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Modeling and Prediction of Traffic Noise Levels

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Abstract: Noise is unwanted sound and Noise due to traffic is increasing due to increasing vehicular movement on the roads. The increased noise levels lead to several adverse impacts on health. Vijayawada the second most important city in the State of Andhra Pradesh, India is considered as a commercial capital of the State and is very close to the existing capital of the State. This made the increasing of the traffic manifold in the city besides the associated noise pollution. Traffic noise is studied at four locations representing Residential, Commercial, Industrial and Silent zones. Traffic flow is determined at these locations and simultaneously noise levels are determined for three days varying the distance from the sampling point to the center of the road. The data is collected, compared with the permissible limits and analyzed. It is noted that the equivalent sound levels (Leq) at all the four locations are beyond permissible limits for that zone. The data is used to develop Multiple Linear Regression (MLR) and Artificial Neural Network (ANN) models. The analysis revealed that the ANN model is more reliable with respect to the actual data for prediction. Several empirical models are also established for determining the relationship among Leq, Traffic flow per hour and percentage of heavy vehicles. The results obtained are encouraging. It is noticed from the traffic flow data in the city that 2-and 3- wheelers contribute to 65% of the traffic while heavy vehicles contribute to only 9% of the traffic.

Keywords: Traffic noise, Noise Pollution, Equivalent sound level, Modeling, Multiple Regression, Artificial Neural Networks.

I. INTRODUCTION

Noise is unwanted sound (Garg, 2014). It causes many adverse impacts such as annoyance, sleeplessness, loss of hearing, poor efficiency in working, irritation, and high blood pressure etc. (Mondal, 2013). Noise is usually emitted from many sources such as domestic, commercial, industrial, and transportation related activities. Growing vehicle population in urban regions is resulting in traffic congestions, alarming levels of noise and air pollution. Traffic noise is affected by factors such as traffic volume, vehicle mix, pavement type and vehicle condition (Marathe, 2012, Vilas and Nagarale, 2013, Suhas and Adavi, 2015). The overall traffic noise is hence dependent on the characteristics of the vehicle and the associated parameters of the traffic flow.

Noise level is measured in terms of decibels (dB) and expressed in terms of A-weighted scale which resembles human ear response. The Noise levels are measured using a sound level meter and calculated values such as L10, L50 & L90 are used to estimate equivalent value of sound level (Leq). The Leq denotes the time weighted average of the sound levels (CPCB, 2016). Sometimes it may not be sufficient to describe the fluctuating noise levels using Leq alone. Hence, the noise quality parameters such as Traffic Noise Index (TNI), and Noise Climate (NC) are used. TNI indicates the degree of variation in a traffic flow (Langdon and Scholes, 1968), expressed in dB (A) while NC is the range over which the sound levels are fluctuating in an interval of time. The Noise Pollution (Regulation and Control) Rules, promulgated in 2000 prescribed the permissible limits of noise levels for different urban areas under Indian conditions (CPCB, 2016, Doshi et al., 2015) and are given in the Table-1.

Mishra *et al*., (2008) studied the adverse impacts of noise on male and female population comprising of different age groups in Roorkee. The analysis indicated that automobiles and loud speakers are major sources of noise pollution. Significant adverse impacts such as effect on hearing, interference with communication, annoyance, sleep disturbance, deafness, are noticeable from the respondents. Public awareness and education are some of the probable solutions suggested for mitigating the problems. Mondal (2013) studied the vehicle origin noise at twelve different locations in Burdwan during specific time intervals and observed that noise levels are beyond the permissible limits. Based on the survey conducted through a questionnaire related to public health, he inferred that irritation, mental stress, annoyance, sleep loss are some of the adverse impacts caused due to increased noise pollution.

Table-1: Prescribed Ambient Noise Limits in India

S No	Area category	Permissible Limits, Leq dB (A)	
		Day Time	**Night Time**
1	Industrial Area	75	70
2	Commercial Area	65	55
3	Residential Area	55	45
4	Silent Area	50	40

Note:
1. Day time: 6 a.m. to 10 p.m. Night time: 10.00 p.m. to 6.00 a.m.
2. Silence zone is an area comprising not less than 100 meters around hospitals, educational institutions, courts, religious places or any other area which is declared as such by the competent authority. Use of vehicular horns, loudspeakers and bursting of crackers shall be banned in these zones.
3. Mixed categories of areas should be declared as one of the four above mentioned categories by the Competent Authority and the corresponding standards shall apply
4. dB(A) Leq denotes the time weighted average of the level of sound in decibels on scale A which is relatable to human hearing.

