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Highway traffic noise modeling and estimation based on vehicles volume and speed

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Abstract. Traffic noise estimation models are useful in evaluation of the noise pollution in current circumstances. They are helpful tools for design and planning new roads and highways. Measurement of average traffic noise level is possible when traffic speed and volume are known. The objective of this study was to devise a model for prediction of highway traffic noise levels based on current traffic variables in Iran. The design of this model was to take the impact of traffic congestion into consideration and to be field tested. This study is a library research augmented by field study conducted on Saeedi Highway located south west of Tehran. The period for the field study lasted 5 days from 7-12 February, 2013. This study examined liner and non-liner methods in formulation of its model. Liner method without a fixed coefficient was the best fit for the intended model. The proposed model can serve as a decision making tool to estimate the impact of key influential factors on sound pressure levels in urban areas in Iran.

Keywords: noise modeling; highway; volume; speed

1. Introduction

Noise is a pollutant in metropolitan areas. Highway traffic noise is a source of environmental pollution. Noise pollution studies have led to the development of models that help in prediction of noise levels based on a number of variables including vehicle volume and speed.

City expansions have increased the number of vehicles frequenting in city streets. The number of vehicles in a city represents the symbol of citizen's well-being. City residences continue driving their vehicles in spite of the fact they are culprit for producing various types of pollution, among them, noise pollution. Traffic is the main source of noise pollution in metropolitan areas. Noise pollution has damaging effects on hearing and is the cause of many disabling physical and mental illnesses with irreparable consequences.

Tehran is a metropolitan area suffering from high noise pollution level. Vehicles make the main source of noise in Tehran. Private vehicles make up half of all the vehicles crossing urban streets every day. About half of vehicles in Tehran produce above standard noise levels. Standard noise is 55 decibels during day and 45 decibels for nights with an accepted standard deviation of 15 decibels. The noise level in Tehran highways and roads is much higher than the standard.

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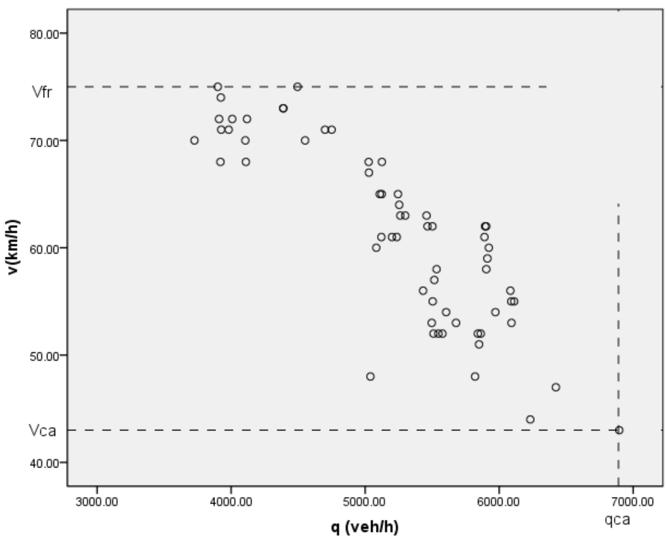
The only noise pollution study in Iran was the one conducted for Hamadan City in 2009. No model has been proposed so far for prediction of average hourly sound level produced by traffic in the main streets of Tehran. The need for a model for estimation of noise level based on vehicle volume and speed is evident.

A statistical formulation with high coefficient of determination may provide a quantitative explanation for current circumstances given certain environmental parameters. Such model may predict and provide solutions when those environmental parameters change. If we were to study the noise emission on a given pathway with a certain model, we enter the required data including traffic volume, speed, hearing distance, and similar variables in order to study their effects on sound pressure level. The predictive model of noise pollution in city pathways is obtained based on the best-fit regression formulation. This model can predict sound pressure level in various conditions as variables change.

FHWA is the most common noise traffic model. It was original proposed by US Federal Highway Administration in 1970. New improved versions have been developed over time.



