Development of Noise Prediction Model for Road Traffic at Selected Hospitals of Surat City Using Genetic Algorithm Optimization

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The patients of hospitals are vulnerable to noise and can adversely be affected due to noise exposure. Mixed landuse such as residential zones and commercial centres, hospitals located beside commercial buildings, etc., are commonly seen phenomena in India. This leads to an increase in noise levels in silence zones and violates the standard norms given by CPCB. This study aims to develop a noise prediction model by the application of a genetic algorithm for selected hospitals in Surat city A Genetic Algorithm based mathematical model is designed for three hospitals in Surat city, Gujarat, namely (1) Sushrut hospital and (2) Tristar hospital and (3) Reliance hospital. For the prediction model, the daytime (9:00:00 A.M – 9:00:00 P.M) 12 hrs. data is used. It was collected as per CPCB guidelines at each location using KIMO DB 300/2, Class – 2 sound level meter. Data like traffic composition, vehicle speed, meteorological parameters and geographical features were also recorded. Many factors affect the noise levels. But in this study, three major factors included in the noise prediction model are traffic flow (composition), speed of vehicle and aspect ratio. The predicted noise levels are compared with measured noise levels. The coefficient of determination (R2) values for all three locations are either nearer to 0.7 or greater than 0.7. Also, the values of Karl Pearson's coefficient of correlation (r) for each location are more significant than 0.8 near 1. These all indicate that the noise prediction model is strongly correlated with monitored data. Also, the model gives the results accurate within 0.649%, and globally, the models are found valid within ±1.5%. Hence, it is concluded that the model shows very precise and satisfactory results.

Keywords: Noise prediction model, silence zones, hospitals, genetic algorithm optimization.

2023. In Satyasai Jagannath Nanda & Rajendra Prasad Yadav (eds.), *Data Science and Intelligent Computing Techniques*, 859–867. Computing & Intelligent Systems, SCRS, India. https://doi.org/10.56155/978-81-955020-2-8-73

1 Introduction

Sound is crucial to our daily lives, but noise is not. Noise can be described as an unpleasant sound. Road traffic noise is the most ubiquitous and detrimental source of noise. Unfortunately, it is most difficult to control.

Some studies show that most cities in India have faced serious noise pollution problems in the last few decades due to urbanization and industrialization (Mishra et al., 2010; Ranpise et al., 2021).[7] [9] Few studies have been conducted aiming at noise pollution in silence zones of urban areas of India(Garg et al., 2017; Hunashal & Patil, 2012).[3] [4] At home and work, many of us are subjected to distressing levels of noise. The main factors for noise pollution are transportation, in the form of motor vehicles. Some other sources of noise pollution are construction work, loudspeakers, community noise, airport noise and machinery work at factories.

Environmental pollution such as water, air, hazardous waste, and noise pollution has always been a cause of concern, affecting society's health as well as the world's delicate ecosystems(Sonaviya & Tandel, 2019). [11] According to World Health Organization, noise is the second leading environmental cause of health problems followed by air quality impact(WHO, 1987, 2011).[13] The significance of control of environmental noise in human life cannot be overstated. Noise has a considerable effect on public health and has a severe influence on human activities. High levels of noise exposure cause annoyance, sleeplessness, difficulties in concentration and problems in cognitive tasks (Brown & van Kamp, 2017; Lee et al., 2019; Mishra et al., 2010; WHO, 2011).[1] [5] [14] Especially, environmental noise has an impact on hypertension, cardiovascular risks, and sleep disturbance.

Noise prediction modelling is required to ensure environmental noise control. To collect information for noise mitigation plans, noise prediction models are developed. It is commonly used in the mapping(Ranpise et al., 2021) [10] of road traffic, airport, and rail noise.

There is no validated and authorized model for road traffic noise prediction for silence zones in India. With the growing vehicular population and mixed land-use pattern trend, there is an urgent need for a traffic noise prediction model, not only to predict the noise levels but also for noise abatement measures(Ranpise et al., n.d.; Tandel & Jem, 2013).[12] Multiple linear regression is not very encouraging; MLR models are weak because R2 values indicate the poor strength of MLR models. In contrast, the genetic algorithm is generally better than MLR(Bu et al., 2013; Rahmani et al., 2011; Ranpise et al., n.d.; Tandel & Jem, 2013).[2]