Traffic noise pollution is assessed using noise quality parameters such as L10, L50, L90, Noise Climate (NC), and Traffic Noise Index (TNI) (Kavitha, 2014, Ramakrishna et al., 2017, Ramakrishna et al., 2019). Swain and Shreerup (2013) used empirical formulae based on percentage of heavy vehicle flow and distance from sampling point to centre of road where vehicles are moving to estimate L10, L50 and L90. They are subsequently used to calculate the equivalent noise (Leq) levels. The sampling duration time varied from a few hours to 24 hours while the sampling interval varied from a few seconds to few minutes. The ambient noise levels irrespective of traffic conditions are also studied, analyzed (Ramakrishna et al., 2017, Ramakrishna et al., 2019) and compared with the relevant permissible standards. Traffic flow is usually represented in terms of Passenger Car Unit (PCU), which represents the same impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single car (Marathe, 2012). Traffic noise levels are often correlated with PCUs (Tandel *et al*., 2011, Swain and Shreerup, 2013, Vilas and Nagarale, 2013).

A number of studies pertaining to traffic noise levels (Vidyasagar and Nageswarrao. 2006, Balashanmugam *et al*., 2013, Ambika *et al*. 2015) are available where they concluded that traffic noise levels are exceeding permissible limits. Sundarakumar (2011), Ramakrishna et al (2017, 2019) studied ambient noise levels in and around Vijayawada, and concluded that the noise levels are elevated in urban areas compared to suburban areas. Ramakrishna et al (2019) also observed that that the traffic flow is increased in Vijayawada in terms of 4-wheelers and 2-wheelers compared to that in 2017. Similar observations of high traffic noise levels beyond permissible limits are noticed in Palestinian city of Hebron (Zuhdi and Husein, 2012), Tokat city of Turkey (Ozer et al., 2009), Karachi (Muhammad et al., 2010), in Sri Lanka (Terrance et al., 2015), in Tehran (Parvin et al., 2016). Muhammad et al (2010) noticed that heavy noise levels in Karachi are primarily due to the 3-wheelers, 2-wheelers and minibuses that are plying without silencers. Mohammad et al., (2015) observed that the Leq values of the traffic noise levels in a city in Tehran did not show a statistically significant difference between weekdays, time of the day, and sampling time. Mahmoud and Ali (2014) studied the indoor and outdoor noise levels in an academic campus, noticed high noise levels and attributed that the increased noise levels are due to the movement of vehicles in the campus.

Since the Leq value of traffic noise depends on different parameters such as traffic flow, percent of heavy vehicles, age and condition of vehicles, condition of pavement, barriers on the pavement etc., its prediction can be determined using Multiple Linear Regression (MLR) or Artificial Neural Networks (ANN) models. The linear regression and correlation for prediction of the noise levels are used by Alpesh et al (2017) for Una town of Gujarat, Shalini and Kumar (2018) for Varanasi, Golmohammadi et al (2019) for Hamadan city in Iran, Sanik et al (2013) for Taman Kelisa town in Malaysia, Baffoe and Ducker (2018) used MLR model for noise level prediction from Tarkwa community in Ghana.

ANN is used for prediction of noise levels by Arora and Mosahari (2012) for vehicular traffic on Agra-Firozabad highway, Zannin et al (2018) modeled the efficiency of noise barriers using ANN in Curitiba in Brazil, Francis and Leonardi (2015) studied the traffic noise levels in Villa S. Giovanni in Italy using ANN, compared with that from MLR and concluded that ANN model is more effective in obtaining reliable results, Al-Mutairi and Al-Rukaibi (2012) used ANN for predicting traffic noise levels in four districts of Kuwait and concluded that ANN is producing reliable results of modeling, Mansourkhaki et al (2018) compared results obtained using ANN and MLR for traffic noise levels in Tehran and concluded that ANN is relatively better in predicting results. It is understood that the MLR and ANN are very widely used tools in prediction of trends in engineering and scientific studies and hence Sirisha et al (2008), Ramakrishna (2011), Babu et al (2003), Ramakrishna and Babu (2003) successfully used ANN and MLR for water quality modeling purposes.

