

# **Traffic Noise Investigation and Modelling for Signalized Intersections**

*A Dissertation Submitted*

In Partial Fulfilment of the Requirements

for the Degree of

**Master of Engineering**

in

**Production Engineering**

by

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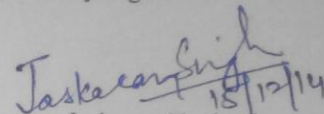
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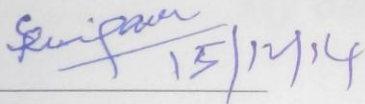
# CERTIFICATE

I hereby declare that the thesis entitled "Traffic Noise Investigation and Modelling for Signalized Intersections" is an authentic record of my study carried out as requirements for the award of the degree of **Master of Engineering in Production Engineering** at **Thapar University, Patiala** under the supervision of **Dr. S.P. Nigam**, Visiting Professor and **Mr. Daljeet Singh**, Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala during July, 2012 to December, 2014. The matter embodied in this report has not been submitted in partial or full to any other university or institute for the award of any degree.

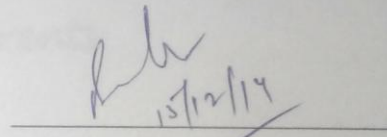
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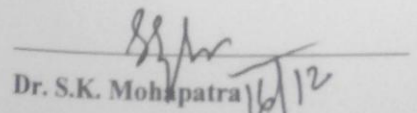
  
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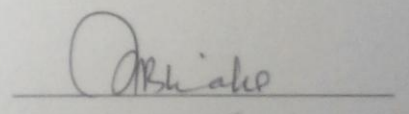
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*Dedicated to  
My Beloved Parents*

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# Abstract

Traffic noise is a typical area of conflict between individual mobility needs and legitimate societal aspirations for quieter lifestyles. With millions of Indian citizens suffering from unacceptable levels of noise, much of it caused by the transport sector as a whole – there is a clear need for India to take a driving role in promoting targeted legislation for progress. Traffic noise from highways creates problems for surrounding areas, especially when there are high traffic volumes and high speeds.

In India, the transportation sector is growing rapidly and number of vehicles on Indian roads is increasing at a very fast rate. This has led to overcrowded roads and pollution. So, a need is being felt to develop a noise prediction model suitable for Indian conditions.

The present work represents a traffic noise prediction model where the acoustic analysis of vehicular traffic noise considered at a signalized intersection on an urban road in Patiala City (Punjab). The numbers of sets of data were recorded for 1 hour duration at different time and dates in a random manner in order to account for statistical temporal variations in traffic flow conditions.

The noise measurement descriptors recorded were  $L_{eq}$ ,  $L_{10}$ ,  $L_{50}$  and  $L_{90}$ . Sound level meter (CESVA SC 310) was used for these measurements. The noise parameters measured were traffic volume for near side, traffic volume for far side, mean speed on near side and mean speed on far side. The regression analysis, Correlation test, t-test and Frequency analysis for 1/1 Octave Band were applied for traffic noise modeling in the present study.

In regression analysis, the values of  $R^2$  were above 0.70 for all descriptors and the percentage error varied between  $\pm 5\%$ . In the Correlation test, the most impacting factors affecting sound descriptors were found and ranked in order. The t-test expressed no significant difference between the two and ‘t-critical’ value was greater than ‘t-statistical’. In frequency analysis for 1/1 octave band, results indicated that 125, 250, 500 and 1k Hz frequencies were most influenced in sound level spectrum.

**Key Words:** Traffic Noise Modelling, Regression Analysis, Correlation Test, t-Test and 1/1 Octave Band, Signalized Intersections/Traffic Lights.

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# Nomenclature

$c_{centre}$  = Centre Frequency

$dB$  = Decibel

$dB(A)$  = A-Weighted Decibel

$f_{upper}$  = Frequency of Upper Limit

$f_{lower}$  = Frequency of Lower Limit

$L_{eq}$  = Equivalent Continuous Sound Level

$L_{10}$  = 10 Percentile exceeded Sound Level

$L_{50}$  = Median value of Sound Level

$L_{90}$  = 90 Percentile exceeded Sound Level

$NPL$  = Noise Pollution Level

$Pa$  = Pascal

$SPL$  = Sound Pressure Level

$SL$  = Sound Level

$S_n$  = Mean Speed on Near Side, km/h

$S_f$  = Mean Speed on Far Side, km/h

$TNI$  = Traffic Noise Index

$V_n$  = Volume of Traffic for Near Side

$V_f$  = Volume of Traffic for Far Side,

# Chapter 1

## Introduction

---

### 1.1 Introduction to Noise

The term Noise means any unwanted or undesirable sound. Sounds which disturb people or make them difficult to hear wanted sounds are called Noise [25]. The human ear to noise sensitivity depends on a number of factors like humidity, wind factor, traffic density etc. A sound wave of 55 dB(A) is considered as a disturbing sound where as a sound wave of 65 dB(A) is considered as deemed in tolerable which causes several critical sleep disturbance.

### 1.2 Traffic Noise

Traffic Noise pollution is nowadays one of the biggest environmental problems in the world. The major contributor of noise pollution is traffic noise. It is increasing day by day with increase in number of vehicles on the road. At present, there are over 600 million vehicles in the world. If the number of vehicles increases with the same rate, the number of vehicles on earth would double in next 20 years. There is also a significant rise in vehicles in India. The traffic noise amounts to 55% of the total noise which are produced by the vehicles in the environment. The road traffic noise is mainly cost by the combination of rolling noise and propulsion noise (engine noise, transmission noise and exhaust system). The tyre road interaction is the main source of noise pollution is main source of noise pollution for cars travelling above 55 kmph and trucks above 70 kmph, depending on the age weight and driving condition of vehicle.

The level of highway traffic noise mainly depends on [40]:

1. Traffic Volume: Roads with more vehicles are generally louder.
2. Traffic Speed: At higher speed the traffic noise is louder.
3. Percentage of Heavy Trucks on the road.

New tyre designs like randomized tread pattern, narrow lateral grooves etc and quite ranges. As held to achieve a significant progress in both sources of noise. But still there is a much scope for progress as quieter cars can not eliminate irrational and erratic driving behaviour, traffic density or technical defects which give us multiline effect on noise

emission. With increase in road traffic and introduction to heavier vehicles have counter balance the real progress which was achieved by better car and technology.

With the increase in traffic on the road and highways, the noise levels often surpass the acceptable and prescribed limits. Some of these limits are shown in Table 1.1.

**Table 1.1:** Ambient Air Quality Standards in respect of Noise [18]

Area Code	Category of Area / Zone	Limits in dB(A) $L_{eq}$ *	
		Day Time	Night Time
A	Industrial area	75	70
B	Commercial area	65	55
C	Residential area	55	45
D	Silence Zone	50	40

Note: - 1. Day time might mean from 6.00 a.m. to 10.00 p.m.

2. Night time shall mean from 10.00 p.m. to 6.00 a.m.

3. Silence zone is a region containing not less than 100 metres around educational institutions, hospitals, courts, religious places or some other region which is proclaimed as such by the competent authority.

4. Mixed classifications of regions may be proclaimed as one of the four above mentioned classifications by the competent authority.

\* dB(A)  $L_{eq}$  means the time weighted average of the level of sound in decibels on scale A which is relatable to human hearing. [9]

A “decibel” is a unit in which noise is measured.

“A”, in dB(A)  $L_{eq}$ , means the frequency weighting in the measurement of noise and identifies with frequency response attributes of the human ear.

$L_{eq}$ : It is energy mean of the noise level over an indicated period.

(Source: The Noise Pollution (Regulation and Control) Rules, 2000, Central Government, India)

When exposed to traffic noise, humans have acute and chronic defects causing disturbance in sleep and insomnia. It may also cause annoyance, hearing loss, mental disorders and adverse physiological and psychological impacts. It also increases the activity of endocrine glands which produces high B.P, increases heart rate, and may even cause change in the composition of blood.

Noise Induced Hearing Loss (NIHL), is a type of sensorial hearing loss. Exposure to noise of high intensity for a long time can damage or destroy sensory hair cells of the inner

ear which may lead to irreparable hearing loss. The generally accepted noise level is below 30 dB (A). Another major effect of high traffic noise level is on the property prices in urban areas. Mostly people do not like to pay high prices for property in the vicinity which has got very high outdoor noise levels.

There is a constant and regular increase or rise in the number of vehicles in India, specially 2 wheelers. All these vehicles may surpass the prescribed or accepted noise levels in various zones of the community/area which produces noise pollution.

- **Sound:** Sound energy is transmitted through the air (or through other particles) as a travelling pressure wave. Displacement wave amplitude may range from  $10^{-7}$  mm to a few mm/sec in the air. [37]
- **Frequency:** Frequency is cycles/sec of a sound wave. It is expressed in terms of Hertz, denoted by 'Hz'. It can be expressed as;

$$F = \frac{1}{T}$$

Where; f= frequency. ( $s^{-1}$  or Hz)

T= time period for 1 cycle. (s)

- **Wavelength:** Wavelength is the distance between two successive analogous points in the sound wave.

$$\lambda = \frac{c}{f}$$

Where;  $\lambda$  = wavelength. (m); c = speed of sound. (m/s); f = frequency. ( $s^{-1}$  or Hz)

### 1.3 Physical properties of Sound

The amplitude of sound wave can be measured by measuring the associated pressure disturbances. In other words, we have to measure the difference in pressure from its ambient value. This difference in the pressure is called 'Acoustic pressure'. In terms of physical units of pressure, the sound wave can be measured in Pascal (Pa). The audible sound pressure varies in a wide range of  $2 \times 10^{-5}$  Pa (20  $\mu$ Pa) i.e. Threshold of hearing ( $P_t$ ) to near about 100 Pa i.e. Threshold of pain ( $P_p$ ).

Sound Pressure Level (S.P.L): is determined by;

$$S.P.L = 20 \times \log_{10} \left( \frac{p}{p_{ref}} \right)^2 \quad \text{Where;}$$

p = measured sound pressured.

$$p_{ref} (\text{Air}) = 20 \times 10^{-6} \text{ Pa} = 20 \mu\text{Pa}$$

$p_{ref}$  = reference sound pressure.

$$p_{ref} (\text{Water}) = 10^{-6} \text{ Pa} = 1 \mu\text{Pa}.$$

There are several advantages of this logarithmic scale over a linear scale. The most important advantages are:

1. A linear scale would lead to use of some enormous and unwieldy numbers.
2. The air responds not linearly, but logarithmically to stimulus.

Conversion from one scale (N/m<sup>2</sup>) to the other scale (dB) can easily be done by use of the following table. (Table 1.2)

**Table 1.2:** Environmental conditions at different SPL [39]

Sound sources (noise) with distance	Sound Pressure Level $L_p$ dB
Jet aircraft, 50 m away	140
Threshold of pain	130
Threshold of discomfort	120
Chainsaw, 1 m distance	110
Disco, 1 m from speaker	100
Diesel truck, 10 m away	90
Kerb side of busy road, 5 m	80
Vacuum cleaner, distance 1 m	70
Conversational speech, 1 m	60
Average home	50
Quiet library	40
Quiet bedroom at night	30
Background in TV studio	20
Rustling leaves in the distance	10
Hearing threshold	0

## 1.4 Frequency Spectrum

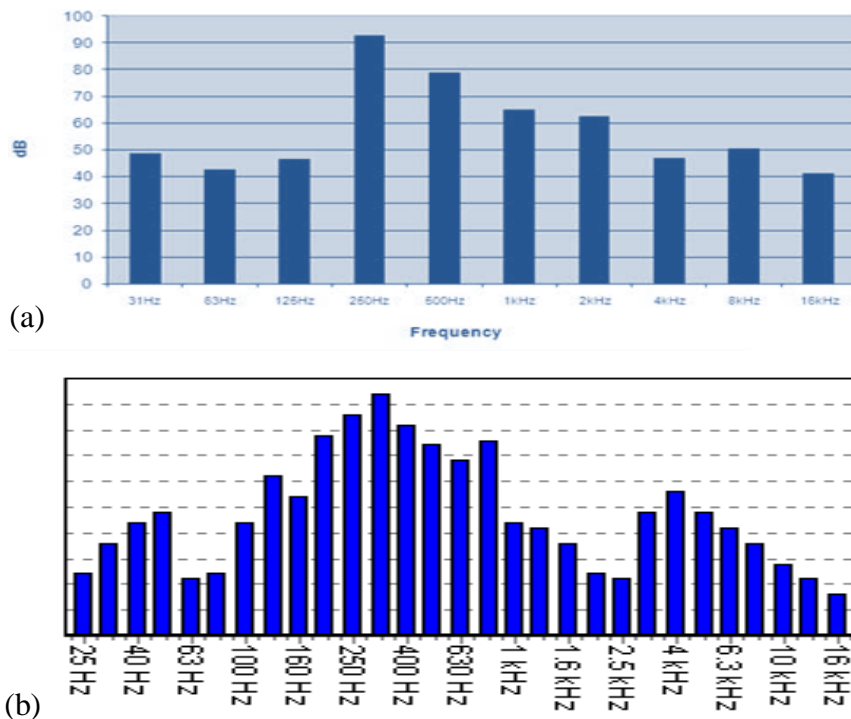
There are a number of different frequencies mixed in a sound source. The musical tone of a timber is characterized by its harmonic spectrum. In our environment, sound can be referred to as a noise which includes different frequencies. The sound signal which contains a mixture of all audible frequencies, is distributed all over the audio spectrum in an equal manner is called 'White Noise'.