This study aims to develop a noise prediction model by applying a genetic algorithm to selected hospitals in Surat city. "An area comprising not less than 100 metres around hospitals, educational institutions and courts may be declared as silence zone by the competent authority (CPCB)(Ministry of Environment and forest, 2000)".[6] Based on this guideline of silence zones of CPCB, three hospitals, namely, Sushrut hospital, Tristar hospital and reliance hospital selected for study purposes. According to ambient air quality standards in respect of noise given in Noise (Pollution and Control) Rules – 2000, the LAeq limits during daytime and nighttime should be 50 dB(A) and 40 dB(A), respectively. The study also tries to establish the effects of traffic speed, traffic composition and aspect ratio on the road traffic noise levels. In this study, the aspect ratio is nothing but the ratio between the heights of the building to the width of the road. Based on this variation of equivalent traffic noise level concerning the aspect ratio, it is clear that when the aspect ratio is increasing for a particular road then the equivalent traffic noise level is also increasing due to the reverberation effect of noise.

The objectives of the studies are:
To assess and compare road traffic noise levels around selected hospitals of Surat city with permissible (CPCB) silence zone norms.
To develop a noise prediction model for road traffic at selected hospitals of Surat city using a genetic algorithm.
To derive a correlation between measured and predicted noise levels.

2 Methods:(Data Collection, Mathematical Modelling)

Data collection-Noise monitoring was carried out at three hospitals, namely (1) Sushrut hospital, (2) Tristar hospital (3) Reliance hospital. Noise data was collected using KIMO DB 300/2 (Automatic sound level meter, a class – 2 sound level meter). Data was collected for daytime (9:00 AM – 9:00 PM) for a total 12-hrs duration according to CPCB protocol (Ambient Air Quality Standards in Respect of noise notified under Noise (Pollution and Control) Rules, 2000) (Ministry of Environment and forest, 2000).

Noise data was stored in a storage device with appropriate file names, and then this data was then extracted using LBD23 software. Noise levels for 15 min intervals were extracted for each location. So, 48 readings of noise levels (Leq) for each hospital have been considered for noise prediction modelling. Traffic composition data were collected using a video graph. Vehicles passing from the road were categorized into 2-W, 3-W, 4-W and heavy vehicles (H.V, which includes buses and trucks). Speed of each vehicle, i.e., 2-W, 3-W, 4-W and H.V, were measured using a Falcon HR radar gun. During the time of noise monitoring, meteorological parameters like wind speed, temperature and humidity were noted. Measurement shows ideal wind speed, temperature and humidity, i.e., absence of extreme climatic conditions. The site survey was carried out for collecting data on the road width and height of the building. Road width was measured using a measuring tape, and the height of a single floor was assumed as 3.5 m. So, the height of the building was calculated by multiplying the number of floors by 3.5.

Mathematical modelling - Creating an objective function (fitness function) in a genetic algorithm is a significant task(Bu et al., 2013). To optimize the proposed model (Leq, i, prediction values), a computer program of G.A was written using MATLAB software. The objective function is the minimization of the Sum of Square Error (SSE):

$$E = \sum_{i=0}^{N}(L_i - L_{eq,i})2 \qquad (I)$$

Li and Leq, i are measured, and predicted values of noise levels at i time, respectively. Here, Li values are monitored, and for Leq, i, which is the predicted noise level, the mathematical model was developed empirically for actual Indian road traffic conditions.

$$L_{eq,i} = a + b * q(i) + c * v(i) + d * ar \qquad (II)$$

Where a, b, c and d are coefficients that are unknown and will be obtained after optimization using G.A and
q (i) = 10Log(Q), v(i) = 10Log (Veq), ar are the representations of traffic flow (traffic composition), speed of vehicle and aspect ratio respectively which were monitored (known parameters)
formulas of Q, Veq and ar are given below:
Q is the traffic composition of 2-W, 3-W, 4-W and H.V, converted into a singleunit P.C.U (passenger car unit).
For 2-W, 3-W, 4-W and H.V, P.C.U were taken at 0.5, 1.5, 1 and 3, respectively.
So,

$$Q(P.C.U) = \frac{(Q2w*0.5+Q3w*1.5+Q4w+Q\ H.V*3)}{Q\ total} \qquad (III)$$

Where Q2-W, Q3-W, Q4-W, QH.V., are traffic flow of 2-W, 3-W, 4-W and H.V during each 15 min.
Vehicle speeds of 2-W, 3-W, 4-W and H.V are converted into equivalent speed (Veq) using the following formula (Rahamani et al. 2011)(Rahmani et al., 2011),[8]

$$Veq = \frac{(V2w * Q2w * 0.5 + V3w * Q3w * 1.5 + V4w * Q4w + VHV * VQ\,H.V * 3)}{Q\ total} \quad (IV)$$