1.1 Study Zone

The study zone, Vijayawada is located on the banks of Krishna River, in Krishna district of Andhra Pradesh (Refer Fig.1). It is the second largest city in the state by population and is often referred as the Commercial capital of Andhra Pradesh. It is 18.5 km from the state capital, Amravati and lies at an altitude of 11 m above MSL. An estimated population of 18,39,720 (13 lakhs urban population and remaining is rural population) are residing in the city with a floating population of 4-5 lakhs per day (VijayawadaPolice, 2019). Two major National Highways, NH 16 & NH 65, passes through the city and provides road connectivity with other states and major cities. The Inner Ring Road connects NH 16 and NH 65 to serve the main purpose of easing traffic congestion.

The Andhra Pradesh State Road Transport Corporation (APSRTC) is head quartered in Vijayawada. The city is having a total road length of 1264 km with 16 bridges and connecting two major roads MG Road and Karl Marx Road besides a number of connecting lanes where public transport is provided. The number of non-transport and transport vehicles moving in the city are estimated as 6,78,004 while 94,937 respectively (VijayawadaPolice, 2019). The APSRTC operates more than 450 city buses in the city while another 2,600 APSRTC buses transit into the Pandit Nehru Bus Stand, one of the largest bus stands in south India spread in 28 acres, from various places connecting Vijayawada. Besides, about 1700 vehicles belonging to educational institutes in and around the city move on the roads (VijayawadaPolice, 2019).

1.2 Objective

The present study is taken up with the following objectives:

- To determine the relation between the noise levels and the traffic flow parameters namely vehicle flow (Q), Percentage of heavy vehicles (P), and the distance of measurement (d).
- To propose a mathematical or empirical relation satisfying all the functional parameters of the present study using Multiple Regression and Artificial Neural Networks.
- To analyze the obtained data with respect to the prescribed guidelines and assess the adverse impacts on environment.

II. MATERIALS AND METHODS

To meet the objectives of the present study, four sampling locations are identified representing Residential (Ajit Singh Nagar), Commercial (Benz Circle), Industrial (NTTPS Gate) and Silent (PVP Siddhartha Public School) zones in Vijayawada. The details of the locations are shown in Fig.1.

Sampling is done at each of the location for three days from 8:00AM – 10:00AM, 11:00AM – 1:00PM, 2:00PM – 4:00PM, 5:00PM – 7:00PM at 2 minute intervals. The distance of centre of the road to the sampling point is varied to determine impact of distance on Leq values. Simultaneously, the traffic data is collected at each location. The number of vehicles moving, their classification into 2-, 3-, 4- and heavy vehicles is determined. The data is consolidated separately day wise and cumulatively by calculating the traffic noise parameters like **Q** (Vehicle flow per hour), **P** (percentage of heavy vehicles), **d** (distance between center line and sampling position). A digital sound level meter that can measure sounds in the range of 0-130 dB is used. The collection of traffic volume data and noise sampling is shown in Fig. 2. The Multiple Regression analysis is conducted using MS-Excel while ANN modeling is performed using Pythia-4.2 Version.

2.1 Formulae used in the Study

The study of noise level involves a series of empirical parameters and relations mainly when the concept of traffic is considered as a key source responsible for noise. The relations used in this study (Swain and Shreerup (2013) are as follows:

$L10 = 61 + 8.4 \, Log (Q) + 0.15P – 11.5 \, Log (d)$ ------ (1)

$L50 = 44.8 + 10.8 \, Log (Q) + 0.12P – 9.6 \, Log (d)$ ------ (2)

$L90 = 39.1 + 10.5 \, Log (Q) + 0.06P – 9.3 \, Log (d)$ ------- (3)

$Leq = L50 + (L10 - L90)^2 / 56$ --------- (4)

$NC = L10-L90$ ---------- (5)

$TNI = 4 (L10-L90) + L90 – 30$ dB (A) ----------- (6)

Where

Q = vehicles flow per hour.

P = percentage of heavy vehicles in %.

d = Distance from c/c of the road to source of receiver in meters.