A sound wave with only one frequency component is called 'Pure Tone'. This sound is not common in nature. However, the example of this sound is the sound produced by a tuning fork. Since the sound usually has a number of frequency components, its characteristics can be determined by pressure amplitudes at different frequency components. So the characteristics of a steady sound can be described by a graph of frequency v/s amplitude, which is called 'Frequency Spectrum' of the sound.

The sound measuring instruments are mainly designed to measure the frequency spectrum. For the simplicity and convenience to measurement, the instrument is designed to measure the energy content in a particular range of frequencies called 'Octave Bands'.

## 1.5 Frequency Analysers

When we need more and detailed information about a complex sound, the frequency range (20 Hz-20 KHz) can be split into bands or sections. This is done electronically by a sound level meter. The bandwidth of the bands is usually of the order 1/1 Octave or 1/3 Octave. To analyse a narrow band of noise data, we require more advance instruments. In octave band, the highest frequency is twice that of lowest. For example: 1/1 Octave filter has a lower frequency of 707 Hz with a central frequency of 1 KHz and upper frequency of 1.414 KHz. Any of the frequency, below or above these limits is neglected. A 1/3 Octave of an Octave Band has a width of 1/3. The graphical representation of 1/1 and 1/3 Octave Bands:



**Figure 1.1:** Frequency Spectrum (a) 1/1 Octave band [28] (b) 1/3 Octave band [27]

So, for 1/1 Octave Band:  $f_{\text{upper}} = 2f_{\text{lower}}$

for 1/3 Octave Band:  $f_{\text{upper}} = 2^{1/3}f_{\text{lower}}$

$$f_{\text{centre}} = \sqrt{f_{\text{lower}} \cdot f_{\text{upper}}}$$

## 1.6 Traffic Noise Sources

There are different sources of traffic noise which can be categorized as:

1. Automobiles
2. Railways
3. Aeroplanes
4. Ships

## 1.7 Traffic noise Controlled measures

### 1.7.1 Control at the source

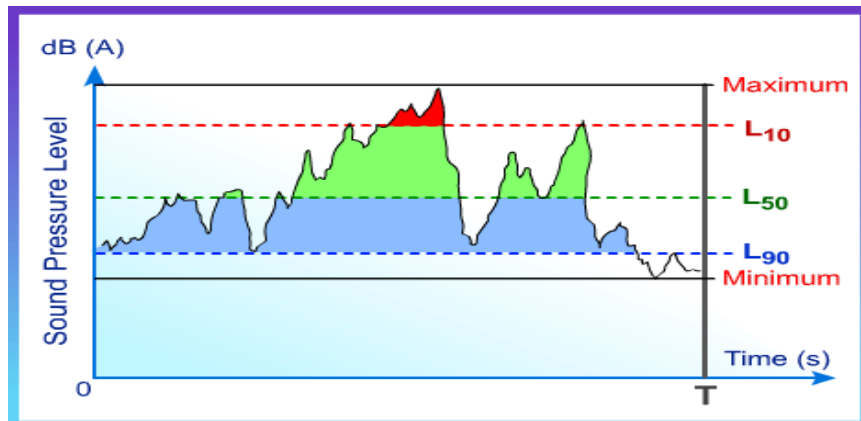
The noise sources can be controlled by:

- Reduction of traffic volume.
- Regulating the speed limits for vehicles.
- Regular maintenance of the road.
- Source path receiver concept.
- Upgrade of traffic management scheme.
- Providing divergence of commercial vehicles from the areas which are noise sensitive's.
- Use of underground alignments.
- Noise emission standard enhancements.

### 1.7.2 Traffic Noise Descriptors

- $L_{\text{max}}$ : Maximum noise level during noise event or a designated time interval.
- $L_{\text{eq}}$  (24h): Equivalent continuous source level which is a measure of energy level of a time varying noise.
- $L_{10}$  (1h): Noise level which exceeds 10% of the 1 hr period, generally used for road noise during the time peak traffic flow.

- $L_{50}$  (1h): Noise level which exceeds 50% of the 1 hr period, it is statistically the mid-point of the noise readings. It represents the median of the fluctuating noise levels.
- $L_{90}$  (1h): Noise level which exceeds 90% of the 1 hr period, generally used as a measure of background noise level.



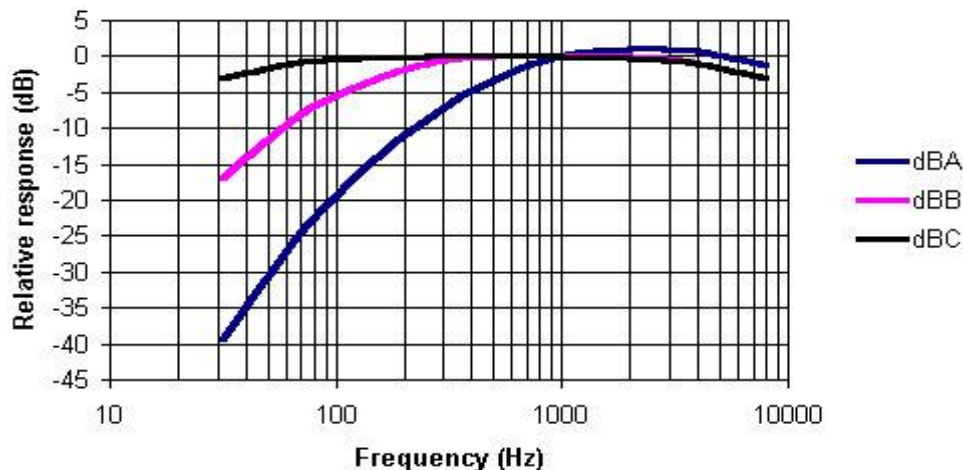
Please note that  $L_{10} > L_{50} > L_{90}$  for the same sound or noise.

**Figure 1.2:** Traffic Noise Descriptors [26]

## 1.8 Decibel

Decibel is a logarithmic unit which used to describe the ratio of the signal level - power, voltage, sound pressure or intensity or more other things. Human ears are more sensitive to sound frequency in the range of 1 kHz to 4 kHz. Higher sound pressures are more acceptable in higher and lower frequencies than the frequencies in mid-range [10]. During acoustic design in sound measurement, knowledge about human ears is very important. Some of the common filters are:

- 1). Weighting – A
- 2). Weighting – B
- 3). Weighting – C



**Figure 1.3:** dB ABC Criteria [12]

### 1.8.1 Weighting - A

Filter A is widely used decibel filter. It is denoted by an expression dB(A). It corresponds to the inverse of 40 dB (at 1 kHz) equal loudness curve for the human ear. Sound level meter using this dB(A) filter is less sensitive to very high and low frequencies. As shown in the figure, the graph of A-Weighting is virtually duplicates the human ear's sensitivity by critical against low frequencies noise.

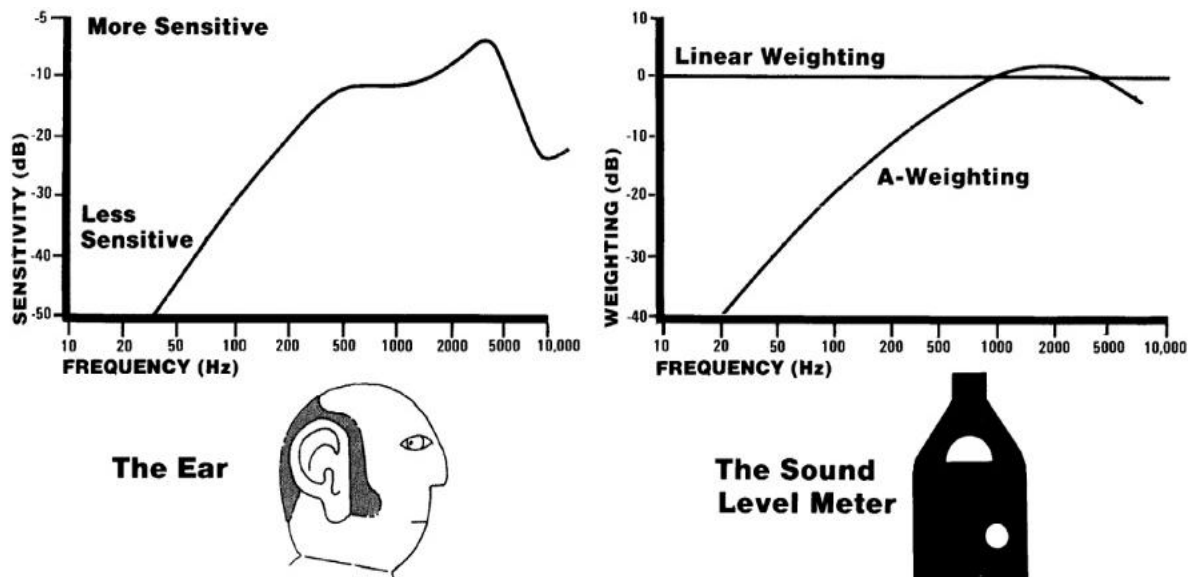


Figure 1.4: Sound Level Meter Weighting and the Sensitivity of the Ear. [15]

### 1.8.2 Weighting - B

The intermediate B-Weighting approximates the ear for medium loud sounds. Filter B is between Filter A and C. It is denoted by an expression dB(B). Filter B is rarely used.

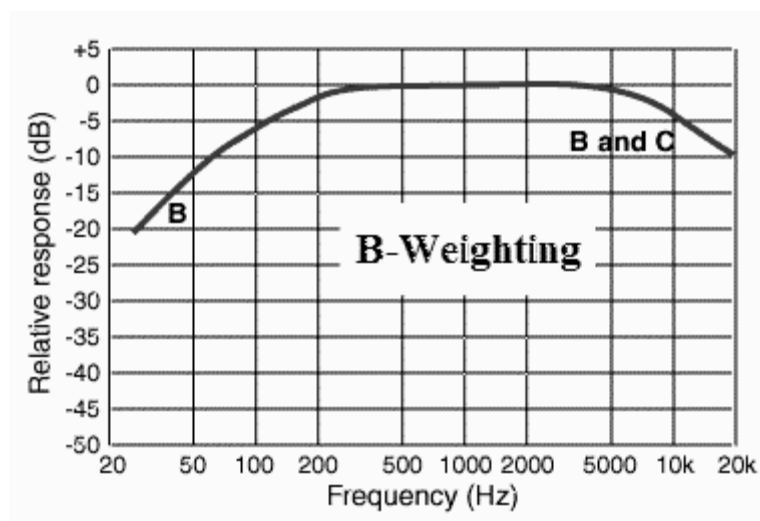


Figure 1.5: B-Weighting Curve [36]

### 1.8.3 Weighting - C

The C-Weighting does not filter out as much of the lows and highs as the other weighting. Filter C is linear over many octave and is very suitable for subjective measurements taken at very high sound pressure levels. It is denoted by an expression dB(C).

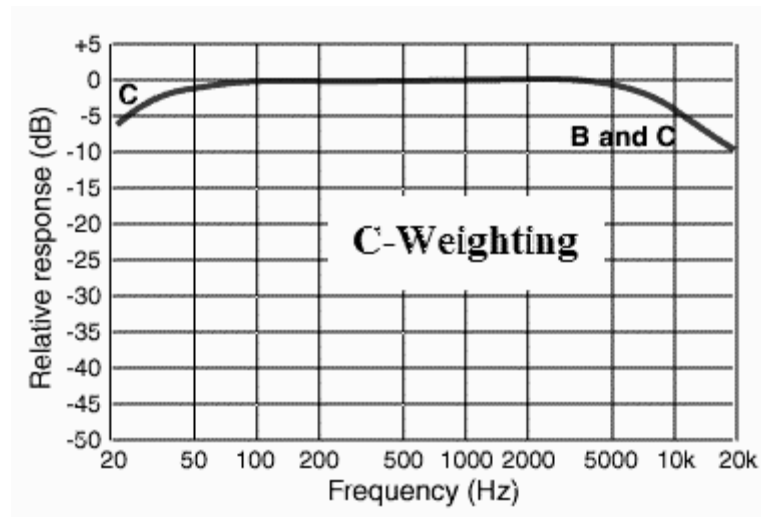


Figure 1.6: C-Weighting Curve [36]

## 1.9 Elements of Sound Level Meters

- i. **Microphone:** Most of the microphone used for measurement purpose generates a voltage which is proportional to sound pressure and is electrical analogy of sound waves impinging on microphone diaphragm. This mechanism converts pressure variations into the sound wave signals. Different available microphones are:
  - Capacitors (Condensers) Microphone
  - Pre polarized Microphone
  - Piezoelectric Microphone
- ii. **Amplifier:** Amplifier the signal received form microphone to just permit measurement of low S.P.L. it amplifies sound over a wide range of frequencies. It keeps amplification a constant.
- iii. **Rectifier:** It rectifies the analog signal to digital signal.
- iv. **Calibrator:** A calibrator provides a means of assuring the full acoustic instrumentation system's (i.e., cable, microphone, and recording instrumentation) sensitivity by producing a known sound pressure level at a known frequency, usually 94 or 114 dB at 1 kHz. [23]

- v. **Meter:** Sound level meter or sound meter, measures sound pressure levels which is commonly used noise pollution studies for the quantification of different kinds of noise (like industrial, aircrafts and environmental noise). The readings from sound meter do not correlate with human perceived loudness [38].