And, ar = $\frac{Heightofbuilding}{Widthofroad}$. Now finally, the equation of Leq. will be,

$$L_{eq,i} = a + b * 10\log(Q) + c * 10\log(V_{eq}) + d * ar \quad (V)$$

The above-obtained equation is the final noise prediction model, where a genetic algorithm optimizes coefficients a. b, c and d (Table 1).
Considering the practical limits, assumptions made in the development of the noise prediction model are enumerated below:

1. This model is valid for only daytime (12 hr.) equivalent noise with A-weighted frequency (i.e., Leq).
2. The level of service of the road was considered either B or C.
3. 2-W here represents all the types of motorized two-wheelers, irrespective of engine capacity (The same holds for 3-W, 4-W and H.V.).
4. There is no artificial or natural noise barrier between the source and observer.
5. The model is applied for ideal meteorological conditions, and vehicle acceleration & deceleration was not considered, i.e. the modes of vehicle motions are cruising with a steady uniform speed.

3 Genetic Algorithm Optimization Methodology

For noise prediction using a genetic algorithm, measured data was used as input. Measured noise levels data, traffic count, vehicle speed and aspect ratio of each station were imported from an m – file created in MATLAB. After importing all the parameters, a genetic algorithm code was run. Parameter selected were population size 1000, population type double vector, uniform creation function, no of iterations 1000, tournament selection, crossover rate 0.8 with single-point crossover, mutation rate 0.25, upper bound and lower bound of coefficients [30, 0, -5, 0] and [80, 1, -5, 1] respectively. These all values are very problem-specific. After an exhaustive sensitivity analysis, these parameters were finalized.
The stepwise procedure of genetic algorithm optimization is given below in the form of a flow chart (The procedure is the same for all the locations):

Step 1: Measured data used as input.

Step 2: Maximum no of generations (iterations) was specified. Here, the maximum number of generations (Ngen, max =1000) was fixed after running the G.A program with various iterations like 1500, 2000, and 2500, but there was no improvement in objective function after (Ngen, max =1000).

Step 3: Parameters range was defined after analyzing measure data. The defined range of coefficients was, for a ∈ [30, 80], b and d ∈ [0, 1] and c ∈ [-5, 5]. So, the upper bound and lower bund were [30, 0, -5, 0] and [80, 1, 5, 1] respectively. The initial population was taken at 1000, and a double vector population type has been set.

Step 4: Noise level (Leq) calculated.

Step 5: Objective function computed.

Step 6: The genetic operators applied. Which includes selection, crossover and mutation. Tournament selection was selected, and crossover rate and mutation were kept at 0.8 and 0.25, respectively. The single-point crossover function was set.

Step 7: Optimization terminated at the number of fixed generations (Ngen, max =1000). Values of coefficients printed.

4 Results and Discussion

At the end of code termination in MATLAB, the values of a, b, c and d for each location from the prediction model are given in the table below:

Table 1. Values of coefficients

Sr. No	location	Coefficients			
		a	b	c	d
1	Sushrut hospital	63.361	0.233	-0.225	0.959
2	Tristar hospital	63.504	0.063	0.149	0.354
3	Reliance hospital	64.149	0.11	0.137	0.98

So, the expressions for all three locations, namely Sushrut hospital, Tristar hospital, and Reliance hospital obtained respectively are:

$$(1) L_{eq} = 63.361 + 0.233 * 10 log(Q) - 0.225 * 10\, log(V_{eq}) + 0.959 * ar$$

$$(2) L_{eq} = 63.504 + 0.063 * 10 log(Q) + 0.149 * 10\, log(V_{eq}) + 0.354 * ar$$

$$(3) L_{eq} = 64.149 + 0.11 * 10 log(Q) + 0.137 * 10\, log(V_{eq}) + 0.98 * ar$$

The predicted values of noise levels obtained from the above equation are compared with measured noise levels. The scatter plots for each location are given below:

