [15 min] (dBA)= 55.07+ 0.0116*Traffic Volume + 0.252*Average Traffic Speed+ 0.358* % of Heavy Vehicles + 0.152 *% of Cars + 0.469* % of Buses +0.384*% of 2W +0.331*% of 3W
	0.892	Leq [hr] (dBA) = 56.32+ 0.0301*Traffic Volume + 0.171*Average Traffic Speed+ 0.0691* % of Heavy Vehicles + 0.328 *% of Cars
	0.934	L10 [hr] (dBA) = 51.071+ 0.0372*Traffic Volume + 0.147*Average Traffic Speed+ 0.370* % of Heavy Vehicles +0.0592*% of 2W

To check the validity of the comprehensive model developed in this study, 180 sample observations within the collected noise data from all the highway sections is utilized. Non-parametric testing (chi-square test) for all models were conducted to know the difference between observed and predicted values. Accordingly, Chi-square test (χ^2) was performed between the observed and predicted values of Leq (dB), where χ^2 (calculated) is appeared to be 22.825 and χ^2 (Critical) at the 5% level of significance is 69.90. Since the χ^2 (calculated) is less than χ^2 (critical), it can be concluded that difference between observed and predicted values are insignificant, that are shown in Table 9.

Table 9. Observed v/s predicted noise levels [Leq (dB)] for the developed model

OBSERVED (O)	**PREDICTED (E)**	**(O-E)²/E**	**OBSERVED (O)**	**PREDICTED (E)**	**(O-E) ²/E**	**OBSERVED (O)**	**PREDICTED (E)**	**(O-E)²/E**
102.2	99.389	0.079490	90.4	96.356	0.368203	106.8	101.587	0.267505
103.3	100.478	0.079236	92.8	96.785	0.164093	105.6	101.989	0.127884
106.2	102.518	0.132212	97.2	97.037	0.000273	103.7	99.305	0.194505
107.8	103.565	0.173203	94.6	100.256	0.319097	104.2	98.830	0.291728
105.6	102.649	0.084830	96.2	99.317	0.097842	105.3	99.997	0.281206
104.5	100.564	0.154040	96.4	97.588	0.014461	109	105.214	0.136213
105.6	101.701	0.149466	94.7	99.567	0.237945	106.2	100.105	0.371101
103.8	99.569	0.179780	94	99.965	0.355914	106.5	102.654	0.144085
102.8	101.132	0.027507	94.2	99.256	0.257577	104.8	101.589	0.101488
103.1	100.752	0.054738	92.6	97.390	0.235572	104.1	100.105	0.159459
102.2	100.439	0.030877	104.3	100.256	0.163097	106.9	102.541	0.185283
101.3	99.881	0.020161	104.9	100.256	0.215088	105.9	102.056	0.144781
105.9	101.504	0.190376	103.2	101.425	0.031053	108.6	105.786	0.074841
103.1	100.908	0.047612	103.4	101.478	0.036403	108.1	104.852	0.100607
103	100.365	0.069203	105.4	100.835	0.206713	107.9	105.411	0.058761
103.8	100.695	0.095732	103.6	98.377	0.277277	100.8	101.776	0.009362
104.5	101.260	0.103696	104.8	100.041	0.226367	101.4	101.527	0.000159
104.2	100.662	0.124351	102.8	98.893	0.154332	103.2	103.791	0.003370
102.9	99.673	0.104480	104.6	100.424	0.173662	104.8	106.319	0.021702
105.2	100.422	0.227285	104.1	100.685	0.115863	101.4	104.952	0.120202
102.7	98.871	0.148257	103.4	98.116	0.284597	103.8	103.295	0.002466
102.6	100.253	0.054952	105.7	100.404	0.279394	100.8	100.840	0.000016
101.7	99.589	0.044753	102.8	98.583	0.180371	100.6	101.663	0.011119
103.9	101.955	0.037121	103.6	98.256	0.290619	102.8	101.839	0.009073
108.4	105.847	0.061573	105.1	99.768	0.284919	101.6	102.801	0.014032
106.1	102.058	0.160067	105.8	100.782	0.249881	102.8	102.813	0.000002
107.2	104.126	0.090762	102.7	98.782	0.155429	100.1	101.193	0.011810
105.4	103.044	0.053852	105.4	100.256	0.263900	100.9	100.962	0.000038
106.8	104.260	0.061890	104.1	99.635	0.200098	97.5	102.365	0.231251
106.5	103.257	0.101866	102.4	98.635	0.143741	101.4	101.786	0.001465
106.4	103.148	0.102540	104.5	99.569	0.244231	103.5	104.411	0.007944
109.1	106.215	0.078390	105.3	100.256	0.253739	100.5	104.614	0.161750
108.7	104.256	0.189403	106.8	103.256	0.121618	101.7	102.575	0.007463
105.4	101.177	0.176305	103.3	99.965	0.111236	102.8	103.216	0.001674
104.7	100.756	0.154376	99.8	103.563	0.136744	102.9	105.344	0.056719
110.6	108.146	0.055699	101.6	107.959	0.374563	101.1	106.352	0.259360
105.4	102.535	0.080031	100.9	105.241	0.179058	101.2	106.784	0.291951
105.8	101.532	0.179374	100.6	104.254	0.128042	101.6	105.652	0.155404
105.1	102.201	0.082250	99.4	104.236	0.224365	99.2	104.256	0.245224
111.7	105.657	0.345579	100.8	105.670	0.224458	103	102.951	0.000024
109.6	107.412	0.044558	108.2	107.475	0.004897	106.7	103.790	0.081579
107.8	105.315	0.058660	102.5	105.237	0.071158	102.2	103.979	0.030423
106.4	102.479	0.150031	101.8	106.215	0.183476	103.8	105.087	0.015759
107.1	103.744	0.108589	100.1	102.365	0.050134	104.2	102.398	0.031723
108.7	109.563	0.006799	104.1	108.812	0.204045	101	103.946	0.083480
109.6	106.247	0.105816	103.9	108.531	0.197568	104.2	104.557	0.001219
106.2	102.696	0.119536	103.8	108.730	0.223491	101.9	105.693	0.136134
105.1	102.657	0.058138	103.1	106.324	0.097765	104.6	105.442	0.006725