Figure 1.7: Sound Level Meters [29]

### 1.10 Noise Measurement Procedure

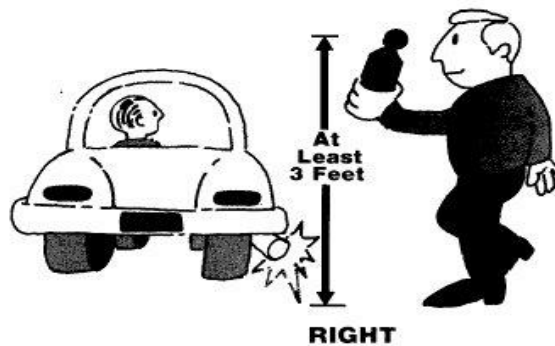


Figure 1.8: Right Way of Measurements [15]

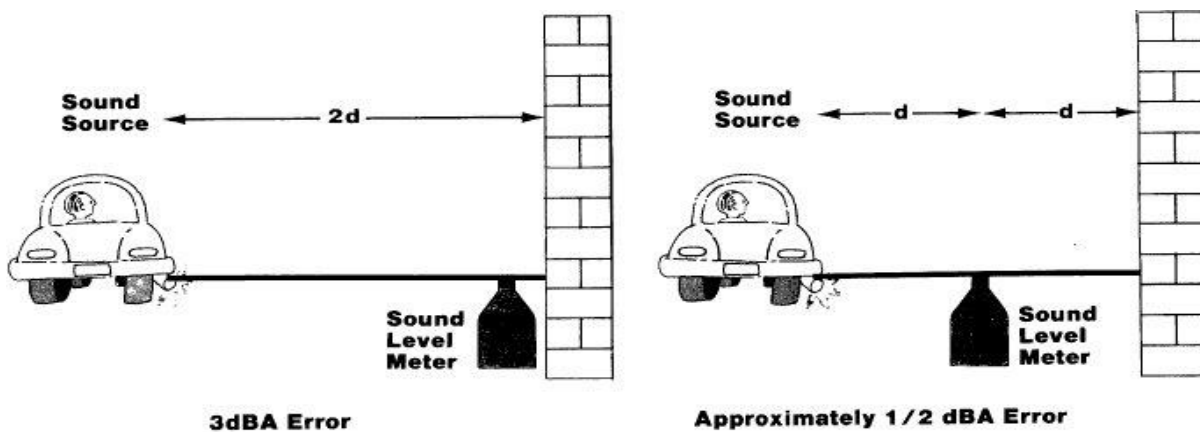


Figure 1.9: Error Caused by Reflecting objects [15]

## 1.11 Barrier Walls

A noticeable amount of traffic noise can be decreased by constructing or increasing the heights of barrier wall. Though certain guidelines must be followed in order to make barrier wall effective. [41]

**Materials:** It should be solid with no penetration. Any type of opening or gate can degrade its effectiveness. Usually concrete walls are preferred over the others. A barrier does not necessarily have to be a wall. There is a misconception that land scrapings or vegetation's could act as a successful barrier for traffic noise unless the vegetation is very thick and dense.

**Distance:** A barrier is more effective if it is placed nearer to the source or the receiver. Noise barriers are generally effective for homes within 300 ft off the roads.

**Height:** Noise from automobile traffic is mainly from the tyres on the pavement which is 0 ft above the ground. Noise from large trucks (typically engine and exhaust noise) is approximately 8 ft above the ground. In order to be active, the wall must block the line of sight from the noise source to the receiver. Though 6 ft high walls can reduce auto traffic noise but will do less in the case of heavy truck traffic. In case, if a home is situated on a hill or is elevated above the road, even a 6 ft wall is not adequate in blocking the line of sight for auto traffic.

As mentioned above depending upon the line of sight issues the increase of 1-2 ft. Of height of an existing wall may make a difference. However, increasing the height of the wall by few feet will not provide a noticeable reduction if the wall is already blocking the line of sight. The general rule of thumb as stated by the Department of Transportation is that if the height of a wall is increased by 1 ft. which is already blocks the line of sight; it reduces the noise level by ½ decibel.

**Isolation Quality:** By extending the isolation quality of the home we can reduce the Traffic noise. The noise is primarily transmitted through the weakest points. In home the weakest points would be windows and doors. By upgrading the window assemblies the isolation quality of the existing windows will increase but it would not show good results if the window assemblies are already of good quality.

The isolation quality of a window is expressed in terms Sound Transmission Class (STC) rating. The higher rating represents the better isolation quality of the window. Generally the STC of a single pane window is 22-25 and for dual pane window its value is 27-32. Windows with higher STC ratings called speciality windows are also available.

**Masking:** Sound masking can be implemented inside or outside the home. It can be accomplished by using an electronic sound masking system which generates white noise/pink noise into the room environment to cover up unwanted sound by using an auditory masking.

**Control at the Source:** We as a resident can't control the traffic noise from the source. But this noise can be controlled by a number of ways to design the future roads. With an increase in speed limit of vehicles and also a shorter distance between home and road the intensity of traffic noise increases. A number of ways can be used to reduce the traffic noise, like the use of rubber asphalt can reduce the traffic noise by 4-5 decibels more as compare to the noise reduced by conventional asphalt.

**Table 1.3:** Relationship between STC and noise control effectiveness

Changes in Sound Level, dB	Changes in Apparent Loudness
1	Almost barely perceptible
3	Just observable
5 - 6	Clearly noticeable
10	Twice (or half) as loud

Note: This chart can also be applied for variations in Sound Transmission Class ratings.

## 1.12 TRAFFIC NOISE MODEL

### 1.12.1 Need of Road Traffic Noise Modelling

The need to recognized road traffic noise as one of the main source of environmental pollution led to the development of Road Traffic Noise Model which is enabling to determine the noise level from the fundamental variables like traffic flow, speed of the vehicles and sound emission level by using regression analysis of the experimental data. A traffic noise model also helps us in designing roads and highways. It is also used for the assessment of existing or future changes in traffic noise conditions. These are commonly used to predict sound pressure levels in terms of the standards set by the government authorities. [16]

The development of FHWA TNM noise prediction system was the result of a constant effort to develop such a system which can use latest technology to calculate the noise level of traffic. Earlier FHWA highway traffic noise prediction model was being used to calculate the traffic noise. This technique comprised the acoustic

algorithms and computer architecture etc. it was in use till 1970's. Since that time, important advancements have been made in the technology and methodology for noise prediction, design, barrier analysis, and coding and computer software design. Between 1970 and 1990, over \$500 million were spend on construction and design of barrier, the FHWA identified the need to design, test, document and develop a traffic noise prediction model that cover these advancements. This shows the need of new traffic noise prediction model resulted in the FHWA TNM. It has advanced computer hardware and software to improve on ease of use of modelling highway noise and the accuracy, including the effective design, cost-efficient.

The FHWA TNM contains the following components:

- Modelling of five standard types' vehicle, including automobiles, motorcycles, medium trucks, buses and heavy trucks, as well as user-defined vehicles.
- Modelling of both interrupted-flow traffic and constant-flow.
- Sound level computations depends on a 1/3 octave-band data base and algorithms.
- Graphically-interactive noise barrier optimization and design.
- Attenuation over/through dense vegetation rows of buildings.
- Multiple diffraction analysis.
- Parallel barrier analysis.
- Contour analysis, including sound-level difference contours, barrier insertion loss contours and sound level contours.

### **1.12.2 Models in Recent Use**

The prediction models considered here speak to national reactions to noise pollution concerns, which emerged from the extraordinary build in auto possession after World War II, furthermore from the current enthusiasm toward natural matters by and large. The FHWA Traffic Noise Model Version 1.0 is an advancement of the prior FHWA Traffic Noise Prediction Model. With that exception, the models considered here had parallel autonomous advancement, but with some hypothetical collaboration. Most present models expect point sources, albeit some accept line sources. The Japanese model (ASJ Model- 1993) receives this structure. Steele gave a more general result. This result concedes to streets of any shape with either line or numerous point sources, however with time, not separation decided spacing's. This takes into consideration quickening and braking and also consistent stream.

- **FHWA Traffic Noise Model Version 1.0**

The FHWA TNM E9, Version 1 was presented by Anderson et al. Albeit determined from the STAMINA 2.0 project, it has numerous considerable enhancements. It concedes to imports from CAD projects and STAMINA 2.0. Changes on prior models incorporate procurement for acceleration, stop signs, traffic signals, toll stalls and so forth. An alternate change is the procurement for the data of client characterized vehicles utilizing their REMEL information. This is spoken to as one-third octave band spectra.

- **The CoRTN Procedure**

The CoRTN technique for the estimation of street activity commotion was produced for the United Kingdom Department of the Environment by Delany, Harland, Hood, and Scholes. It is utilized as a support to street outline, furthermore for the determination of privileges to the sound protection of private homes at open cost under the British Land Compensation Act. This recent impacted the decision of  $L_{10}$  as the index of noise. CoRTN is recognized by its broad utilization of curve fitting between empirical information, actually when this was known not to adjust to hypothesis and it treats  $L_{10}$  as though it were Lebesgue measurable. The descriptor is accordingly a pseudo-  $L_{10}$ . This incredibly simplifies the counts, though with the associative misfortune of validity. This model accepts a line source and constant velocity movement, and in Britain is the sole instrument for the appraisal of street activity natural effects by street powers. Calculation of Road Traffic Noise (CoRTN) was supplanted by a more helpful, Predicting Road Traffic Noise, which took after Delany, et al.'s justification for the method.

- **RLS 90**

Richtlinien für den Lärmschutz an Straßen (RLS-90) (Guidelines for Noise Protection on Streets) is the unacknowledged lawful standard for noise prediction in Germany. The current 1990 issue supplanted the first 1981 issue. It joins traffic flow design information where the real flow is not known. It is not quite the same as others considered here for including a project for parking lots.

- **Mithra**

Mithra is a business programming package created by the French firm, 01db, L'acoustique numerique. It holds an extensive ray-tracing package, which makes

note of climatic and ground impacts, diffraction and reflection because of cuttings; and also local topology, structures and screens. Traffic is accepted to structure a line source. Roads are partitioned into five classes, and six sorts of road surface are considered. Mithra incorporates the figuring of Railways.

- **STL-86**

Modele de Calcul de Bruit du Traffic Routier Pour Ordinateur: Manuel d'utilisation du logiciel Stl-86 Version1.0 is distributed by the Swiss Federal Office for Environmental Protection. It is consonant with Modeále de Bruit du Traffic Routier dans les Zones Habitees, ready by Balzari & Schudel, designers and town organizers, and Grolimund & Petermann, furthermore distributed by the Swiss Federal Office for Environmental Protection. This model joins in it a Traffic model and also the Noise model. The yield of this traffic model is the normal traffic flow data for this and other traffic noise prediction models. Likewise with different models, the noise model is subdivided into an emission segment and a propagation area.

- **ASJ Method (1993)**

In 1975, the Acoustical Society of Japan distributed a strategy for predicting a pseudo- $L_{50}$  coming about because of free flowing road traffic. It was accounted for by Koyasu, and up-dated by Takagi *et al.*, and Yamamoto *et al.* The up-date holds an immediate strategy for calculating  $L_{eq}$ , and determining the pseudo- $L_{50}$  from the result, ought to agreeability with the more seasoned model be needed. This is termed the A-Method. ASJ likewise incorporates an observational system called the B-Method. This is substantial just a long way from the line source.

# Chapter 2

## Literature Review

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### 2.1 Introduction

A lot of research has been done to analyze and predict road traffic noise and develop certain mathematical models. The recognition of road traffic noise as one of the main sources of environmental pollution has led to develop models that enable to predict noise level from fundamental variables. Traffic noise prediction models are required as aids for designing roads and highways. Some of the important is described below:

**Arnaud Can *et al.* (2008)** [2] studied the requirement for traffic noise prediction models that consider traffic dynamics has been shown for urban areas and such models coupled with noise emission law. The study was based on statistical level estimation and  $L_{Aeq}$  to test different noise and traffic sources over a 10 min period for four scenarios. Tests on those scenarios reflect that urban traffic conditions are carried on. In urban traffic conditions, macroscopic conservation law model appeared sufficient for  $L_{Aeq}$  estimation and high level estimation was improved near traffic intersections. Noise sources must be aggregated on cells to decrease the calculation time of noise emission propagation. The grid of line source representation seems to be more relevant than a grid of a pint source representation.

**Arnaud Can *et al.* (2008)** [3] captured urban traffic noise *Dynamics* with the help of Acoustic descriptors. The analysis conducted was based on the five different points taken at different typical urban traffic situations. The descriptors used at that time failed to characterize urban traffic noise at this scale. The five points selected for acoustical measurements correspond to four typical urban situations: In front of traffic signals, between two signals, in front of bus, set back from the street.

**Arnaud Can *et al.* (2009)** [4] compared the three traffic representations for urban traffic noise assessment.

- (i) A coarse *Static* calculation based on mean speed and flow rates.
- (ii) A refined *Static* calculation based on mean kinematic patterns.

- (iii) A whole *Dynamic* noise estimation model that consider vehicle propagation on the network.

After comparison, it has been found that the coarse *Static* representation for  $L_{Aeq}$  can be accepted if 3 dB(A) is mean error, after including kinematic patterns it reduces to 2.2 dB(A) mean error and finally the *Dynamics* noise estimation model guaranteed  $L_{Aeq}$  estimation with error under 1 dB(A) at each point along the network.

