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Traffic Noise Prediction for Delhi-NCR Using Multiple Regression Modelling Approach

Suman Mann*and Gyanendra Singh

Department of Civil Engineering, Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Haryana, India 131039

Abstract

Traffic noise prediction models are crucial for designing highways to implement preventive measures against traffic noise pollution by analyzing future trends. This study aims to identify the traffic, road geometrical, and environmental parameters that escalate traffic noise pollution, enabling rectification of influencing factors and enhancement of strategies to reduce this pollution. A traffic noise prediction model was developed for the highways of Delhi-NCR using the Multiple Regression approach, incorporating various traffic, geometric, and environmental parameters. Statistical analysis was conducted, and the model was formulated based on data collected from 31 sampling stations on two major Delhi highways. Significant variables identified include the number of lanes, average building height, international roughness index, temperature, wind speed, and humidity. The model's validity is affirmed by a coefficient of determination R2 = 0.75, indicating a good fit.

Keywords: Traffic Noise Prediction Model; Noise Pollution; Significant Variables; Multiple Regression Modelling

1 Introduction

Traffic noise is an important factor to be considered in relation with public health [1]. It is rising as a threat to environment, causing health issues to people living in neighborhood of roads and reducing their quality of life [2]. High levels of noise lead to stress reactions in human body, that occurs even during sleep, and these stress reactions lead to hypertension, cardiovascular disease, cognitive impairment, annoyance and can lead to premature deaths. Traffic noise problem is associated with urban and roadway infrastructure developments and technological progress. Traffic noise management can be achieved by proper planning, designing, traffic control and police measures. Urban planners rely on Traffic Noise Prediction (TNP) models in strategizing noise mitigation measures [3]. Noise models involves assessing and predicting traffic noise levels based on various field measurements [4]. Traffic volume, traffic composition, traffic speed and road geometry are the most significant variables in predicting traffic noise [4–6]. FHWA- USA, CORTN-UK, CNOSSOS- EU, ASJ-RTN, RLS-90 are conventional models used by different countries for traffic noise modelling [3, 5, 7–9]. Adjustment for intersections modelling were included in FHWA, RLS- 90, ASJ-RTN and CNOSSOS, whereas CORTN was later modified for noise estimation at intersections [8, 10, 11]. These models are based on homogenous traffic conditions, whereas countries like India face heterogenous traffic conditions, hence models developed for homogenous traffic conditions cannot be opted for heterogenous traffic conditions [12]. Indian research work in the field of traffic noise is very narrow in comparison to other developed countries [13]. Monazzam et al. developed TNP model using 9 different traffic and road related variables for Ahvaz city [14].

*Corresponding author: suman.mann@dseu.ac.in
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Ranpise et al. developed an artificial neural network model for 3 major arterial roads of Surat, India [15]. Gharibi et al. gave a regression model for a highway in Golestan national park, Iran [16]. Suthanaya carried out traffic noise monitoring for Depanser city, Indonesia and modelled traffic noise against traffic composition [17]. Various TNP models have been developed using various modelling approaches (linear regression and machine learning), which include traffic related variables [9, 18–23]. Machine learning models require large data sets for non-linear mapping and get the benefit of generalization. Machine learning models predict better but cannot quantify the effect of variables contributing to noise pollution. Whereas regression models require small data sets and are able to quantify the effect of variables on traffic noise. Machine learning models are suitable for cost estimation due to traffic noise, but during the planning stage, regression models can be used to study the effect of variables so that proper mitigation measures can be provided. Various regression models have been developed but very few have comprehensively explored the effect of environmental factors along with traffic factors on traffic noise levels. Therefore, in the present study, a statistical model for predicting *Leq* is developed for heterogenous traffic conditions considering 12 different variables from traffic related factors, road related factors, and environmental factors. So that the influencing factors may be rectified, and enhancement can be done for reducing the traffic noise pollution.

2 Methods

2.1 Study area and location

Delhi, the capital of India, is selected as the study area. Two major roads of Delhi, NH-9 and Ring Road, were selected for the study. In total, 31 sampling sites were selected on these two roads based on different land use patterns. Details of the study locations are given in Table 1.