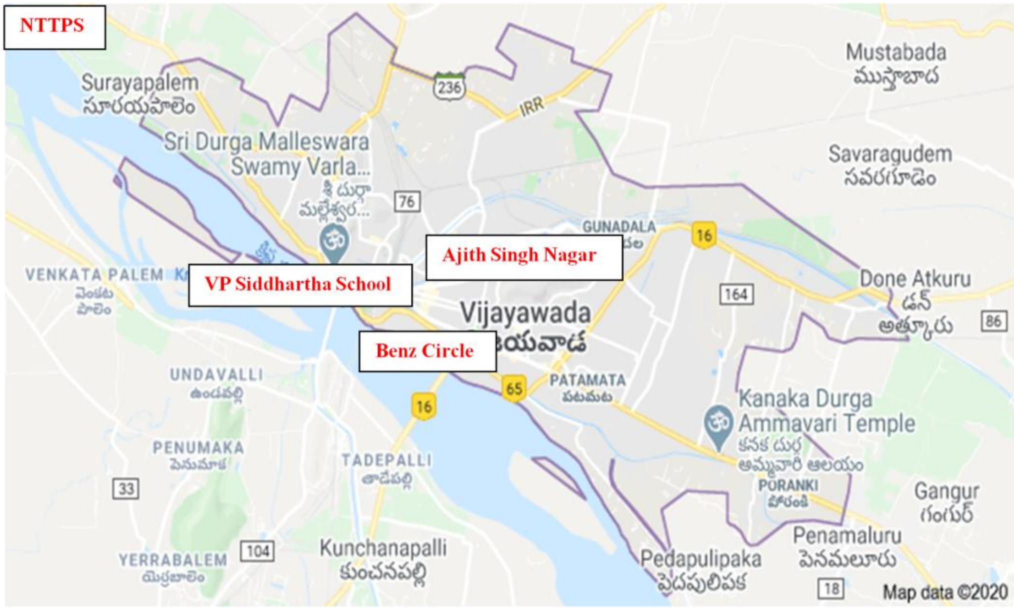
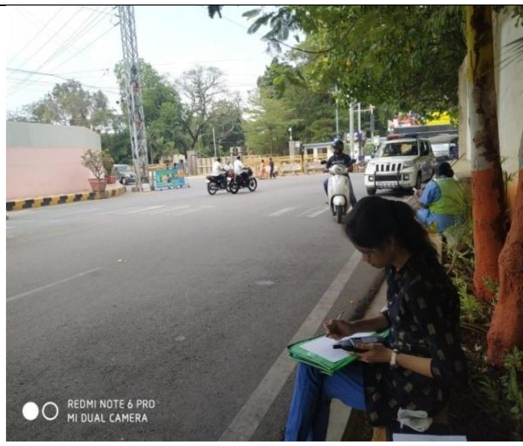


Fig.1: Layout of sampling zones

	
Fig. 2 (a): Traffic volume survey at sampling location	**Fig. 2 (b): Noise level recording at sampling location**

The MLR mode is usually expressed in the form (Ramakrishna, 2011)
Y = Constant + A1X1 + A2xX2+…..+AnXn ---------- (7)
Where A1, A2, etc are the regression coefficients
Y = dependant variable
X = Independent variable
While developing MLR model, 80% of the field data is used for developing the model and the remaining 20% data is used to check its accuracy. Standard deviation (SD) given below is used (Sirisha et al., 2008) to determine the accuracy of the model.

$$SD = \sqrt{\frac{1}{n-1}\left(\frac{Y_a - Y_p{}^2}{Y_a}\right)} \quad \text{------ (8)}$$

Where, Ya and Yp are the actual and predicted values from the empirical model developed for *n* variables.

The ANN behaves as a black box in understanding the relation between input variables and output variables through an interconnected network. The ANN consists of input layers, hidden layers and output layers. The ANN can have more than one output unlike Multiple Regression. The inputs are connected to hidden layers through an activation function and the hidden layers are connected to output layers. The number of neurons in the hidden layer and the number of hidden layers depends on the complexity of the problem in understanding. The optimum network for a specific relation hence depends on the following (Sirisha et al, 2008):

- Number of hidden layers (NNHL),
- Number of neurons in hidden layers (NHL),
- Expected error in prediction called Error tolerance (ET),
- Number of iterations in the network for understanding relation between input and output called as Epochs,

The network curtails when either it completes number of epochs or obtaines desired ET, whichever occurs first. This type of network is known as Back Propagation Network (BPN) as error obtained at the end of first epoch is back propagated in the network till the network obtains the desired ET. The BPN is usually run to obtain the optimum combination of the above parameters. Pythia software is used for this purpose. The data used for developing the MLR model for training and testing model is used for developing and testing the ANN model also for comparison. Standard Deviation defined by Eq. 8 is used to determine its accuracy of prediction. While using the ANN model, the input values should be normalized between 0 and 1 as per the following equation:

Required normalized value = (A – Amin) / (Amax – Amin) -------- (9)
Where, A is the data point to be normalized, Amax and Amin are the maximum and minimum values in the given set of data points

III. RESULTS AND DISCUSSIONS

3.1 Noise Level Distribution

The traffic flow in terms of vehicles per hour (Q) and the noise levels are recorded at each of three sampling locations for three days by varying the distance to the center of the road. The associated parameters such as percentage of heavy vehicles (P), sound level parameters such as L10, L50, L90, Leq, NC and TNI, are computed using Eqs. 1 to 6. The details are given in Table-2.