**A. Can et al. (2010)** [5] compared traffic representations for the appraisal of urban noise frequency focusing on spectrum aspects. The first is *Static*, which is focused on flow rates and means vehicle speeds and second is *Dynamic*, which considers vehicle interaction along the network. The two representations had been compared on the busy three lane street to match their suitability to real on-field noise level. The *Static* representation fails in reproducing spectra envelopes and it underestimates the low frequencies which can conceal the true effect of traffic flow on urban sound quality. *Static* traffic representation assumes a given mean vehicle speed. This could annihilate the accuracy offered by noise emission and sound propagation models. The *Dynamic* representation improves estimation and it guarantees accurate environment noise assessment. *Dynamic* noise models make it possible to consider the impacts of vehicle kinematics on noise pattern.

**Alberto Ramirez et al. (2012)** [6] developed and evaluated dynamic traffic noise prediction model focused on vehicle classes and their speed. The model was tested on two-lane in urban area of city Bogota and established for different types of vehicles on the basis of the fit single  $L_{i, 17sec}$  noise function. The performance of the model showed was more appropriate over the internationally recognized four deterministic models. Moreover, a deterministic model was developed something in particular context to the city of Bogota. The approach utilized is promising for further investigation under given traffic conditions of urban traffic.

**B. De Coensel et al. (2012)** [7] worked on creating green waves to reduce traffic times along major arterial. It was assumed that an improved traffic flow will result in lower vehicle emissions. The combined approach was used because the travel time, noise and air quantity do not necessarily influence in same way. This work reports on computational study in which a microscope traffic simulation model (Paramics) was combined with sub models for the emission of noise (Imagine) and air pollutants (VERSIT+). The model is also used to investigate the influence of traffic intensity, signal co-ordination and signal parameters on the

noise, Carbon Dioxides (CO<sub>2</sub>), Nitrogen Oxides (NO<sub>x</sub>) and particular emission along an arterial road. The influence of cross flow and reverse flow, lane changing or over-taking on emission is neglected. Extract the information from the simulation of a large number of (more simplified) scenario option is used in this journal. It is found that the emission of the air pollutants could be lower by 10-40%, depending on traffic flow and signal timing setting, only if Green waves are achieved. Sound Pressure Level were decreased upto 1 dB(A) near traffic signals and increased 1.5 dB(A) at intersections. Traffic intensity and green split had largest influence on emission while cycle time didn't have significant influence of emission. Cycle time influenced only travel time but not the emission of the pollutants. Introducing green waves resulted in increase of the total emitted noise level upto 0.6 dB(A).

**Balaji Ponnu *et al.* (2013)** [8] studied on undivided street the traffic flow in a three-lane two-way in the city of Chennai through creating speed-flow, multi-class relationships utilizing both Bureau of Public Roads (BPR) and linear models. It has been found from the study that models perform the same irrespective of units with total volume utilized being vehicles and models perform superior with class-wise (with and without course) reliably to total volume models. It was additionally observed that linear models work superior to different models for all vehicle classes modelling 2-wheeler rates and cars, LCVs and bikes have the greater impact on the speed of practically all the classification of vehicles and the stream. One of the other important conclusions from the study is that an ideal utilization of class-wise and class & direction wise models can offer models of preferable fit over two individual class and class-direction models.

**Campbell Steele (2001)** [10] surveyed that traffic noise prediction models in the 1950s and 1960s were intended to predict a single vehicle sound pressure level  $L_p$  at the road side. These models were focused on constant speed experiments, the predicted levels then being communicated as functions of speed, and with zero acceleration. Later models were not proposed to predict single vehicle levels however to predict the equivalent continuous level  $L_{eq}$  for traffic over a picked period. Still later models predicted  $L_{eq}$  under interfered and with changing flow conditions. Early models predicted linear levels though the later models predicted A-weighted levels. A fer more new models predict one-third octave band spectra. Six usually utilized models and others under development are inspected.

**E. Chevallier et al. (2009)** [13] compared the noise levels obtained by three methodologies at signalized intersections and roundabouts, they and were able to capture the results at different conditions as well as go and stop behaviour of vehicles at under saturated and over saturated conditions. The authors distinguished three families of road prediction models namely as *static*, analytic and micro-simulation. The *Static* noise model only consider free flow constant speed traffic with uniformly distributed vehicles and does not consider the traffic *Dynamics*, mainly the varying speed of vehicles on the roadway. The intersection impact on single vehicle *Dynamics* is not explicitly accounted for. At every intersection, the kinematics of vehicle is strongly influenced by single vehicle *Dynamics* in the absence of other traffic and traffic *Dynamics* induced by vehicle intersection.

**E. Chevallier et al. (2008)** [14] proposed a new traffic simulation tool for *Dynamics* noise modelling at roundabouts. The way to capture traffic *Dynamics* impact on noise level is to combine a traffic simulation tool with noise emission law and sound propagation model. This tool removes the major drawback of classical micro-simulation packages.

**H. N. Rajakumara & R. M. Mahalinge Gowda (2008)** [17] developed an empirical traffic noise prediction model using two analytical approaches under interrupted traffic flow conditions. The two analytical approaches are, being the acceleration lane and being the deceleration lane approach. Several locations were chosen to study the areas where traffic junction was high. The data separately analyzed when, on green light vehicles leave and stopped on red light for both acceleration and deceleration from collected traffic noise data. In urban areas of Indian cities during interrupted traffic flow to study the environmental impact of traffic noise this noise prediction model can be used.

**John Pucher et al. (2005)** [19] summarized key trends in India's travel behaviour and transport system, analyzed the increase and causes of most problems and also recommended nine policy improvements, which are; Right way for cyclists and pedestrians, Traffic management, Public transport services, Privatization of bus services, Motor vehicle fuels and technology, Design new roads, Cooperation between different transport agencies, ministries and departments as well, Revised their current land and development regulations, Large increases in funding. To deal with India's transport crisis the author faced the two main obstacles are Financial and Political. Nevertheless, the appearance of Government and as well

as private sector helps to grow awareness that something must be done to manage with India's transport crisis.

**Jijo Mathew *et al.* (2013)** [20] evaluated platoon dispersion using standard Robertson's model in India for heterogeneous traffic conditions and the actual dispersion in the site. As per the studies in Western countries, Robertson predicted a best fit value for 'K' is 0.4, but at present conditions the value estimated of 'K' turns out to be 0.022 which was showing a high dispersion and thus to model the heterogeneous traffic conditions a complex model is required.

In the study it was found that, Two-wheeler and Low Motor vehicle prevailed the platoon compositions and low motor vehicles travelled at higher speed than other vehicles. Vast composition of LMV could lead to much bigger dispersion in the platoon.

The heterogeneous traffic comprises of a mix of vehicle types, where each class travelled with an alternate speed. Notwithstanding, studying the dispersion for each class of vehicles can prompt to much better outputs.

**K. Kumar *et al.* (1999)** [21] measured the sound pressure level dB(A) at 10 sec intervals in the region of an occupied road convey vehicular traffic. To analyze resultant time series, autoregressive integrated moving averages (ARIMA) modelling strategy was used. The time arrangement was discovered to be non stationary. After first differencing, the transformed series gets stationary and discovered to be administered by a moving average process.

**K. Kumar *et al.* (2011)** [22] developed the road traffic noise prediction model mainly for Indian conditions, and Regression Analysis has been used which is based on Calixto model. Regression Analysis has been done to establish a relationship between a dependent variable, generally the noise level (say  $L_{eq}$ ) and the independent variables like traffic volume, vehicle speed, percentage of heavy vehicles etc. The values/data which were observed are further analysed and compared with the values predicted by Calixto model. After comparison, it was seen that Calixto method could be applied for Indian conditions. The model developed in this paper can be used for noise prediction for an existing busy highway or a proposed new highway. Inputs of the model are:

- (i) Traffic flow
- (ii) Percentage of heavy vehicles

Using Calixto model a weighting factor 'n' is calculated that represents weight-age of heavy vehicles over average noise emission level and using regression analysis to correlate the

different traffic parameters a new road transportation noise prediction model is developed for Indian conditions. Present study reveals that using road transportation noise prediction model developed so far traffic noise level can be reduced and so health problems of people living close proximity to busy road highways.

**Naveen Garg *et al.* (2013)** [24] in Europe widely surveyed the airborne sound insulation criteria and the sound descriptors utilized. The work concentrated on significance and need of having adjusted sound insulation criteria in Indian residences for harmonization of sound descriptors with that followed in different nations for controlling the ever expanding traffic noise. Practical implications of these regulations especially identified with material view point w.r.t least and comfort class was additionally discussed. An investigation of research facility sound transmission qualities of dry wall developments and huge concrete developments to discover whether these criteria could be satisfied effectively or not reveals that the dry wall developments in conjunction with huge concrete developments were suitable for attaining acoustic comfort in residences. It was visualized that a clear definition, understanding and practical usage of sound regulations criteria might be significant in controlling the outside traffic noise.

**Rosa Marina Gonzalez *et al.* (2011)** [30] have analyzed and quantified the induced demand in Spain's 16 main areas from 1998 to 2006 for road transport, years when Spain achieved its highest growth rate of mobility. The key role played by the sector and lack of research in this area, provided it's the high level of traffic consumption and negative externalities connected with it (noise, emissions, accidents, traffic consumption) endow greater significant to this type of work. Taking into account a Dynamic Panel Data (DPD), measured the induced demand by applying alternative approaches (GMM based methods and fixed and random effects). The results acquired give confirmation to the presence of an induced demand for transport, however, result varied depending on the estimating method employed.

**Rajiv B. Hunashal *et al.* (2012)** [31] studied the noise condition in Kolhapur, an ancient city of India. This city was facing several noise pollution problems rapidly emerging as urbanized and industrialized city. Noise pollution is one of the major dreads that impact in urban areas the quality of life. Day-Time studied urban noise equality assessment for five critical zones in Kolhapur. Those five zones were; Educational, Industrial-cum-residential, Recreational, Commercial-cum-residential and Silence zone. Noise pollution lists viz.  $L_{90}$ ,  $L_{50}$ ,  $L_{10}$ ,  $L_{eq}$ ,

noise climate (NC), noise exposure index (NEI) and noise pollution level ( $L_{np}$ ) were computed. The results shown that in Industrial-cum-residential zone had highest  $L_{eq}$  of 72.25 dBA followed by Commercial-cum-residential zone was 64.47 dBA, in educational zone was 63.71 dBA, in recreational zone was 53.26 dBA, in silence zone was 42.84 dBA. For educational zone, observed  $L_{eq}$  were above the required limits, while for different zones it was marginally below. The study of noise assessment clearly revealed disturbing state of noise pollution in Kolhapur.

**S.T. Ingle *et al.* (2004)** [32] studied that traffic police have a high danger of listening loss because of street activity exposure. Here appraisals were made at the work place of traffic police of typical sound level and measures got of the listening to status of policemen. This study concentrated on the working of policemen working for 10–12h everyday in noisy environment. The information was gathered on self-reported wellbeing status to determine the hearing threshold of high and low frequencies via poll and an audiometry. Eighty-four percent of the specimen reported trouble in hearing by one or both ears and hearing loss. The pervasiveness of audiometric listening to impedance characterized as a threshold average greater more than 25dB(A) listening to level was 80% for binaural low frequency normal (250, 500 and 1000Hz), 70% for binaural mid-frequency normal (1000, 2000, 3000 and 4000Hz) and 46% for binaural high frequency normal (3000, 4000, 6000 and 8000Hz) in the traffic policemen.

**Saad Abo-Qudais *et al.* (2007)** [33] developed statistical models that have the capacity to predict different noise levels including, minimum, or maximum noise level in terms of parameters impacted each level. Total of 14235 noise level measurements were used to develop this model. Other parameters anticipated to have an impact on noise levels were gathered. These parameters included composition of traffic, traffic volume, horn using effect, traffic speed, width of lane, number of lane, road slope, approach width and pavement surface texture. The parameters influencing each noise level was selected based on scatter plots, statistical *t*-test and simple correlation matrices. Different forms of models were assessed for each noise level. The best of all the models describing the relationship between parameters and noise level impacted it were presented. The reliability of the nonlinear formulated models were estimated based on the significance of each variable at  $\alpha$ -level 0.05, the standard error of the estimates and coefficient of multiple determination ( $R^2$ ). While the dependability of linear developed models were further judged based on general linear regression tests.

Three groups of models were developed, based on the analysis of the gathered data. The first group of models predicted the equivalent noise level as far as traffic speed, traffic volume, British Pendulum Number (BPN) and heavy vehicles. Second group presented models that explained the relationship between heavy vehicles, maximum noise level and use of horns. While, third group presented minimum noise level prediction models regarding lane width and BPN. Verification of the developed models was carry out by comparing the prediction noise levels with those measured at different locations. Results of this verification shown that, the created models were found to have great prediction capability.

**Santosh K. *et al.* (2008)** [34] analyzed important biochemical parameters and evaluated many plant species of Air Pollution Tolerance Index (APTI). The plant species of Anticipated Performance Index (API) was also calculated by taking their APTI values together with other biological parameters and socio-economic. Plants with high API and APTI vales were proposed for the development of green belts. Many of the plants proposed were keystone species. Keystone species are those which play a key role in the maintenance and development of the ecosystem. Other species proposed were of high aesthetic values and socio-economic. Taking into account these two lists, the most suitable plant species were identified in urban areas for green belt developments and proposed for long term air pollution management.