Table 1: Details of Sampling Stations

Sampling Station ID	**Location**
SS1	Shalimar Bagh
SS2	Shakurpur Telephone Exchange
SS3	Punjabi Bagh
SS4	Raja Garden
SS5	Naraina Industrial Area
SS6	Dhaula Kuan Passage
SS7	New Moti Bagh
SS8	Hyatt Hotel
SS9	AIIMS
SS10	South Extension 2
SS11	Lajpat Nagar
SS12	Nizammudin
SS13	IP
SS14	ISBT
SS15	ITO
SS16	Azadpur
SS17	Tikri Border
SS18	Mundka Industrial Area
SS19	Nangloi
SS20	Peeragarhi
SS21	Bhopura Border
SS22	Saraswati Vihar
SS23	Haiderpur
SS24	Mukundpur
SS25	Wazirabad Mode
SS26	Signature Bridge
SS27	Khazoori
SS28	Bhajan Pura
SS29	Yamuna Vihar
SS30	Ashok Nagar
SS31	Mandoli

2.2 Noise measurement

Lutron sound level meter SL 4033SD was used for measurement. For measuring noise levels, the instrument was mounted at a height of 1.5m from the ground on a tripod stand and a distance of 1m from the road façade. Sound levels were monitored two times a day for 1 hour each time. The sampling plot of the study location is shown in Figure 1.

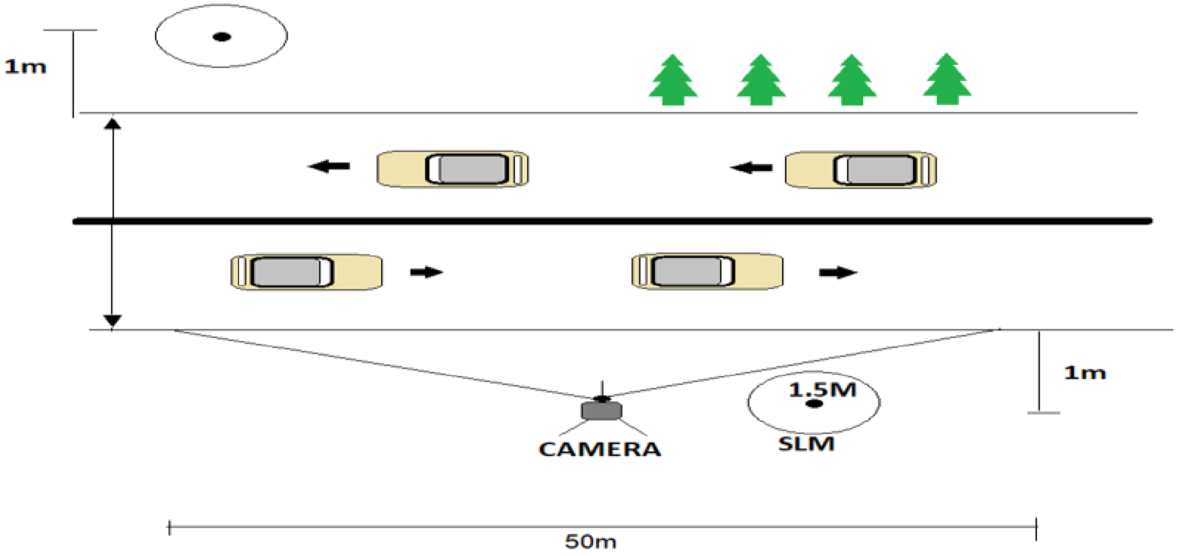

Figure 1: Graphical representation of site

2.3 Traffic, road and environmental data collection

Traffic data was obtained using a video graphic survey. Videos of traffic were simultaneously recorded along with noise measurements, and the videos were later used to obtain total traffic and traffic composition. At each specified location, a road marking of 15m was marked, and the time taken by vehicles to cover this distance was obtained by counting the number of frames. From this, the average traffic speed of the vehicles was calculated. The mobile app Road Bump Free was used to record the International Roughness Index (IRI), and other road-related data was obtained manually at the site. Meteorological data such as temperature, humidity, and wind speed were obtained from the AccuWeather mobile app. The average building height is determined by counting the number of floors and multiplying it by 3.5 m.

2.4 Model development

The whole data set of 31 stations was used to develop a model for Indian cities using regression analysis. Modelling based on Leq(1h) as the dependent variable and 12 other variables as independent variables (shown in Table 2) was performed using SPSS software. The effect of each independent variable on Leq was determined by using a scatter plot and linear regression.