Table-2: Results of noise levels and related parameters at all the sampling locations

Zone	Distance	Q /hour	P %	L10	L50	L90	Leq	NC	TNI
Residential	3 m	505.50	3.15	78.69	69.79	63.24	74.05	15.45	95.04
	4 m	531.75	3.48	77.49	68.87	62.32	72.97	15.17	95.00
	5 m	529.50	3.17	76.31	67.88	61.39	71.85	14.92	91.07
Commercial	7 m	692.50	28.44	79.4	70.77	62.77	75.50	16.63	99.29
	5 m	785.30	25.65	81.12	72.43	64.53	77.34	16.59	100.91
	9 m	590.50	13.83	75.37	67.22	60.15	71.35	15.21	91.02
Industrial	5 m	780.62	15.55	79.59	71.19	63.9	75.53	15.59	96.26
	7 m	788.00	14.65	77.8	69.72	62.53	74.04	15.57	94.81
	8 m	799.12	14.15	77.11	69.17	62.02	73.24	15.09	92.38
Silent	5 m	1136.12	1.18	77.01	69.69	63.21	73.07	13.75	88.29
	7 m	1132.00	0.84	80.44	72.55	65.69	76.24	14.38	93.59
	3.5 m	1110.00	1.15	78.62	70.99	64.53	74.53	14.08	90.89

After comparing the Leq values with the permissible limits given in Table-1, the following observations are noted:

- The Leq values are exceeding the permissible limits at all the sampling locations
- The NC values are almost similar indicating that traffic noises generated at all the zones are similar
- The TNI values are high at all the zones indicating heavy traffic during sampling period
- The Leq values are slightly reducing with respect to distance within the same zone
- The total vehicle flow per hour (Q) is almost same during all the three days of sampling indicating that the traffic flow is uniform

The vehicle flow in the city at all the four sampling locations is collected and analyzed for the percentage distribution of vehicles in each of the sampling locations and in city. The details are given in Table-3.

Table-3: Percentage vehicle distribution in the study region

Category	Zone wise percentage distribution of vehicles during the study				
	Residential	**Commercial**	**Industrial**	**Silent**	**Total**
2-wheelers	69.20%	45.45%	49.29%	45.11%	50.23%
3-wheelers	11.35%	11.17%	14.78%	18.72%	14.80%
4-wheelers	15.94%	20.97%	21.33%	35.08%	25.25%
Heavy vehicles	3.41%	22.39%	14.58%	01.07%	09.78%
Total	100	100	100	100	100

The following observations are noted from Table-3:

- Majority of the vehicles (50-69%) moving in the city are 2-wheelers only. It is evident that, the people in the Residential area mainly (69%) use 2-wheelers than any other modes of travel.
- A total of 65% vehicle comprises of 2-wheelers and 3-wheelers only in the city with Residential zone accounting a maximum of 80% while Commercial zone accounts for 57% only. This is also clear to the fact that 2- and 3- wheelers are usually more in Residential zones than in other zones.
- The combination of vehicle distribution of 2- and 3-wheelers at 65% is higher than that recorded (51%) in 2019 (Ramakrishna et al., 2019) at same locations.
- The percentage of heavy vehicles is very high (22%) in Commercial zone followed by Industrial zone (14%) which is understandable due to the nature of activities happening at these zones. The contribution of 9.78% vehicles in the present study is far less (18%) than noticed in 2019 (Ramakrishna et al., 2019).
- 25% of the total vehicles moving in the city are 4-wheelers. This is slightly less (30%) than that observed in 2019 at same locations (Ramakrishna et al, 2019). The increasing trend (14 to 25%) in the 4-wheeler movements from 2017 to 2020 in the city (Ramakrishna et al., 2017) is confirmed.
- The above information reveals an increase of 2-and 3- wheeler vehicles in the city, and marginal reduction in 4-wheeler and heavy vehicles.
- It is interesting to note from Table-2 that *Leq* is not varying significantly with respect to *Q* and *P*. Higher value of *Q* is not yielding higher *Leq* or higher *P* is also not resulting in higher *Leq* value. The values obtained are more or less consistent with each other within the same zone. This shows that, the *Leq* value may also depend on distribution of vehicles in the traffic flow as well.