OBSERVED (O)	PREDICTED (E)	$(O-E)^2/E$	OBSERVED (O)	PREDICTED (E)	$(O-E)^2/E$	OBSERVED (O)	PREDICTED (E)	$(O-E)^2/E$
95	95.709	0.005248	101.1	106.954	0.320370	103.8	103.896	0.000088
96.8	95.429	0.019691	97.6	105.241	0.554773	102.7	100.593	0.044151
94.7	95.270	0.003408	99.6	104.325	0.214001	104.8	103.208	0.024542
94.5	96.414	0.037995	99.6	105.370	0.315910	105.4	108.355	0.080592
97.9	95.755	0.048067	100.6	106.259	0.301333	101.1	98.594	0.063689
95.8	95.990	0.000376	102.8	106.253	0.112222	101.7	101.853	0.000229
95.1	93.802	0.017975	105.1	102.195	0.082592	102.8	99.147	0.134571
95.4	95.112	0.000869	103.2	100.174	0.091413	100.8	100.474	0.001056
99.6	101.025	0.020102	105.1	101.834	0.104724	101.6	101.903	0.000902
92.1	98.571	0.424821	105.9	102.045	0.145665	101.2	102.141	0.008668
98.7	97.548	0.013608	104.8	101.137	0.132650	102.9	103.057	0.000240
96.2	98.117	0.037463	104.2	101.111	0.094342	104.5	102.455	0.040827
99.8	96.779	0.094291	102.6	99.096	0.123881	102.7	101.567	0.012632
96.4	97.908	0.023221	104.7	101.207	0.120563	103.4	103.622	0.000476
			105.2	101.662	0.123162	103.1	99.582	0.124260

4. Conclusions

Measured noise levels for all the selected highways revealed that both Leq (dBA) and L10 (dBA)are exceeding the noise limits, which can annoy the road users in a menacing way. Moreover, the measured noise levels in the time frame of 15 minutes and one-hour time intervals have shown a clear correlation with both the traffic variables, including volume and speed. At the same time, the results revealed that the combination of volume proportion and road speeds would play a significant role in highway noise level generation. Along with that, observed R^2 values are higher in the models developed with an hourly data [Leq [hr] and L10 [hr]], compared to Leq [15 min] and L10 [15 min]. It indicates that the noise and traffic data averaged over a one-hour interval is close to reality than 15-minutes. Accordingly, models for 15-min time frame resulted in a poor fit compared to the Leq [hr] and L10 [hr]. The comprehensive models developed in this study were validated resulting in a predicted difference of 1 to 10 dB (A) with the observed values. Henceforth, the developed comprehensive model can be effectively used for the noise prediction for the highways with the similar traffic and geometric conditions. Moreover, the proposed model can be effectively used in noise assessment for heterogenic traffic conditions, as the considered vehicle classes for the study covers the most possible modes on Indian highways. Moreover, the study shows that, percentage of two and three wheelers have been dominating the volume proportion in most of the highways selected, showing the need for improved public transportation facilities to keep the average noise levels within the limits prescribed by Central Pollution Control Board (2000) of India. The study can be further extended by assessing the noise levels inside the vehicle on the same highways, in order to compare the noise levels affected by both the commuters (occupants of the vehicle) and the road users including the pedestrians, which is more beneficial in order to formulate the traffic noise regulations.

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