V_i = Traffic speed
q_i = Traffic flow
V_{fr} = Free flowing average speed
q_{ca} = Traffic flow capacity
V_{ca} = Speed at traffic flow capacity

Fig. 1 Volume-speed chart for Saeedi *Highway* in Tehran

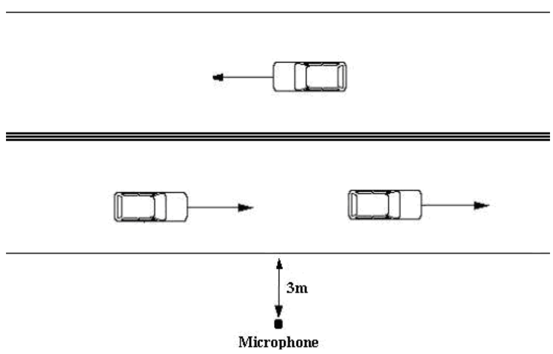


Fig. 2 Standard microphone position for measurement of noise level

2. Methodology

This study is a practical-analytical research. It was conducted on a specific case during a given period. This study was carried on Saeedi highway in Tehran during a limited time window in 2013. This highway is the connecting link between Fath and Azadegan highways. Its average traffic volume is 5206 vehicles per hour. The average vehicle speed was measured at 61.1 km/h. Fig. 1 shows the volume-speed chart for Saeedi Highway.

The recording microphones in this study were placed 3 meters away from vehicle surface and 120 centimeters above road surface (Fig. 2). This is the standard position used in measurement of vehicle noise emission studies. Fig. 3 shows the vehicle sound levels based on the passing time and positional distance from microphones.

The following assumptions apply to this study.

- Noise is only generated by passing vehicles.
- Vehicle speed change is miniscule, therefore, the noise emitted by vehicle acceleration and deceleration is ignored;
- Microphones are placed at the distance where climate change can be ignored.

Microphones were placed in 62 stations along Saeedi Highway. Stations recorded noise emission with advanced instruments installed 3 meters away from the highway curbs. The number of passing vehicles was counted manually. The passing vehicles were grouped into cars, motorcycles, medium trucks, heavy trucks. Average vehicle speed was recorded simultaneously for each group using average speed measurement method.

3. Data analysis and modeling

Data collected for this study were entered into a database for processing and testing with applicable models. A new model was to be designed according to study objectives using the

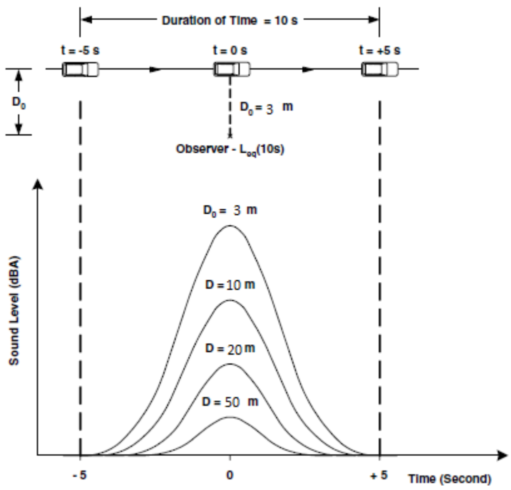


Fig. 3 Noise level versus vehicle position relative to microphone

Table 1 Results of Multivariate Regression Analysis

Model	R	R^2	Adjusted R^2	Std. error
1	0.98[a]	0.96	0.93	1.16559

Table 2 Coefficients of the Proposed Model

Variables	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. Error	Beta		
VOL	0.001	0.000	0.057	3.907	0.000
SPD	0.094	0.014	0.077	6.645	0.000
L1	1.022	0.022	0.868	45.643	0.000

relationships between independent variables and their impact on traffic noise. The independent variables in this study were vehicle noise emission, volume, and speed. The dependent variable was hourly equivalent sound (pressure) level or L_{eq}.

The collected data was entered into SPSS tables after identification of independent variables and calculation of equivalent sound level for all 62 stations. Data analysis included multivariate regression analysis. The primary model was developed after several iterations. The independent variables in the model included vehicle volume and speed plus average noise emission level. The three independent variables were analyzed against raw (not standardized) equivalent sound level as the dependent variable. Table 1 shows the result of multivariate regression analysis. Table 2 shows the determined coefficients for the proposed model. Eq. (1) is the formula for the proposed model.

$$L_{eq}(db) = 0.001 * VOL + 0.094 * SPD + 1.022\widetilde{L} \quad (1)$$

In this formula:

VOL represents the weighted volume of vehicles in a given area (*Veh*/*h*)
SPD represents the speed of passing vehicles in a given area (*km*/*h*)
$\widetilde{L}$ represents the average noise emission for passing vehicles under condition *db*.