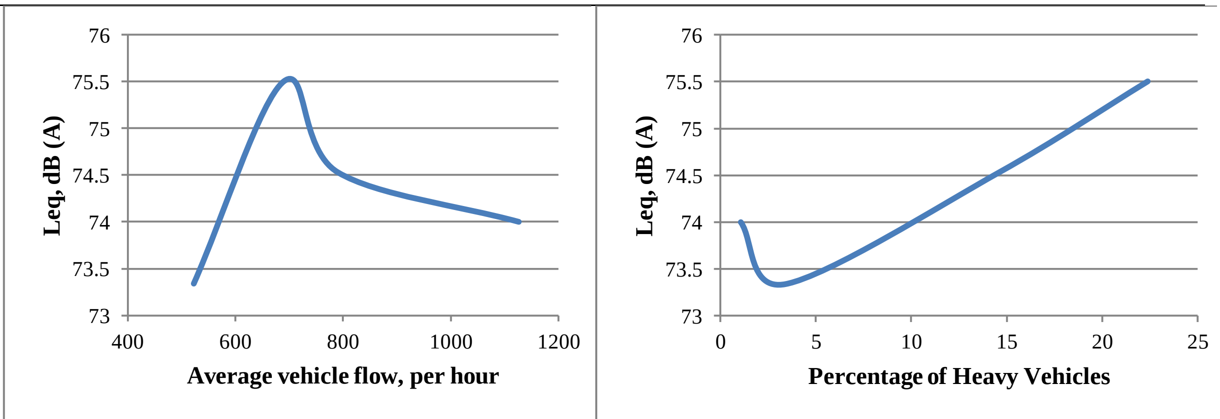


Fig. 3 (a): Variation of *Leq* with respect to *Q*	**Fig. 3 (b): Variation of *Leq* with respect to *P***

The values of *d* given in Table-2 are not same at all the locations but are varying. To understand the variation of *Leq* with respect to *Q* and *P*, the values obtained at each of the sampling zones are reduced to a same distance using the equation for line source transmission:

L1- L2 = 10 log (R2/R1) ------- (10)

Where, L1, L2 are noise levels measured at a distance of R1 and R2 respectively

The values are plotted in Fig. 3 and are analyzed. It is observed from Fig. 3 that, in the present study, the *Leq* is linearly varying with respect to *P*, while the trend is slightly scrambled when it is compared with *Q*. If the value of 75 dB (A) is neglected assuming local disturbance, the trend is also linearly varying. This is in agreement with the trends anticipated in noise pollution.

3.2 Multiple Linear Regression Modeling:

The *Leq* values of traffic noise predominantly depend upon traffic flow and heavy vehicle percentage neglecting other related parameters as detailed earlier. Hence, the MLR model in the present study is developed using the following significant variables assuming a relation as:

$Leq = f\,(Q, P)$ ------ (11)

In developing the model, 16 data points are used for development and 8 data points are used for validating the model under each category. The obtained values are used to model the MLR and compute the SD value for checking its accuracy. The details of the models developed for all the sampling locations are given in Table-4 along with the corresponding value of R^2 and SD.

Table-4: MLR Models developed in the present study

S. No	Zone	MLR Model	R^2	SD value
1	Residential	Y= 70.71 + 0.005554(Q) - 0.16129(P)	0.529	0.0025
2	Commercial	Y= 65.155662 + 0.007255(Q) + 0.196743(P)	0.687	0.0106
3	Industrial	Y= 67.05215+ 0.005511(Q) + 0.199601(P)	0.351	0.0148
4	Silent	Y= 69.72 + 0.003595(Q) + 0.030977(P)	0.534	0.0038

The following observations are noted from Table-4:

- The R^2 value is slightly high probably indicating that, few more parameters are also dependant on Leq that are not considered in the present study
- The SD value is pretty low showing that the predicted values and actual values are in close agreement.
- The reliability of the model will be high if more number of data points are used for training and testing. In the present study, relatively less number of data points are used for developing the model. Hence, there is a possibility that the developed MLR model does not take into account all the variations in the data base leading a noise in the results.
- To develop the MLR model, the data points generated during all the three days of sampling are combined to form a heterogeneous database and used in the model. This may also led to a small bias in the results. When the data is tested on daily basis, relatively encouraging results are obtained.

3.3: ANN Modeling

In ANN modeling, the data points obtained at each sampling location on each day are subjected to combination of learning parameters as detailed earlier. The SD values are computed for each of the combinations and the combination that gave the least value of SD are noted. The data points for all the three days are combined and they are also subjected to ANN modeling as above. The data points used for developing and verifying the MLR models as detailed earlier are used for training and testing the ANN models also. The optimum combination for each of the zones is recorded and is given in Table-5.