**S. Rahmani *et al.* (2011)** [35] created a model utilizing Genetic Algorithm, for foreseeing the traffic noise on the roads in Iran, in 2011. In a genetic algorithm, a population of strings (called chromosomes), which encode candidate solutions (called creatures, individuals phenotypes) to an optimization problem, develops to better solutions. Generally, solutions were spoken in binary as strings of 0s and 1s, yet different encodings are also possible. The evolution typically begins from a population of randomly created individuals and happens in eras. In each era, the fitness of every individual in the population is assessed, multiple individuals were stochastically chosen from the current population (focused on their fitness), and modified (recombined and possibly randomly mutated) to structure a new population. The new population is then utilized in the next iteration of the algorithm. Regularly, the algorithm ends when either a maximum number of eras have been created, or a satisfactory fitness level has been reached for the population. If the algorithm has ended because of a maximum number of eras, a satisfactory solution might possibly have been reached.

**Vikrant Tyagi *et al.* (2005)** [42] measured traffic noise attenuation at diverse 1/3-octave frequencies at control site and three vegetation locations in Delhi, the capital city of India. The study demonstrates that attenuation generally increase with frequency. At low frequencies, maxima (somewhere around 10 and 16 dB) in relative attenuation were seen in the frequency interim somewhere around 315 and 400 Hz. Similarly more relative attenuation (>20 dB) was seen in the high frequency go somewhere around 10 and 12.5 kHz. A fundamentally higher relative attenuation of more than 24 dB was seen characteristically at 3.15 kHz at all the vegetation destinations. The measurements reported here shows a fundamentally high attenuation even at the middle frequencies, which is strikingly not quite the same as prior studies. The results show that vegetation belts could be utilized as successful barriers for traffic noise control along the roadsides.

**V. Tripathi (2012)** [43] observed that Calixto model mainly relies over the road traffic data in order to generate the levels of noise. But besides this road dimension factors also play a key role in the generation of noise levels. The modification in RTM has been done and it takes into account both the road traffic data along with the road dimensions aspects. Thus, it is able to provide much accurate results than the Calixto Method. Traffic in road may depend on the speed of vehicles, volume of traffic and road conditions. The increase in generation of noise day by day, our main aim at carrying out the modification in the RTM and carry out comparative analysis of this model with Calixto model for our data set.

**Xian-Qing Yang *et al.* (2007)** [44] numerically studied the probability  $P_{ac}$  of the event of traffic accidents in the Nagel-Schreckenberg (NS) model with velocity-dependent randomization (VDR). Numerical results exhibit that there was a discriminating density over which car accidents happen, yet underneath which no car accidents occur. Not the same as the accident probability in the NS model, the accident probability in the VDR model repetitively decreases with expansion of car density over the critical density. The estimation of the accident probability was just controlled by the stochastic noise and the quantity of cars on roas. In the stochastic VDR model with as far as possible  $v_{max} = 1$ , no critical density remains and car accidents happen in the entire density region. The braking probabilities of moving cars and standing cars have diverse impacts on the accident probability. A mean-field theory exposes that the accident probability is relative to the mean density of "go and stop" wave for per time step. Hypothetical investigations give amazing concurrence with numerical results in the VDR model.

## 2.2 Gaps and Conclusion

From the literature survey, it has been observed that the work reported in the area of traffic dynamics on urban roads is limited and needs to be investigated in the Indian Scenario. Some of the gaps that have been identified are given below:

- It is observed that not much work has been reported in the area of traffic dynamics in India.
- The link between noise descriptors and the urban traffic situations has not been studied yet.
- The set of descriptors studied in the literature need further investigations on other traffic situations such as a two-way street.

It was found that while studying that many models have been developed for various road conditions. Every country has its own model for the traffic noise to meet the requirements of the government regulations and designers. A review of six traffic noise emission models i.e. FHWA traffic noise model, CoRTN model, RLS 90, MITHRA, STL-86 and ASJ Method has been done.

Through the literature survey it has been found that the research has not been done for the optimization of the available models for Indian scenario. A lot of studies for development of traffic noise model on the traffic lights have not been done on Indian road conditions. So an effort should be made by conducting a study considering various parameters such as traffic volume for near and far side, mean speed and road width near the traffic lights.

# Chapter 3

## Experimental Investigation

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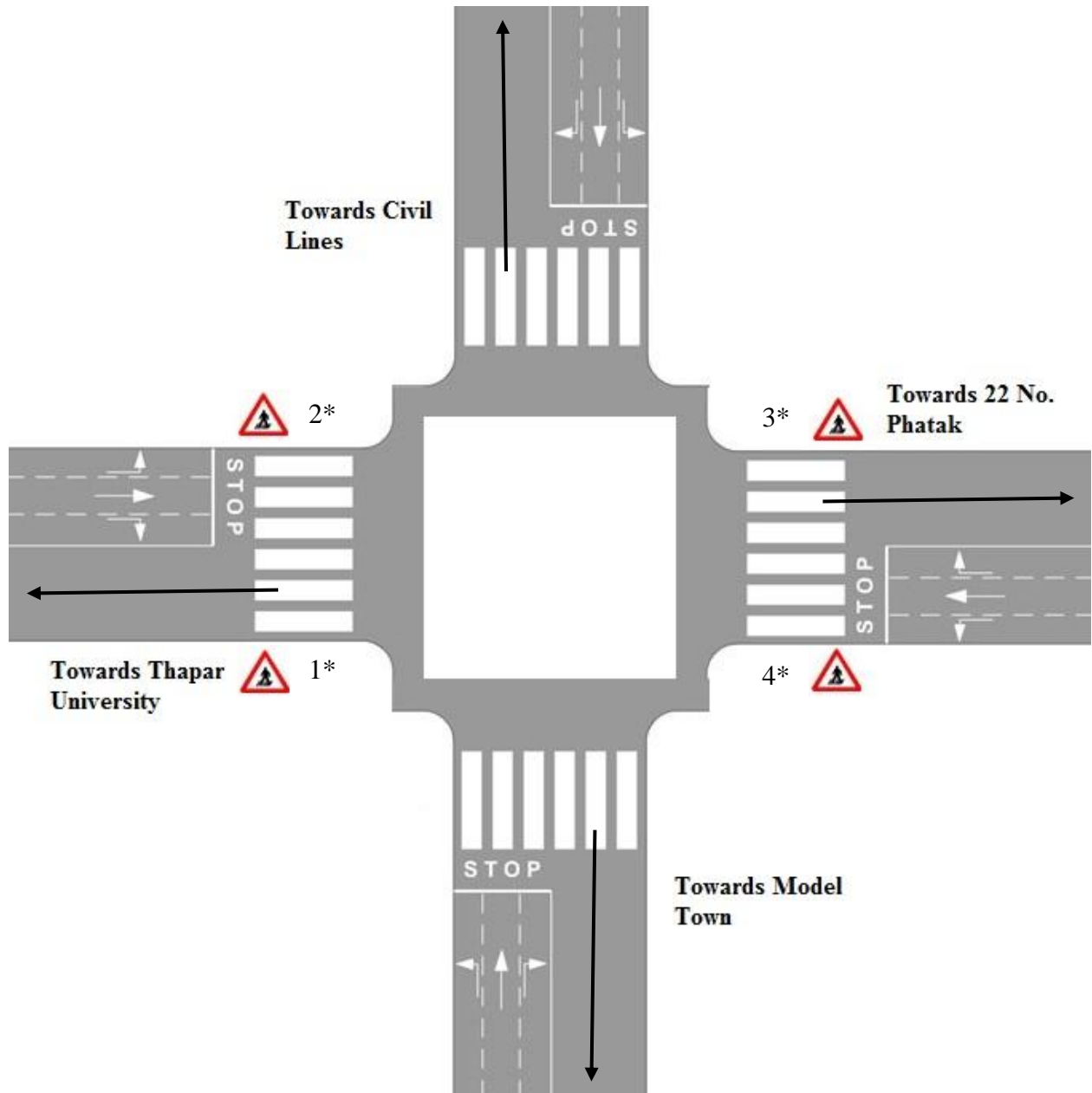
Traffic noise models are needed to predict the noise produced under given road conditions. These can be used to design the roads for the changing traffic conditions in urban as well as highway roads. Thus, it is commonly required to predict sound descriptors such as  $L_{eq}$ ,  $L_{10}$ ,  $L_{50}$ ,  $L_{90}$ . Numbers of models in different countries have been developed using regression analysis and other statistical tools from the gathered data. A survey of the site location says that the different traffic compositions i.e. class of the vehicle for near and far side and its mean speed play a role in traffic noise. The vehicle composition was found much higher for medium vehicles and two wheelers. The average speed was found for near side and far side traffic was varying between 6 to 20 km/h. The higher and lower value of mean speed for near and far side was 5.29 and 24.42 km/h. Traffic noise was worse sometimes by excessive acceleration while over taking and air pressure horns at Intersections.

### 3.1 Site Selection

To predict the traffic noise for traffic lights, the very first task was to select the traffic lights having all corners equally distanced. The traffic lights selected were near Café Coffee Day, Bhupindra Road, Patiala. At the traffic lights due to the green waves sometimes the traffic congestion increased and that leads to high noise problem which includes pressure horns, engine and exhaust noise. Microphone was placed at a height of 1.2 meter and at a distance ' $l$ ' meters from the centre of the divider (Road Width). The distance from divider to one end of the road is 6.7 meters. The microphone was placed at four different locations of the traffic lights. At every location sets of data were differently recorded.

The locations where readings were taken are marked by ' $\Delta$ ' around the traffic lights, as shown in Figure 3.1.

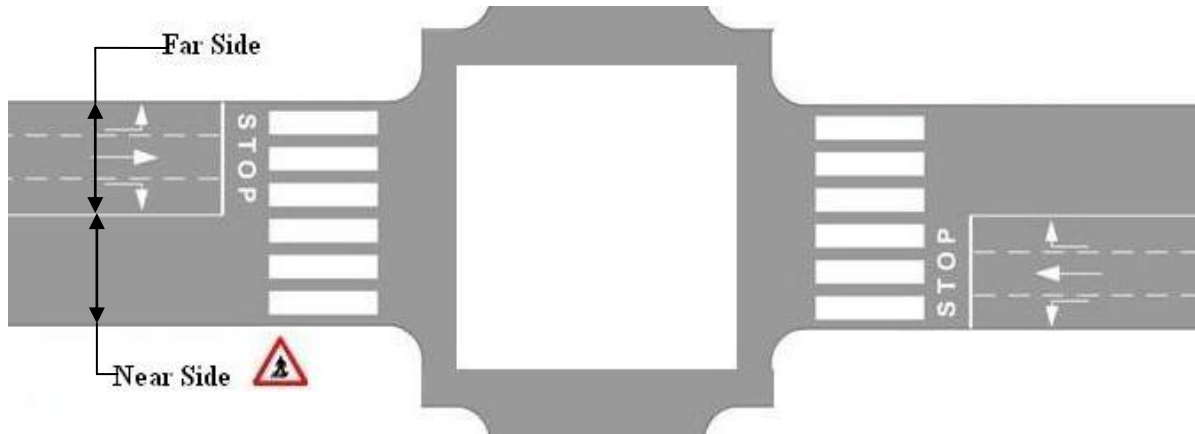
- Sketch for Traffic Lights (Bhupindra Road):



**Figure 3.1:** Site map of Traffic Lights

Where, 1\*, 2\*, 3\* and 4\* are the points from where the readings were measured.

- **Sketch for Near and Far Side**



**Figure 3.2:** Site map of Near and Far Side

### 3.2 Methodology

The  $L_{eq}$ ,  $L_{10}$ ,  $L_{50}$ ,  $L_{90}$  sound levels were collected for 1 hour duration. The number of vehicles in each class that pass a given location was noted. The values of mean speed on an average were measured for each hour. There was some unexpected noise like from horns but the sound generated by the vehicles will be steady. The site selected for the measurement around the traffic lights were such that the role of Stop and Go model can be studied, in which traffic volume and mean speed for near and far side was included. Thus having all the independent parameters a prediction model was formulated.

### 3.3 Measurement Procedure

For traffic noise problem it was useful to have the continuous equivalent sound level  $L_{eq}$ , 10 percentile exceeded sound level  $L_{10}$ , 50 percentile exceeded sound level  $L_{50}$ , 90 percentile exceeded sound level  $L_{90}$ . Such data was collected using a Sound Level Meter (CESVA 310). The values of mean speed were calculated by taking readings of speed at the point of measurement and 30 meter before the traffic lights using Radar Gun.

The sound level meter was calibrated correctly using calibrator before using it to check and correct any errors. The tripod was correctly levelled at the height of 1.2 meter from the ground level or pavement level.

The road width ( $l$ ) was also to be measured corresponding to the point of placing the microphone using measuring tape.

The noise measurements recorded were  $L_{eq}$ ,  $L_{10}$ ,  $L_{50}$  and  $L_{90}$ .

### 3.4 Measurements

Readings for different noise descriptors and parameters were recorded. The vehicle count for near and far side was also done during the measurement period. A large number of 1 hour measurements were taken for each location on different days in random manner in order to account for temporal variations in traffic flow characteristics. The symbols used for different parameters are shown in Table 3.1.