The average noise emission level from passing vehicles in Iran is estimated using equation (2) and based on the data recorded by microphones in this study.

$$\widetilde{L}(db) = 10\log\left[0.02 \times \left[\frac{V}{S + 0.01} \times 10^{0.1\widetilde{L}_i}\right]\right] \quad (2)$$

Where

$\widetilde{L}$ Average noise emission level for passing vehicles under condition *db*

$\widetilde{L}_i$ Mean noise emission level for passing vehicles under condition *dp*. This figure for Iran is 62.3 while the same number for Japan is 46.4.

V Volume of passing vehicles (*veh*/*h*).

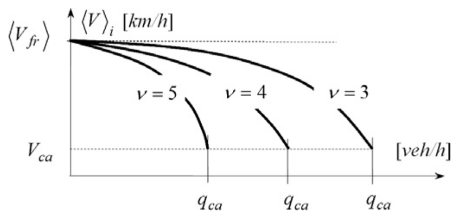


Fig. 4 Speed-volume is a function of υ

Traffic congestion reduces passing speed (Makarewicz and Galuszka) and, therefore, produces lower noise. This is an important factor which was considered in the proposed model. The impact of congestion may be high, average, or low depending on certain factors including free speed, traffic capacity speed, and other similar factors.

In reference to Fig. 4 and considering the heavy traffic together with speed-volume chart of *Saeedi Highway*, two speed-volume and traffic flow charts were overexposed. Traffic flow chart is an exponential equation with power of υ. The value of υ was obtained to be equal 3.

Free speed and full capacity speed in this highway was measured at 80 and 35 km/h, respectively. This study assumes is $\Delta L_{cong} < 0$ (ibid). In traffic congestions, we will have $|L_{cong}| > 1db$. Thus, we cannot ignore the impact of traffic congestion. The following equation is the formula for heavy traffic.

$$\Delta L_{cong} = 10 \times \log \left[1 - \frac{6}{v+3} . \left(1 - \frac{V_{ca}}{\langle V_{fr} \rangle} \right) + \frac{3}{2(v+1)} . \left(1 - \frac{V_{ca}}{\langle V_{fr} \rangle} \right)^2 \right] \tag{3}$$

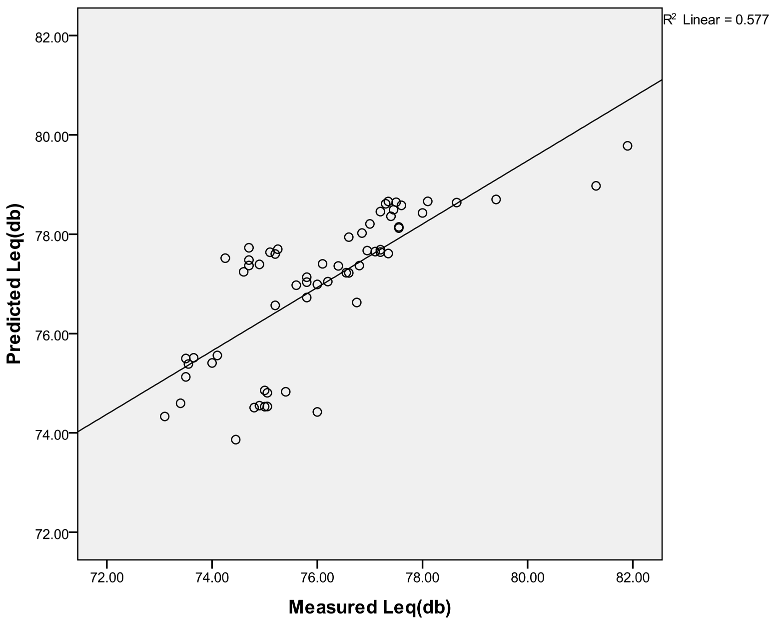


Fig. 5 Estimatedvehicle noise emission by proposed model without a fixed coefficient drawn versus noise levels recorded by 62 stations at a standard distance from the curb