It is noted from Table-5 that, the SD values are relatively low compared to that of MLR models indicating that ANN modeling gives better reliable predictions than that of MLR. The black box nature of understanding of ANN gives the advantage of predicting the unexpected spikes in the data base and hence they can understand better yielding more accurate results.

Table-5: Optimum combination of learning parameters of the ANN models developed

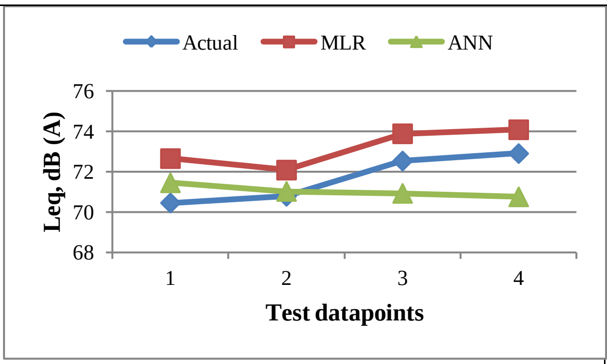
Zone	Optimum Combination	SD value
Residential	NNHL: 3, NHL: 2, Epochs: 1000, ET: 0.1	0.00107
Commercial	NNHL: 5, NHL: 2, Epochs: 5000, ET: 0.1	0.0067
Industrial	NNHL: 6, NHL: 2, Epochs: 1000, ET: 0.1	0.0061
Silent	NNHL: 6, NHL: 2, Epochs: 10000, ET: 0.1	0.0039

3.4. Comparison of MLR and ANN Models

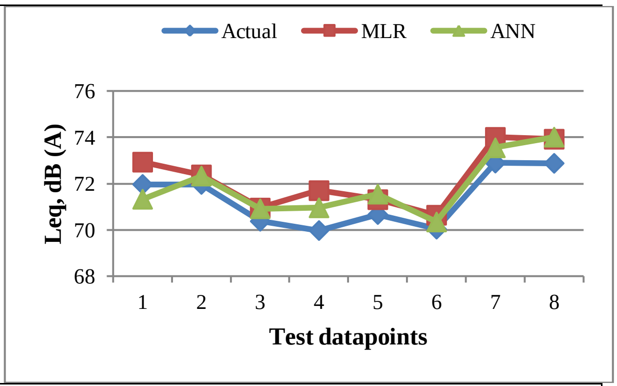
The results obtained for MLR and ANN models are compared and are given in Fig. 4. It is clearly evident from Fig.4 that, the ANN model values are relatively very closer to the actual values than that obtained using MLR model at all the four zones. It indicates that, the ANN model is predicting the values better than the MLR model.

3.5 Establishing relation among Leq, total vehicle flow and distance to the center of the road

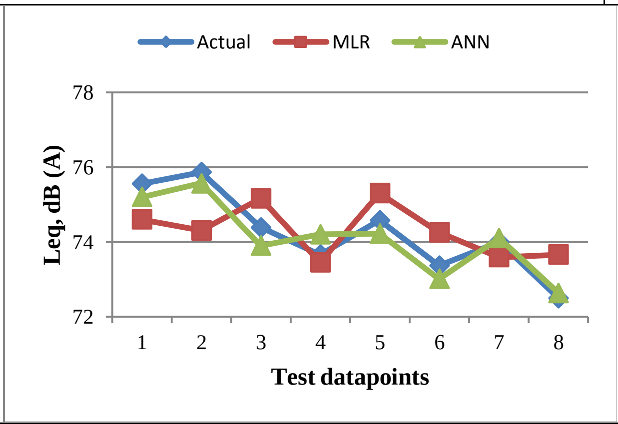
It is interesting to develop the trends for the variation of Leq with distance from center of the road (d) or total vehicle flow (Q). The database obtained for all the sampling locations is separated and plotted in Fig. 4.