Table 2: Model inputs (Independent variables affecting the sound)

Traffic factors	Road factors	Location conditions
Traffic flow (Veh/hr)	Roughness coefficient	Temperature
Average traffic speed and speed variance	Building height	Wind speed
Traffic composition in terms of percentage of 2W, 3W, 4W and/or HV		Humidity

3 Results and Discussion

3.1 Multiple linear regression modelling

The descriptive statistics of dependent and independent variables measured at two main roads of Delhi, on 31 sampling stations for 62 hours (one in rush hours and one in off rush hours) is presented in Table 3. Figure 2 represents the noise levels at all the sampling stations during rush hours and off rush hours. Measured noise levels are above the WHO recommended levels at all the sampling points, likely due to the business and commercial activities taking place in most locations.

Table 3: Descriptive statistics of variables

Variable	Observations	Minimum	Maximum	Mean	Std. Deviation
Dependent variable					
Leq 1 hr (dBA)	62	67.674	83.231	74.591	4.500
Independent variables					
Total traffic flow (vehicles/hr)	62	1807	7591	4721	1608.747
%2W	62	25.774	61.855	39.142	9.320
%3W	62	6.588	29.797	17.556	5.544
%4W	62	20.238	57.250	37.820	11.405
%HV	62	2.898	12.889	5.641	2.070
Average speed (KMPH)	62	24.555	52.874	40.527	5.872
Std deviation of speed (KMPH)	62	0.860	13.725	3.002	2.056
No of lanes (Numbers)	62	3	5	3.774	0.493
IRI (m/Km)	62	0.130	15.030	7.106	2.666
Avg building height (m)	62	0	17.5	7.903	6.010
Temperature (°C)	62	20	30	25.323	2.373
Wind speed (km/h)	62	4	12	7.226	2.028
Humidity (%)	62	35	63	45.806	6.458

For the development of the traffic noise model, Pearson's correlation coefficient test was carried out for a 95% confidence interval to determine the variables having a substantial effect on the dependent variable *Leq* (dBA). Variables with $r \geq 0.2$ were used to linearly regress with *LAeq*. Total traffic flow and Average speed are converted into logarithmic form to attain a linear relationship. Traffic volume and speed are considered in logarithmic form by various researchers [21, 24]. The model was developed using Log traffic flow, Log average traffic speed, Number of lanes, Average building height, International Roughness Index (IRI), Wind speed, Temperature, and Humidity. Variables with significance < 0.05 were considered significant, and other variables were removed from the analysis. Therefore, the Number of lanes, IRI, Average building height, Temperature, Wind speed, and Humidity were considered, and all other variables were rejected from the analysis. As per Table 4, $R^2 = 0.751$, R^2 explains the total variation in the dependent variable *LAeq* due to independent variables, or the contribution of independent variables in the change of dependent variables. In the present model, $R^2 = 0.751$ indicates that our independent variable has a 75% change in the dependent variable. Table 5 represents the comparison of measured and predicted *LAeq* for the data.

Table 4: Regression results

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.866a	.751	.723	2.3668

Table 5: Comparison of measured and predicted *LAeq* for the data

Pair 1	Mean	Std. Deviation (dBA)	Std. Error Mean (dBA)
LAeq 1hr	74.596	4.500	.571
Predicted Value	74.591	3.898	.495

Analysis of variance (ANOVA) test was performed to check the variance among independent variables and *LAeq* (dependent variable). ANOVA results show that the P value is 0.000, which is less than 0.05, hence we can say that there is a significant relationship between *LAeq* (dependent variable) and independent variables. Table 6 shows the coefficients results. The Beta value for the variable temperature is negative, whereas for the Number of lanes, IRI, Average building height, wind speed, and humidity, Beta values are positive. Negative values indicate a negative relationship between the dependent and independent variable, meaning when the temperature (having negative Beta values) increases by 1°C, dependent variable *LAeq* decreases by 0.252 dBA. These results are in confirmation with the findings of Sánchez-Fernández et al. [25]. At increasing temperature, the speed of sound increases, leading it to refract towards higher altitude and leading to lower noise levels at the receiver end. Positive Beta values indicate a positive relation between *LAeq* (dependent variable) and independent variables (Number of lanes, IRI, Average building height, wind speed, and humidity). As per results, noise levels increase by 0.113 dBA with an increase in the number of lanes. Similar results were given by Lu et al. [26], explaining that more lanes indicate more traffic demand leading to an increase in traffic volume, which increases the noise levels. When IRI increases by 1 m/km, *LAeq* increases by 0.090 dBA, these results are in accordance with the results given by Soedirdjo et al. [27]. Average building height also showed a positive relation with noise levels. Tandel and Macwan also published similar results [28]. Murugun et al. proved a linear relationship between noise levels and wind speed [29].