Table 3 Results of multivariate regression analysis for predictive model

Equation	Model specifications					Estimated parameters		
	R^2	F	$df1$	$df2$	Sig.	Constant	$b1$	$b2$
Linear	0.577	81.735	1	60	0.000	6.516	0.904	
Logarithmic	0.571	79.909	1	60	0.000	-222.975	68.855	
Quadratic	0.582	83.603	1	60	0.000	40.940	0.000	0.006

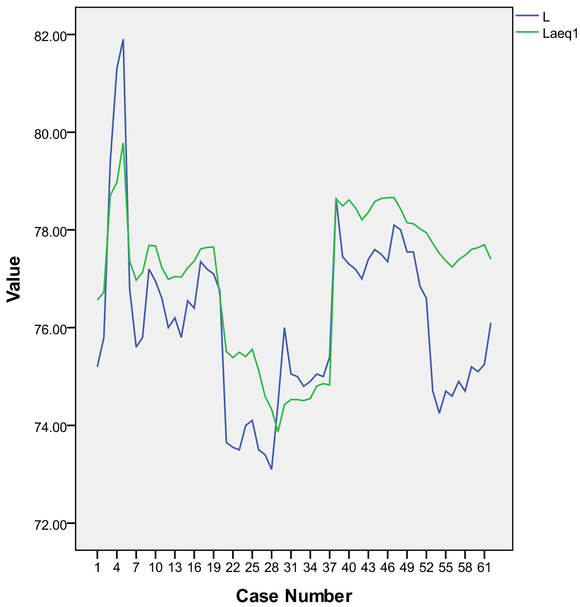


Fig. 6 Measured traffic noise obtained from 62 stations (blue) versus estimated noise emission (green)

After solving Eq. (1) and including the effects of congestion into model, the final equation becomes

$$L_{eq}(db) = 0.001 * VOL + 0.094 * SPD + 1.022\widetilde{L} + \Delta L_{cong} \quad (4)$$

Where ΔL_{cong} represents the impact of traffic congestion.

The correlation coefficient is 0.98 and coefficient of determination is 0.96 (Table 1). These two are important determinants in the regression analysis of this study. Considering the fact that a model without fixed coefficient is not trustworthy, measured noise emission has to be compared with estimated noise emission in order to determine how they are related.

Fig. 5 illustrates the noise emission level predicted by proposed model based on measured values at the standard distance from curb and with a coefficient of determination equal to 0.577. The figure shows the obtained results from model are valid and reliable.

Fig. 5 shows the possibility of a non-linear relationship. Thus, non-linear relation was also examined for further assurance. Regression analysis is a tool for studying non-linear relationship between independent variables and dependent variables. A chart similar to Fig. 5 may be used to confirm a non-linear relation.

Table 3 shows the results obtained from the proposed model. This table is key to interpretation of the results from regression analysis. It shows the fitness of the three models used in this study, amely, linear, logarithmic, and quadratic. The significance levels for all three models are below 0.05. In such case, the best fit option is the one with the highest F value. Table 3 shows that quadratic equation has the highest F value. Therefore, quadratic regression model is best for prediction of the dependent variable based on the estimated values of noise level. However, a high constant coefficient makes the results obtained from this model highly unreliable. Consequently, the linear model is chosen as the next best fit.

Fig. 6 shows noise emission measured at the recommended distance at 62 stations and estimated noise emission level.

4. Conclusions

Modeling was concluded for this study after two iteration of multivariate regression analysis. The best option was linear formulation without a fixed coefficient. The impact of traffic congestion from high volume of traffic on Saeedi Highway was incorporated into the proposed model as a negative number. The proposed model is useful for expressways with free speed of 40 km/h. It is not suitable for side roads or local streets. The proposed model can be a useful tool for estimation of vehicular noise emission. It provides a very low cost approach for identification and control of critical points on a highway. A proper noise emission modeling and estimation can assist in planning for noise reduction trough sound barriers installation, landscaping, planting, or similar schemes along highways.

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