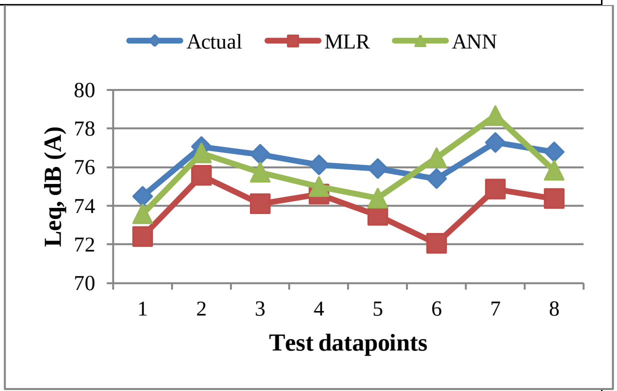
Residential zone



Commercial zone



Industrial zone



Silent zone

Fig. 4: Comparison of MLR and ANN model results of the present study

The data available at the four sampling zones are combined to form a heterogeneous data and a graph is drawn to understand the overall variation of *Leq* with *Q*. The result is plotted in Fig. 5 (a). It is noted that, though the values are not in a regular trend, an overall increasing trend of *Leq* is noticed with increase in the values of *Q*, which is encouraging. The distortions in the Fig. 5 (a) may be attributed to the fluctuations in the traffic flow at each of the locations and the associated noise at these locations. The *Leq* value can be predicted using the linear regression from the data as:

$Leq = 0.03\, Q + 71.83$ ------- (12) with $R^2 = 0.151$

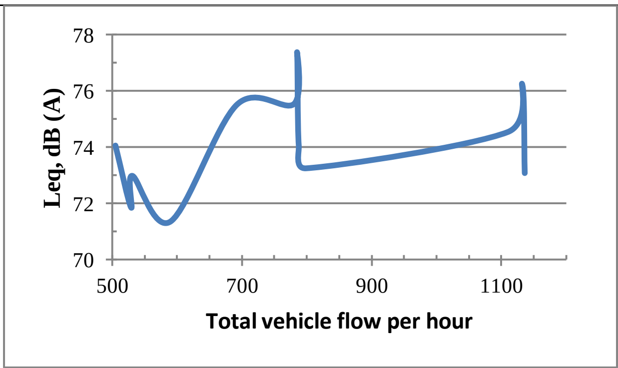


Fig. 5 (a): Relation between *Q* and *Leq* values in the present study

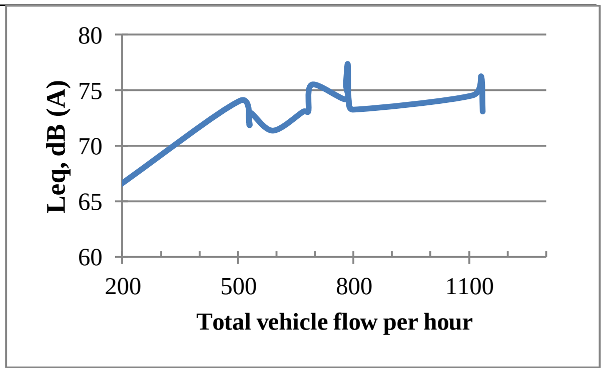


Fig. 5 (b): Relation between *Q* and *Leq* values for the combined data of present study and in 2019

Ramakrishna et al (2019) studied traffic noise in Vijayawada at the same locations in 2019 for fixed distance from center of road. The data available is now merged with the present data to see the trends of the results. By combining the previous data, at each of sampling location data points are now available for four different values of *d*. The data is sorted out to find out the relation between *Leq* and *Q*. The data is plotted and shown in Fig. 5 (b). The results show an increasing trend of *Leq* with respect to *Q*, though there is a slight disturbance in the values of *Leq*. It can be understood because the data that is used to develop Fig. 5 (b) consists of combined data at all the sampling locations besides that of 2019 data available at the same locations. The data is regressed and a linear regression is obtained to determine *Leq* values as follows:

$Leq = 0.006\,Q + 68.73$ --------- (13) with $R^2 = 0.437$

The R^2 value in Eq (12) is better that that obtained from Eq (11), which is encouraging. This may be due to the availability of more data points used in the analysis. The variation of *Leq* values with respect to *d* are also examined (Refer Table-2). It is noticed that, the *Leq* value is slightly reducing with respect to distance within the same sampling zone. This is also an encouraging trend. Similar trend is noticed for the combined data of present study and that of 2019 data, revealing similar conditions of traffic flow in the region.

IV. SUMMARY AND CONCLUSIONS

Traffic noise level modeling is carried out in Vijayawada in 2020. Four sampling locations representing Residential, Commercial, Industrial, and Silent zones are identified. Traffic flow survey is conducted and noise levels are simultaneously collected at these locations for three days varying the distance to the center of the road. The traffic noise levels are exceeding the permissible limits at all the four locations. The results are modeled using Multiple Linear regression and ANN. The results indicated that ANN model predictions are in better agreement with the actual values. Empirical models are also obtained for variation of *Leq* values with traffic flow and the distance to the center of road. Encouraging results are obtained.

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