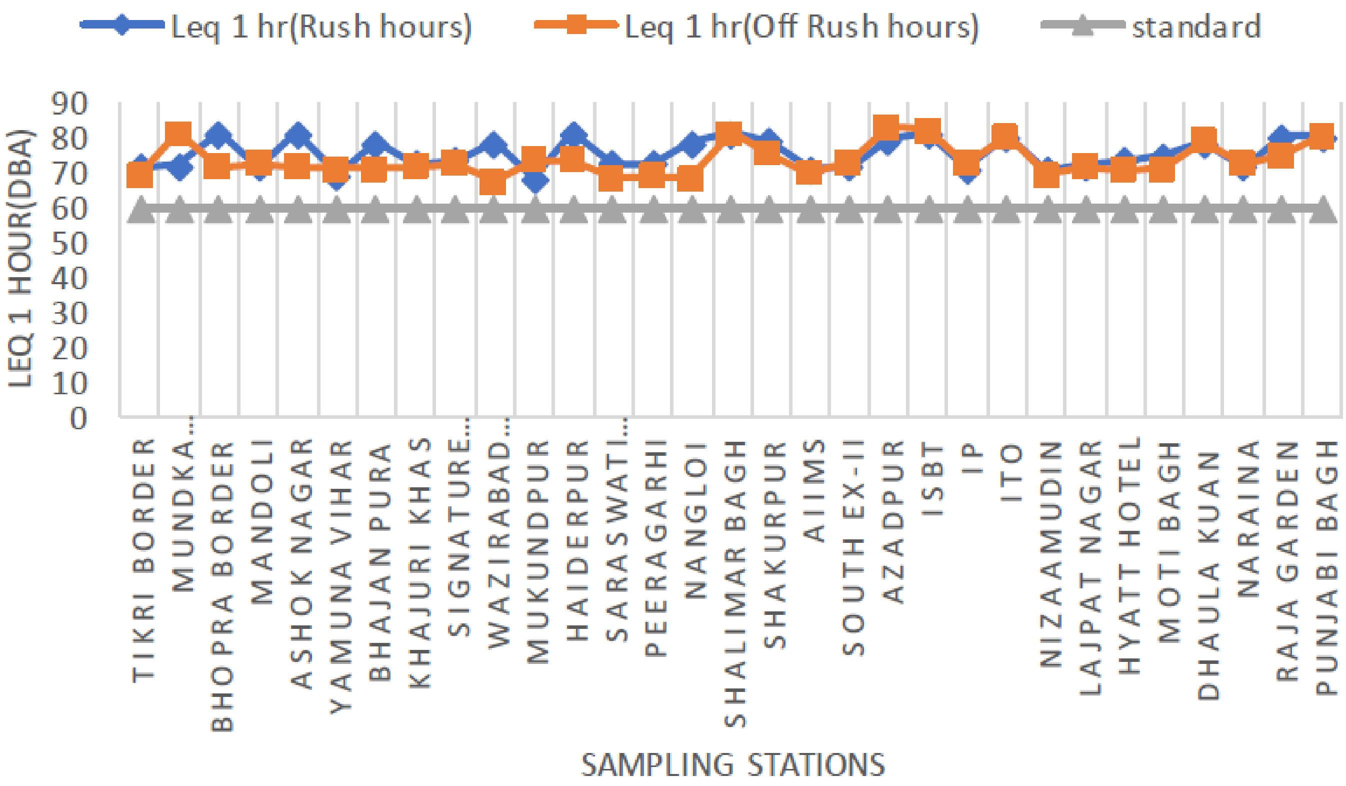

Figure 2: Noise levels at all sampling stations during rush hours and off rush hours

Table 6: Regression coefficients of the developed model

Model	Unstandardized Coefficients	Standardized Coefficients			
	B	Std. Error	Beta	t	Sig.
Constant	77.151	5.804		13.293	.000
No of lanes	1.033	.651	.113	1.587	.018
IRI	.152	.118	.090	1.287	.003
Avg building height	.107	.054	.143	2.000	.050
Temp	-.478	.191	-.252	-2.503	.015
Wind speed (km/h)	1.453	.209	.655	6.957	.000
Humidity (%)	.106	.051	.153	2.072	.043

4 Model validation

The accuracy of developed models was tested based on R^2 and other errors, as given in Table 7. The goodness of fit of the regression model was evaluated by comparing the observed and predicted values. A scatter plot between observed and predicted noise levels was plotted along a 45-degree line as shown in Figure 3. As per the developed model, the mean difference between predicted $LAeq$ 1hr and observed $LAeq$ 1hr is less than 0.0003 dBA. Thus, the developed model can predict traffic noise levels accurately for Indian cities.