**Table 3.1:** List of Parameters and Symbols

<b>Parameters</b>	<b>Symbol</b>
Volume of Traffic for Near Side	$V_n$
Volume of Traffic for Far Side	$V_f$
Mean Speed of Traffic on Near Side	$S_n$
Mean Speed of Traffic on Far Side	$S_f$

# Chapter 4

## Results and Discussions

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### 4.1 Traffic Noise Modelling

Traffic noise modeling has various uses like evaluating the effect of road change, prediction of noise, the performance of noise barrier if applied and change of different parameters. The fundamental component of traffic noise modeling contains the noise created by source and its propagation through air and its constriction between the source and receiver. The source data to traffic noise are depend on the volume of every vehicle class as noise changes from different class to class and the acceleration and deceleration of vehicles, operating mode of the vehicle and the segment of roadway inside the line of sight to the receiver position. The propagation of sound incorporates the number of paths, acoustics character of the ground, site geometry and building/barriers rows if present between the source and the receiver. Most of the models also take into account the type of pavement in regard to the tyre-pavement interaction noise, temperature conditions, the wind and interrupted flows.

In traffic noise modeling there are certain assumptions about the vertical distribution of source on vehicle in operating mode and the height of the vehicle producing noise.

#### Step 1

Collect the data and information indicating corresponding values and variables.  
(APPENDIX-A)

#### Step 2

Plot the graph between each descriptor ( $L_{eq}$ ,  $L_{10}$ ,  $L_{50}$ ,  $L_{90}$ ) and the variables considered. From the scatter diagram one can have a visualization of nature of each relationship. (Figure 4.1 – 4.16)

#### Step 3

The curve fitting can be obtained by doing multiple analyses in “Microsoft Excel”. By regression analysis a mathematical equation can be developed.

Also a correlation test is also done to have a comparison that which parameter considered is having more impact on a particular sound descriptor. Output for the correlation is shown in Tables (4.1 – 4.4).

A t-test is also done to check the goodness to fit for  $\alpha = 0.05$ . Output of the t test for each predictor is shown in Tables (4.5 – 4.8).

Graphs for various sound descriptors have been plotted for various parameters considered. Graphs can be shown on Figure (4.5 – 4.16).

Frequency analysis is also done for the traffic noise and the graphs for 1/1 Octave band are shown in the Figures (4.17 – 4.20).

**Site:** Traffic Lights Intersection near Café Coffee Day, Bhupindra Road, Patiala.

**Measurement Period:** 1 Hour

Sound Level Meter at 7 meter from the center of the lane and at a height of 1.2 meter.

**Temperature (Range):** 23 – 35° C

**Humidity (Range):** 10 – 34%

**Summary:**

- I. Duration of data collection: 100 Hours
- II. No. of days: 25 Days
- III. Dates: 30<sup>th</sup> August to 28<sup>th</sup> September
- IV. Duration: 9:00 A.M – 11:00 A.M, 3:00 P.M – 5:00 P.M.
- V. Critical Observations: On Sunday and holidays the vehicle composition has decreased thus leading to the lower value of  $L_{10}$  and  $L_{eq}$ . In some cases there was excessive increase of  $L_{10(1sec)}$  to 108 dB(A) because of some old used three wheeler, blowing air pressure horn by the bus nearby the Sound Level Meter and the sound of the exhaust from two wheelers.
- VI. Traffic volume found to be varying throughout the day, having maximum composition during early and late hours i.e. 9:00 A.M to 10:00 A.M and 4:00 P.M to 6:00 P.M, but the traffic volume at its peak at 2:00 P.M to 3:00 P.M because of students coming back from schools.
- VII. Vehicular composition of cars and two-wheeler was found to be very high as compared to other vehicle categorized throughout the day.
- VIII. The data being measured from the location was shown in APPENDIX-A.

### 4.1.1 Regression Analysis for Equivalent Sound Level ( $L_{eq}$ )

The first step after gathering data from all areas at the traffic lights is to create a model from it. A regression analysis has been done to formulate an equation for each location's equivalent sound level that could be applied to predict it.

From the equations it was observed that the individual model formed had an error of - 4.6 to 7.4 for Traffic Lights between predicted and the measured value. Though the percentage error for the readings was found to be within  $\pm 7\%$  but the  $R^2$  values were found to be 0.77 for the respective traffic lights. So, an equation was developed that could be applied to the traffic lights location and give more accurate model. The analysis also depicts a picture of the factors that affect most the equivalent sound level.

#### Regression Output:

<i>Regression Statistics</i>	
Multiple R	0.87
R Square	0.77
Adjusted R Square	0.76
Standard Error	2.65
Confidence Level	95%
P-Value of F-Significance	0.00
F-Value	157.96
Observations	60

<i>Variables</i>	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	27.96	1.70	16.38	<b>0.00</b>
$V_n$	0.0016	0.001	0.87	0.38
$V_f$	0.01	0.002	5.34	<b>0.00</b>
$S_n$	1.42	0.07	19.22	<b>0.00</b>
$S_f$	1.28	0.07	18.04	<b>0.00</b>

#### Equation for $L_{eq}$ :

$$L_{eq} = 27.964 + 0.0016 V_n + 0.012 V_f + 1.429 S_n + 1.288 S_f$$

### Summary:

- From the regression result it was found that the model has the various parameters considered, out of which the four parameters  $S_n$  and  $S_f$  are highly impacting the  $L_{eq}$  as the p-value for it lies below 0.05 and thus it is very significant.
- The overall p-value (0.00) for the model is also very low ( $< 0.05$ ), thus the model is significant for 95% confidence level.
- The  $R^2$  value (0.77) for the model is near to 1 and the model can explain the variations very well.

### 4.1.2 Regression Analysis for 10 Percentile Sound Level ( $L_{10}$ )

$L_{10}$  sound levels were recorded to get a picture of factors that affect most the maximum noise levels of sound exposure on traffic lights. A regression analysis has been done to formulate an equation for each traffic light's  $L_{10}$  sound level that could be applied to predict it.

From the equations it was found that the individual model formed had an error of - 4.26 to 4.91 for Traffic Lights between predicted and the measured value. Though the percentage error for the readings was found to be within  $\pm 3\%$  but the  $R^2$  values were found to be 0.70 for the respective traffic lights. So, an equation was developed that could be applied to the traffic lights location and give more accurate model. The analysis also depicts a picture of the factors that affect most the equivalent sound level.

### Regression Output:

<i>Regression Statistics</i>	
Multiple R	0.77
R Square	0.70
Adjusted R Square	0.69
Standard Error	1.14
Confidence Level	95%
P-Value of F-Significance	0.00
F-Value	26.61
Observations	60

<i>Variables</i>	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	71.87	0.73	98.13	<b>0.00</b>
V <sub>n</sub>	0.006	0.00	8.40	<b>0.00</b>
V <sub>f</sub>	0.001	0.00	1.08	0.27
S <sub>n</sub>	0.08	0.03	2.53	<b>0.01</b>
S <sub>f</sub>	0.04	0.03	1.45	0.14

**Equation for L<sub>eq</sub>:**

$$L_{10} = 71.87 + 0.006 V_n + 0.001 V_f + 0.08 S_n + 0.04 S_f$$

**Summary:**

- From the regression result it was found that the model has the various parameters considered, out of which the four parameters S<sub>n</sub> and S<sub>f</sub> are highly impacting the L<sub>10</sub> as the p-value for it lies below 0.05 and thus it is very significant.
- The overall p-value (0.00) for the model is also very low (< 0.05), thus the model is significant for 95% confidence level.
- The R<sup>2</sup> value (0.70) for the model is also near to 1 and the model can explain the variations very well.

**4.1.3 Regression Analysis for 50 Percentile Sound Level (L<sub>50</sub>)**

L<sub>50</sub> sound levels were recorded to get a picture of factors that affect most the maximum noise levels of sound exposure on traffic lights. A regression analysis has been done to formulate an equation for each traffic light's L<sub>50</sub> sound level that could be applied to predict it.

From the equations it was found that the individual model formed had an error of - 3.91 to 4.61 for Traffic Lights between predicted and the measured value. Though the percentage error for the readings was found to be within ±4 % but the R<sup>2</sup> values were found to be 0.78 for the respective traffic lights. So, an equation was developed that could be applied to the traffic lights location and give more accurate model. The analysis also depicts a picture of the factors that affect most the equivalent sound level.

### **Regression Output:**

<i>Regression Statistics</i>	
Multiple R	0.84
R Square	0.78
Adjusted R Square	0.77
Standard Error	1.06
Confidence Level	95%
P-Value of F-Significance	0.00
F-Value	57.78
Observations	60

<i>Variables</i>	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	63.92	0.68	93.39	<b>0.00</b>
V <sub>n</sub>	0.007	0.00	10.32	<b>0.00</b>
V <sub>f</sub>	0.0008	0.00	0.96	0.33
S <sub>n</sub>	0.016	0.02	0.55	0.58
S <sub>f</sub>	0.12	0.02	4.49	<b>0.00</b>

### **Equation for L<sub>eq</sub>:**

$$L_{50} = 63.92 + 0.007 V_n + 0.0008 V_f + 0.016 S_n + 0.12 S_f$$

### **Summary:**

- From the regression result it was found that the model has the various parameters considered, out of which the four parameters S<sub>n</sub> and S<sub>f</sub> are highly impacting the L<sub>50</sub> as the p-value for it lies below 0.05 and thus it is very significant.
- The overall p-value (0.00) for the model is also very low (< 0.05), thus the model is significant for 95% confidence level.
- The R<sup>2</sup> value (0.78) for the model is also near to 1 and the model can explain the variations very well.

#### 4.1.4 Regression Analysis for 90 Percentile Sound Level (L<sub>90</sub>)

L<sub>90</sub> sound levels were recorded to get a picture of factors that affect most the maximum noise levels of sound exposure on traffic lights. A regression analysis has been done to formulate an equation for each traffic light's L<sub>90</sub> sound level that could be applied to predict it.

From the equations it was found that the individual model formed had an error of - 4 to 5.4 for Traffic Lights between predicted and the measured value. Though the percentage error for the readings was found to be within ±3 % but the R<sup>2</sup> values were found to be 0.70 for the respective traffic lights. So, an equation was developed that could be applied to the traffic lights location and give more accurate model. The analysis also depicts a picture of the factors that affect most the equivalent sound level.

#### Regression Output:

<i>Regression Statistics</i>	
Multiple R	0.76
R Square	0.70
Adjusted R Square	0.69
Standard Error	1.16
Confidence Level	95%
P-Value of F-Significance	0.00
F-Value	68.25
Observations	60

<i>Variables</i>	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
Intercept	58.32	0.74	78.19	<b>0.00</b>
V <sub>n</sub>	0.006	0.00	8.15	<b>0.00</b>
V <sub>f</sub>	0.001	0.00	1.82	0.06
S <sub>n</sub>	-0.014	0.03	-0.45	0.64
S <sub>f</sub>	0.15	0.03	5.12	<b>0.00</b>

#### Equation for L<sub>eq</sub>:

$$L_{90} = 58.32 + 0.006 V_n + 0.001 V_f - 0.014 S_n + 0.15 S_f$$

### Summary:

- From the regression result it was found that the model has the various parameters considered, out of which the four parameters  $S_f$  and  $V_f$  are highly impacting the  $L_{90}$  as the  $p$ -value for it lies below 0.05 and thus it is very significant.
- The overall  $p$ -value (0.000) for the model is also very low ( $< 0.05$ ), thus the model is significant for 95% confidence level.
- The  $R^2$  value (0.70) for the model is also near to 1 and the model can explain the variations very well.

From the regression analysis it was found that there are certain parameters that affect the particular sound level. These factors are identified by their corresponding  $p$ -value. If the  $p$ -value lies below 0.05 then that factor is considered to be highly significant, but it cannot be said that other factors that do not have  $p$ -value less than 0.05 do not have any effect on noise descriptors as they do have some impact on them though not significant. Thus those parameters cannot be neglected from the equation. If it is tried to exclude those parameters then the correlation between the predicted and the measured values loses its significance.

The noise levels  $L_{eq}$  have been calculated and given in tables for the completeness of the information. Some investigations may like to do the analysis on the basis of  $L_{eq}$  data.

For the purpose of analysis and recommendations for control measures, the noise level  $L_{10}$  (peak value) has been used all over except the regression analysis where both  $L_{10}$  and  $L_{eq}$  have been used.

Values of  $L_{50}$  have been used to give the idea consider to the maximum noise levels measured. Generally high values of large  $L_{avg}$  represent the cases of vehicles without proper silencers, vehicle honking almost continuously, loud speakers playing etc.

Values of  $L_{min}$  represent the minimum noise levels evaluated. Usually, they are slightly lower than the background noise.  $L_{90}$  values have been taken and reported as background noise in findings in various appendices.

## 4.2 Correlation Test

By correlation analysis it was found that which factor has the most and which one has least effect on the different statistical parameters. A rank has been assigned to have a picture of which factor is affecting most a particular sound descriptor. A correlation coefficient greater than 0.5 to 1 is considered to be good.

### A) Correlation test for $L_{eq}$

**Table 4.1:** Correlation Output for  $L_{eq}$

<i>Factors</i>	<i>Symbol</i>	<i><math>L_{eq}</math> Correlation Coefficient</i>	<i>Rank</i>
Volume of Traffic for Far Side	$V_f$	0.787	1
Volume of Traffic for Near Side	$V_n$	0.726	2
Mean Speed on Far Side	$S_f$	0.518	3
Mean Speed on Near Side	$S_n$	0.305	4

From the correlation test it was found that the Equivalent Sound Level ( $L_{eq}$ ) and all the various factors except mean speed on near side have a very good positive correlation. This means that the  $L_{eq}$  value will increase significantly with increase in the parameter's magnitude having correlation coefficient in between 0.5 and 1.