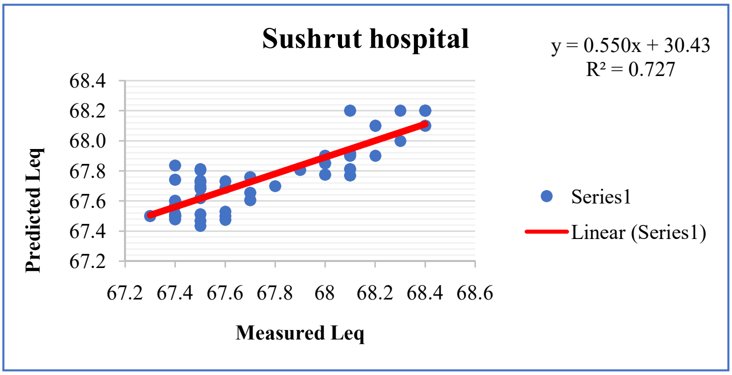

Figure 1. Leq measured Vs Leq predicted at Sushrut Hospital

Figure 1, indicates the variation of predicted Leq values against the measured Leq values at Sushrut hospital. The values of predicted noise level come very nearer to measured noise level, except some points are scattered and dispersed. The value of the coefficient of determination (R2) comes out to be 0.727, greater than 0.7. So, a strong correlation between predicted and measured noise levels was found. Pearson coefficient of correlation (r) has been calculated using excel, which comes out to 0.853. Maximum and minimum values of absolute error (measure Leq – predicted Leq) are 0.330 and 0.437.

So, the predicted values of Leq are pretty accurate and within ± 0.45 dB < 1% with measured values of Leq. The maximum and minimum values of %Error are coming out to 6.49% and -0.484%, respectively.

At Tristar hospital, the predicted noise level values come very nearer to the measured noise level, and the coefficient of determination (R2) is 0.687, which is very close to 0.7 (figure 2). The predicted values of Leq are quite accurate and within ± 0.25 dB (±0.35%) with measured values of Leq. The maximum and minimum values of % error were 3.23% and -0.30%, respectively.

Also, in the Reliance Hospital graph, the predicted noise level comes nearer to the measured noise level. The distribution on the expected side is very dispersed between 74 to 76 dB. The value of the coefficient of determination (R2) comes out to be 0.852; it is also greater than 0.7(figure 3).

The reason behind that may be because, at the location of Reliance Hospital, a road stretch, homogeneous traffic and zero or minimum unauthorized parking were observed. These lead to less horn honking and cruising traffic, leading to lesser spikes in actual Leq values. Pearson coefficient of correlation (r) has been calculated using excel, which comes out to 0.923. Maximum and minimum values of absolute error (measure Leq – predicted Leq) are 0.558 and 0.20. So, the predicted values of Leq are quite accurate and within ± 0.6 dB with measured values of Leq. The maximum and minimum values of % error are 2.73% and -0.760%, respectively.

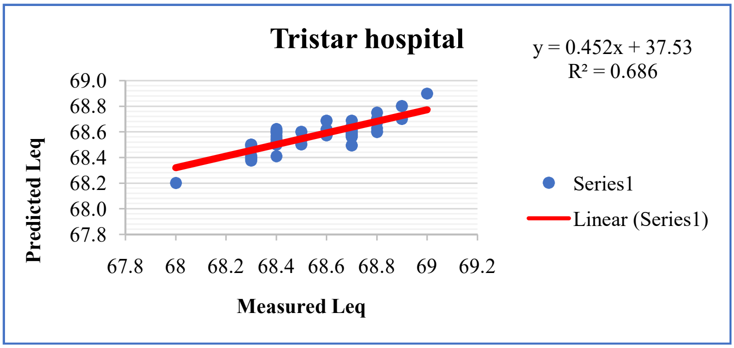

Figure 2. Leq measured Vs Leq predicted at Tristar hospital

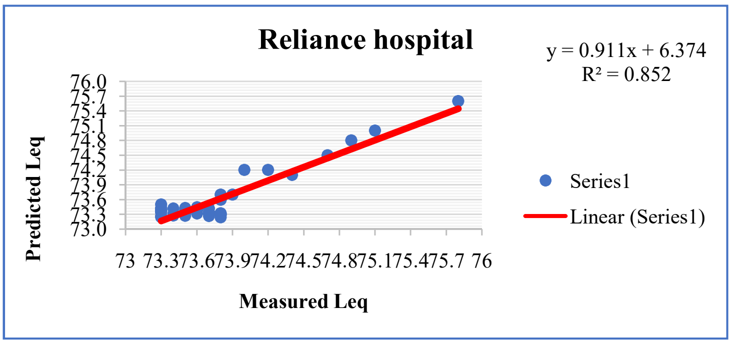

Figure 3. Leq measured Vs Leq predicted at Reliance hospital

The comparisons of all three locations by various errors like MSE (Mean Square Error) and % error are below. Also, the coefficient of determination (R2) and Pearson coefficient of correlation is mentioned for all three locations.