Table 7: Comparison of measured and predicted $LAeq$ for the data

Pair 1	Mean	Std. Deviation (dBA)	Std. Error Mean (dBA)
$LAeq$ 1 hr	74.596	4.500	.571
Predicted Value	74.591	3.898	.495

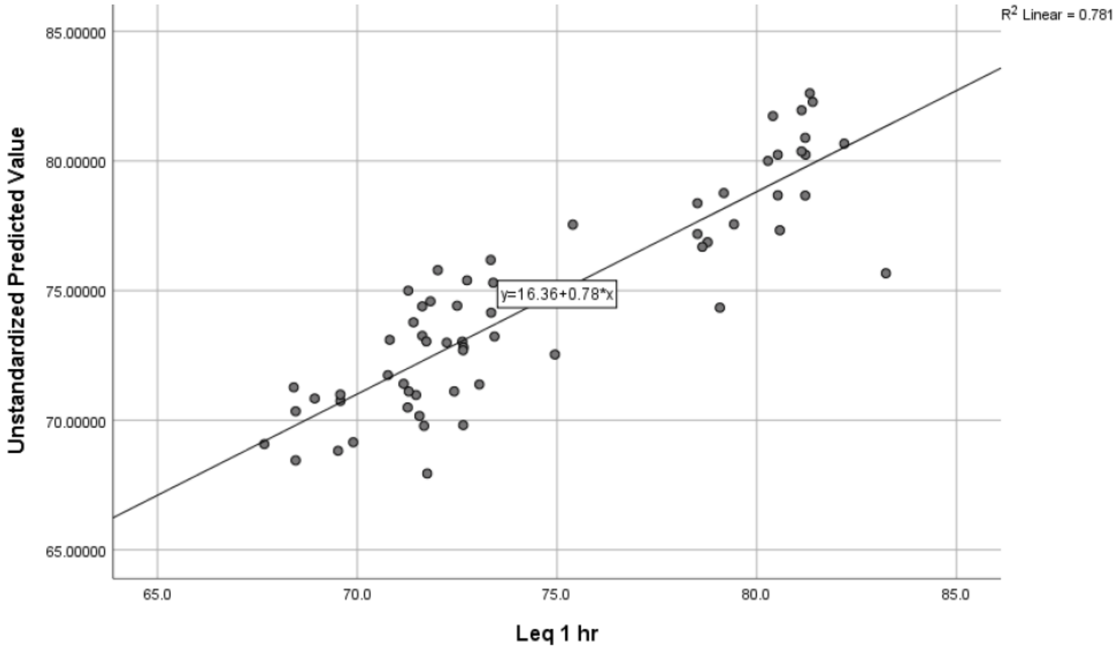

Figure 3: Scatter plot between predicted and observed *LAeq*

5 Conclusion

The present paper developed a traffic noise prediction model for highways in India with heterogeneous traffic conditions. Data sets for the dependent variable *LAeq* 1hr and twelve influencing variables were collected from two major roads in Delhi during May – June 2023. Out of the 12 explanatory variables, only 6 were found significant in the present study. The Number of lanes, IRI, Temperature, Humidity, Wind speed, and Average building height are considered in model development. The study revealed that IRI and Wind speed are the most significant factors affecting traffic noise. Results indicated that Temperature is negatively associated with noise levels, whereas all other factors are positively associated with noise levels. The mean difference between observed *LAeq* 1hr and predicted *LAeq* 1hr is 0.003 dBA. The developed model has higher prediction accuracy with a determination coefficient equal to 0.75. The developed regression model provides a simple linear equation which is easy to understand and can be used to check out the mitigation measures for reducing and controlling noise pollution due to traffic. The benefit of regression models is that they need fewer data sets and can be used in the planning stage where environmental impact assessment has to be done. The suggested mitigation measures in the study area are:

- Use of intelligent transport system to control traffic mobility, volume, speed, and composition.
- Technological solutions can be implemented: like the construction of noise barriers using sonic crystals, Poroelastic road surfaces for reduction of tyre/road noise.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contribution

Suman Mann: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation, Visualization, Investigation, Validation, writing; **Gyanendra Singh**: Supervision, Reviewing, validation and editing.

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