### B) Correlation test for $L_{10}$

**Table 4.2:** Correlation Output for  $L_{10}$

<i>Factors</i>	<i>Symbol</i>	<i><math>L_{10}</math> Correlation Coefficient</i>	<i>Rank</i>
Volume of Traffic for Near Side	$V_f$	0.863	1
Mean Speed on Near Side	$V_n$	0.623	2
Volume of Traffic for Far Side	$S_f$	0.335	3
Mean Speed on Far Side	$S_n$	0.170	4

From the correlation test it was found that the Equivalent Sound Level ( $L_{10}$ ) and all the various factors except mean speed on far side have a very good positive correlation. This means that the  $L_{10}$  value will increase significantly with increase in the parameter's magnitude having correlation coefficient in between 0.5 and 1.

### C) Correlation test for $L_{50}$

**Table 4.3:** Correlation Output for  $L_{10}$

<i>Factors</i>	<i>Symbol</i>	<i><math>L_{50}</math> Correlation Coefficient</i>	<i>Rank</i>
Volume of Traffic for Near Side	$V_f$	0.748	1
Mean Speed on Far Side	$V_n$	0.703	2
Volume of Traffic for Far Side	$S_f$	0.553	3
Mean Speed on Near Side	$S_n$	0.143	4

From the correlation test it was found that the Equivalent Sound Level ( $L_{50}$ ) and all the various factors except mean speed on near side have a very good positive correlation. This means that the  $L_{50}$  value will increase significantly with increase in the parameter's magnitude having correlation coefficient in between 0.5 and 1.

### D) Correlation test for $L_{90}$

**Table 4.4:** Correlation Output for  $L_{90}$

<i>Factors</i>	<i>Symbol</i>	<i><math>L_{90}</math> Correlation Coefficient</i>	<i>Rank</i>
Mean Speed on Far Side	$V_f$	0.858	1
Volume of Traffic for Near Side	$V_n$	0.695	2
Volume of Traffic for Far Side	$S_f$	0.539	3
Mean Speed on Near Side	$S_n$	0.219	4

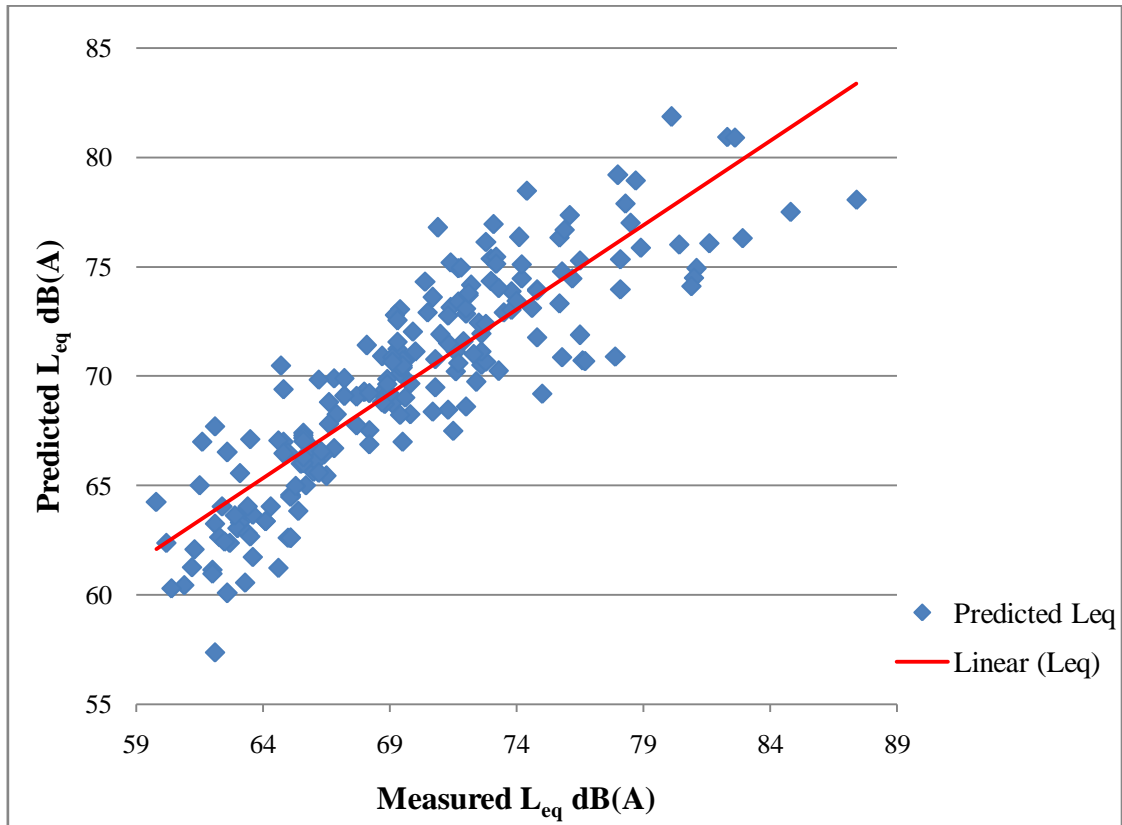
From the correlation test it was found that the Equivalent Sound Level ( $L_{90}$ ) and all the various factors except mean speed on near side have a very good positive correlation. This means that the  $L_{90}$  value will increase significantly with increase in the parameter's magnitude having correlation coefficient in between 0.5 and 1.

Some parameters that do not have good correlation coefficient between 0.5 to 1 cannot be neglected as they do have some impact on the sound level and thus always maintain their significance as though they have low correlation but they do have some impact on noise levels.

### 4.3 t - Test

**t-Test for Various Statistical Sound Predictors:** For comparing the sound level in both cases a 2t-test is performed.

#### A) For $L_{eq}$ :



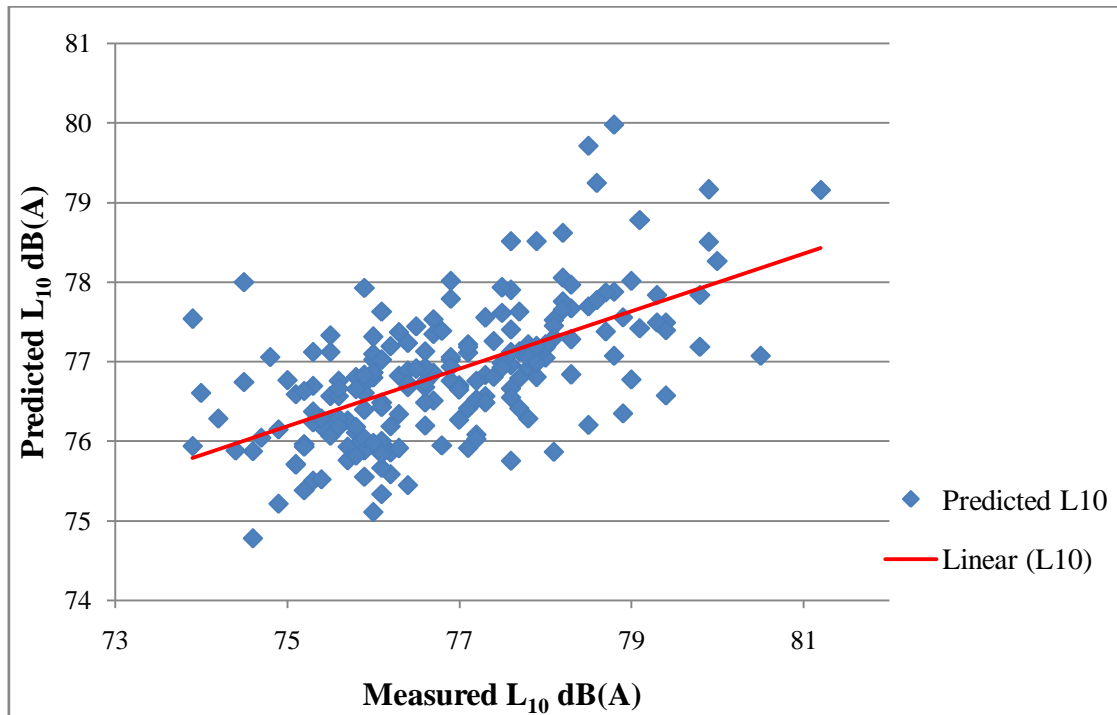
**Figure 4.1:** Predicted  $L_{eq}$  VS Measured  $L_{eq}$

**Table 4.5:** T-Test output for  $L_{eq}$

	$L_{eq}$	Predicted $L_{eq}$
Mean	69.701 dB	69.673 dB
Variance	11.511	9.481
Observations	60	60
df	59	
t Stat	<b>0.121</b>	
P(T<=t) two-tail	0.903	
t Critical two-tail	<b>2.000</b>	

Since calculated 't' (t-statistical) was less than the tabulated 't' (t-critical), therefore  $H_0$  was accepted at 5% level of significance having  $\alpha = 0.05$  and it may be concluded that there is no significant difference between 'L<sub>eq</sub>' and 'Predicted L<sub>eq</sub>'.

**B) For L<sub>10</sub>:**



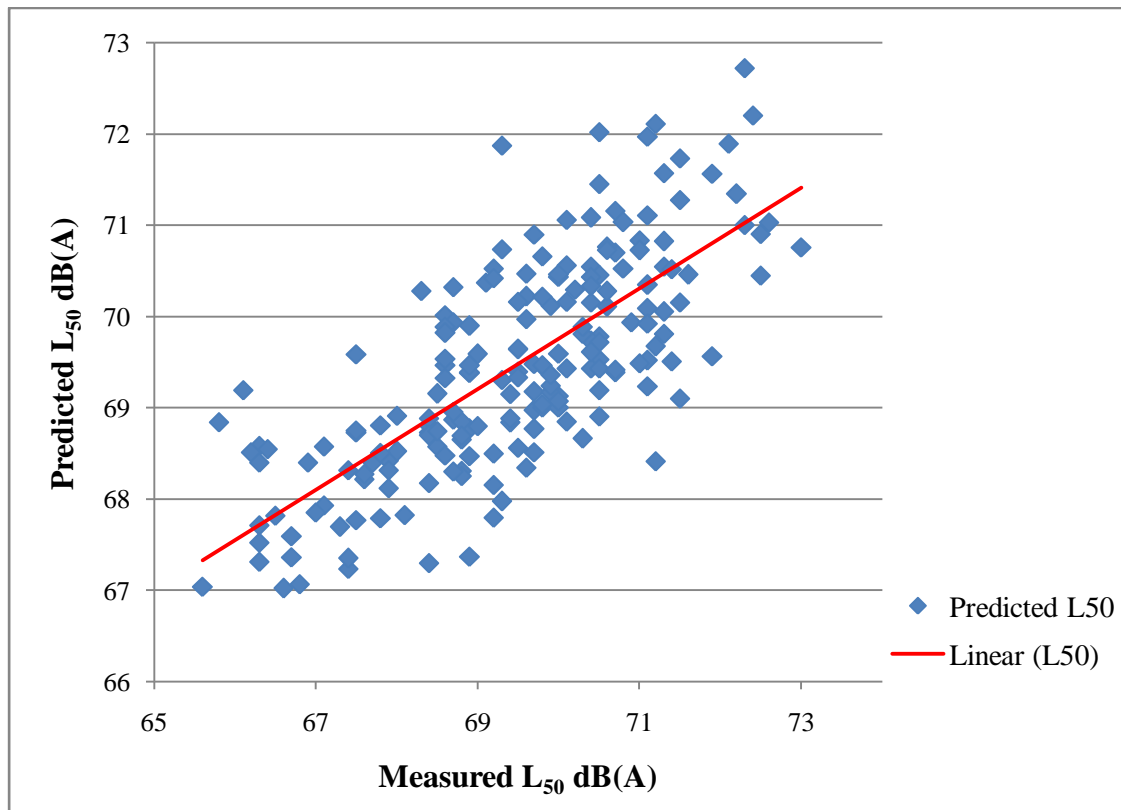
**Figure 4.2:** Predicted L<sub>10</sub> VS Measured L<sub>10</sub>

**Table 4.6:** T-Test: Output for L<sub>10</sub>

	<b>L<sub>10</sub></b>	<b>Predicted L<sub>10</sub></b>
Mean	76.784	76.834
Variance	1.400	0.501
Observations	60	60
df	59	
t Stat	<b>-0.460</b>	
P(T<=t) two-tail	0.647	
t Critical two-tail	<b>2.000</b>	

Since calculated 't' (t-statistical) was less than the tabulated 't' (t-critical), therefore  $H_0$  was accepted at 5% level of significance having  $\alpha = 0.05$  and it may be concluded that there is no significant difference between 'L<sub>10</sub>' and 'Predicted L<sub>10</sub>'.