Table 2.Comparisons of various errors and coefficients for all three noise prediction models

Location	Equation	%Error		MSE	R2	r
		Max	Min			
Sushrut Hospital	63.361 + 0.233*(10Log(Q)) - 0.225*(10Log(Veq)) + 0.959*ar	6.49	-0.484	0.036	0.728	0.853
Tristar Hospital	63.504 + 0.063*(10Log(Q)) + 0.149*(10Log(Veq)) + 0.354*ar	3.23	-0.30	0.018	0.687	0.829
Reliance Hospital	64.149 + 0.11*(10Log(Q)) + 0.137*(10Log(Veq)) + 0.98*ar	2.73	-0.76	0.067	0.852	0.923

Where MASE = Mean Absolute Square Error, MSE = Mean Square Error, R2 = Determination coefficient and r = Karl Pearson correlation coefficient.

Here, it can be seen that the coefficient of determination (R2) for all three locations is either nearer to 0.7 or greater than 0.7, which indicates that predicted values of noise levels are very near to measured values of noise levels. So, the noise prediction model for all three hospitals is giving desired and satisfactory results. Comparing the coefficient of correlation of all three locations, it is found that R2 of Reliance hospital > R2 of Sushrut hospital > R2 of Tristar hospital (Table 2). The reason behind that may be because, at the location of Reliance Hospital, a road stretch, homogeneous traffic and zero or minimum unauthorized parking were observed. These lead to less horn honking and cruising traffic, leading to lesser spikes in actual Leq values.

So, it can be said that the model is giving more fit values of predicted noise level for Reliance hospital compared to the other two models. It is giving the results accurate within ±0.8%, and globally it can be seen that the models are found valid within ±1.5%. Hence, it can be summarized that model is very accurate within the range.

5 Conclusion

The present study conducted noise monitoring at selected three hospitals, namely (1) Sushrut hospital, (2) Tristar hospital and (3) Reliance hospital of Surat city. Road traffic noise prediction models for all three locations were developed using actual onsite measurements of traffic composition (2-W, 3-W, 4-W, H.V.), average traffic speed, road width, and building height. There is no validated and authorized model for road traffic noise prediction for silence zones in India. With the growing vehicular population and mixed land-use pattern trend, there is an urgent need for a traffic noise prediction model, not only to predict the noise levels but also for noise abatement measures.

The coefficient of correlation of all three locations, and it was found that R2 of Reliance hospital > R2 of Sushrut hospital > R2 of Tristar hospital. It may be because of homogeneous traffic conditions with free flow of traffic. So, it can be said that the model gives more fair values of predicted noise level for Reliance hospitals than the other two. The model for all three locations gave very accurate results within ±0.8%. Hence, considering all these results, the model was found very accurate and satisfactory for predicting Leq values of hospitals.

This model can be applied to hospitals (silence zones) with similar land use and road traffic pattern. Also, this study can be helpful to transportation planners for noise attenuation in silence zones. The key advantage of noise modelling is the ability to visualize the effects of noise over a large area. This

developed model can help in the design of roadways and other arterial roads of tier-II cities such as Surat. It can help in the assessment of existing or envisaged changes in traffic noise near hospital buildings. It is possible to use separate variables for two-wheelers, three-wheelers, four-wheelers and heavy vehicles. This model further can be developed by including more input variables such as road surface type, and meteorological parameters like wind speed, humidity and temperature, etc.
Noise abatement strategies like the construction of noise barriers such as partition walls, brick walls, vegetative, steel railing, ground-mounted noise barriers etc., for hospitals buildings and other sensitive buildings can apply. Municipal corporation authorities can strictly enforce speed limits for heavy vehicles passing through this area. Rigid instruction and suggestions about the no-honking zones, and the adoption of proper land use plans in the urban area should be there. In the urban area and in the area of hospital building trees plantation and disposition surrounding the buildings can be made for reduction of noise.

Scope of work
The following aspects can further enhance the accuracy and reliability of the developed prediction model:

In this work, only three significant parameters like road traffic composition (Q), vehicular speed (V) and aspect ratio (AR), were included. Considering more parameters like type of pavement, road gradient, and meteorological parameters in prediction may give better results.

Other evolutionary computing techniques like artificial neural network (ANN) and Monte Carlo simulation can also be applied to develop noise prediction models.

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