**C) L<sub>50</sub>:**



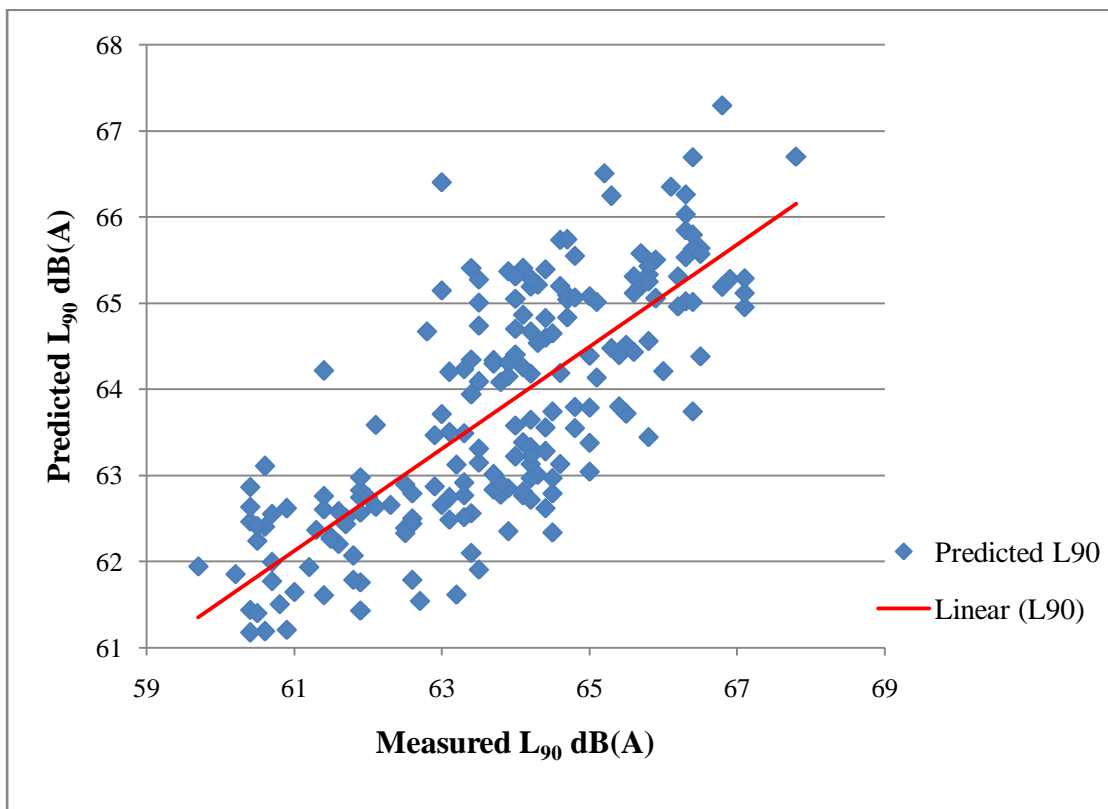
**Figure 4.3:** Predicted L<sub>50</sub> VS Measured L<sub>50</sub>

**Table 4.7:** T-Test Output for L<sub>50</sub>

	<b>L<sub>50</sub></b>	<b>Predicted L<sub>50</sub></b>
Mean	69.411	69.426
Variance	2.107	1.067
Observations	60	60
df	59	
t Stat	<b>-0.135</b>	
P(T<=t) two-tail	0.892	
t Critical two-tail	<b>2.000</b>	

Since calculated 't' (t-statistical) was less than the tabulated 't' (t-critical), therefore H<sub>0</sub> was accepted at 5% level of significance having  $\alpha = 0.05$  and it may be concluded that there is no significant difference between 'L<sub>50</sub>' and 'Predicted L<sub>50</sub>'.

**D) L<sub>90</sub>:**



**Figure 4.4:** Predicted L<sub>90</sub> VS Measured L<sub>90</sub>

**Table 4.8:** T-Test Output for L<sub>90</sub>

	<b>L<sub>90</sub></b>	<b>Predicted L<sub>90</sub></b>
Mean	63.709	63.732
Variance	2.845	1.655
Observations	60	60
df	59	
t Stat	<b>-0.187</b>	
P(T<=t) two-tail	0.851	
t Critical two-tail	<b>2.000</b>	

Since calculated 't' (t-statistical) was less than the tabulated 't' (t-critical), therefore H<sub>0</sub> was accepted at 5% level of significance having  $\alpha = 0.05$  and it may be concluded that there is no significant difference between 'L<sub>90</sub>' and 'Predicted L<sub>90</sub>'.

**Result Summary:**

To perform t-test, it was first needed to assume the Null Hypothesis ( $H_0$ ) and Alternative Hypothesis ( $H_1$ ). 193 samples were taken and t-test was done on them.

Let,

Mean value for measured  $L_x = \mu_1$

Mean value for predicted  $L_x = \mu_2$                       where,  $L_x = L_{eq}, L_{10}, L_{50}, L_{90}$  for each test.

So, assume hypothesis

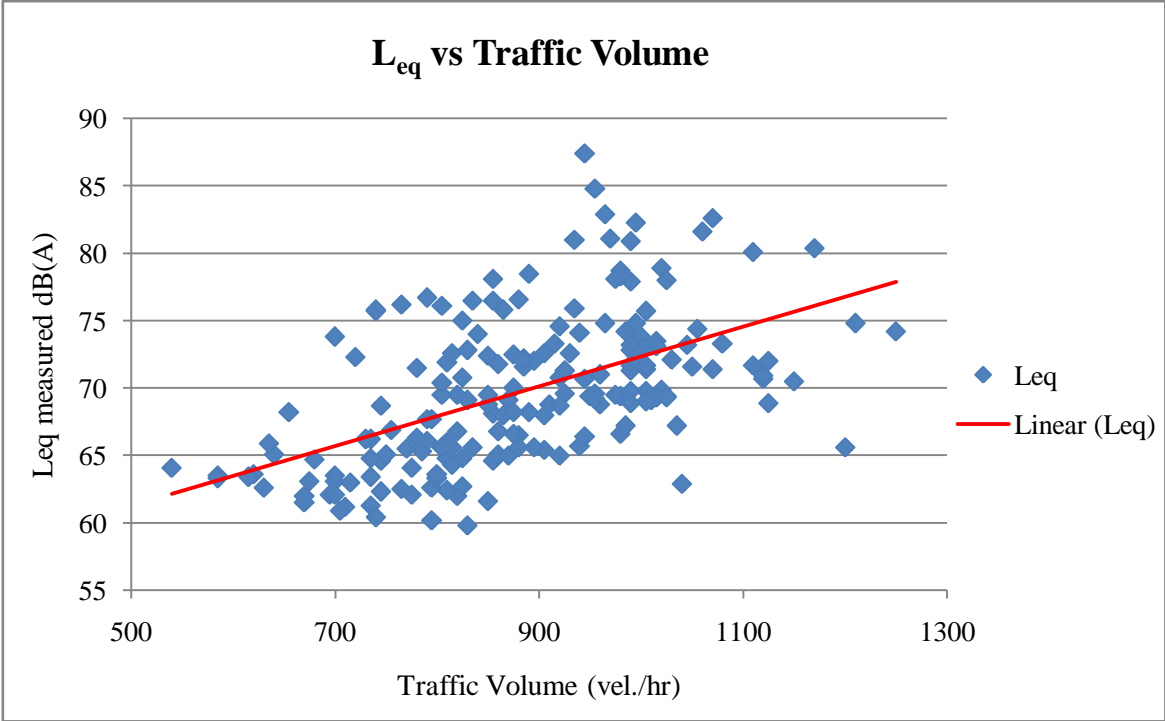
$H_0: \mu_1 = \mu_2$                       (Null Hypothesis)

$H_1: \mu_1 \neq \mu_2$                       (Alternate Hypothesis)

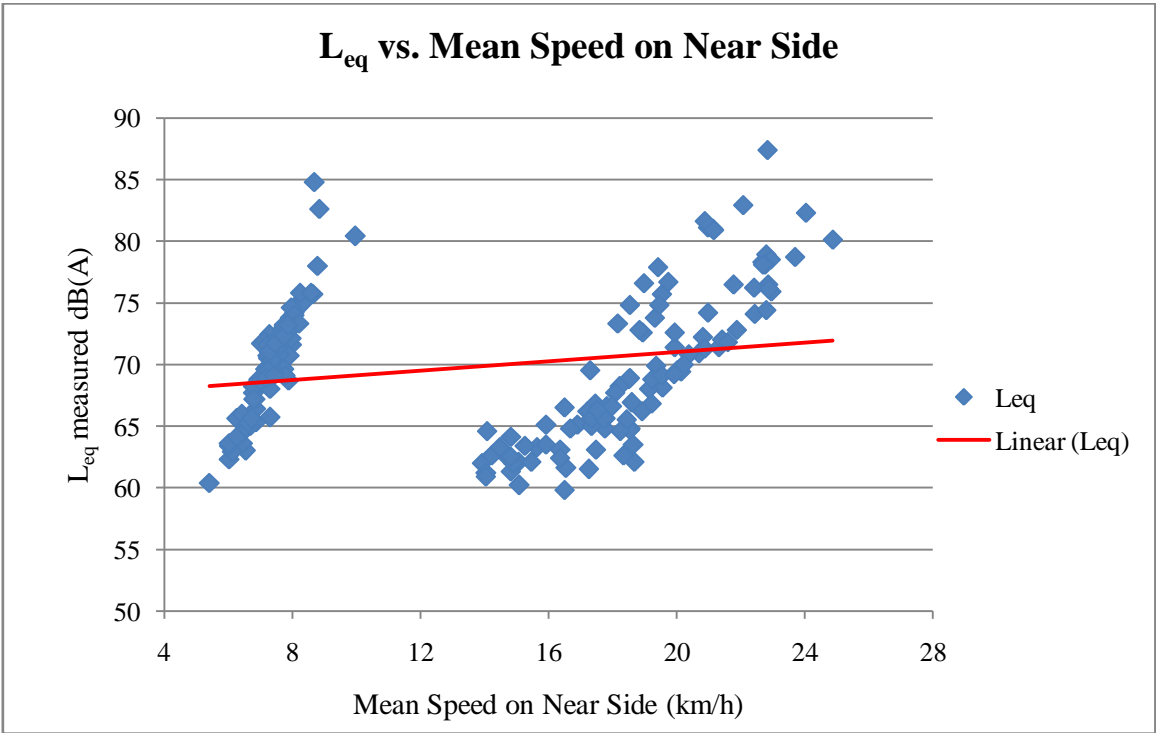
It was found that in all the cases the calculated t value 't-stat' was less than or between the tabulated t value 't-critical'. So the null hypothesis was accepted. This means that the mean value of the predicted and measured values of sound was same.

The table for each test sample chosen is shown in APPENDIX – B, C, D and E.

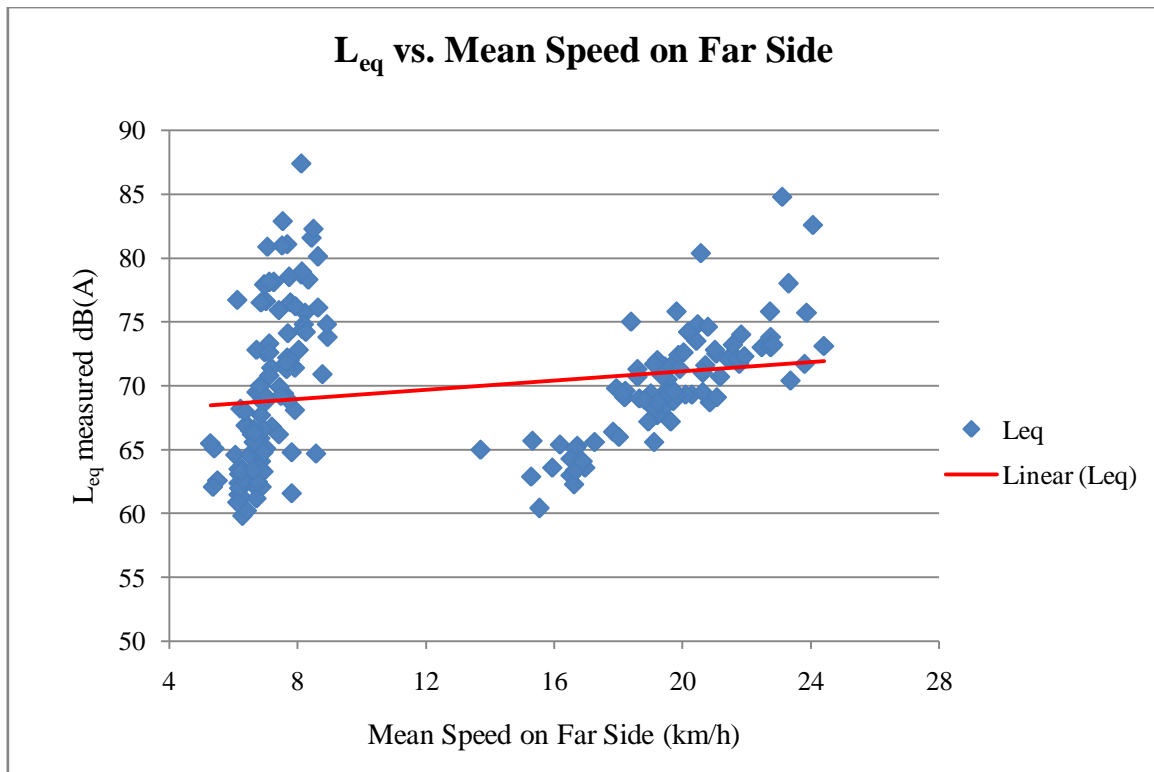
# Graphs for $L_{eq}$



**Figure 4.5:**  $L_{eq}$  vs Traffic Volume



**Figure 4.6:**  $L_{eq}$  vs Mean Speed on Far Side

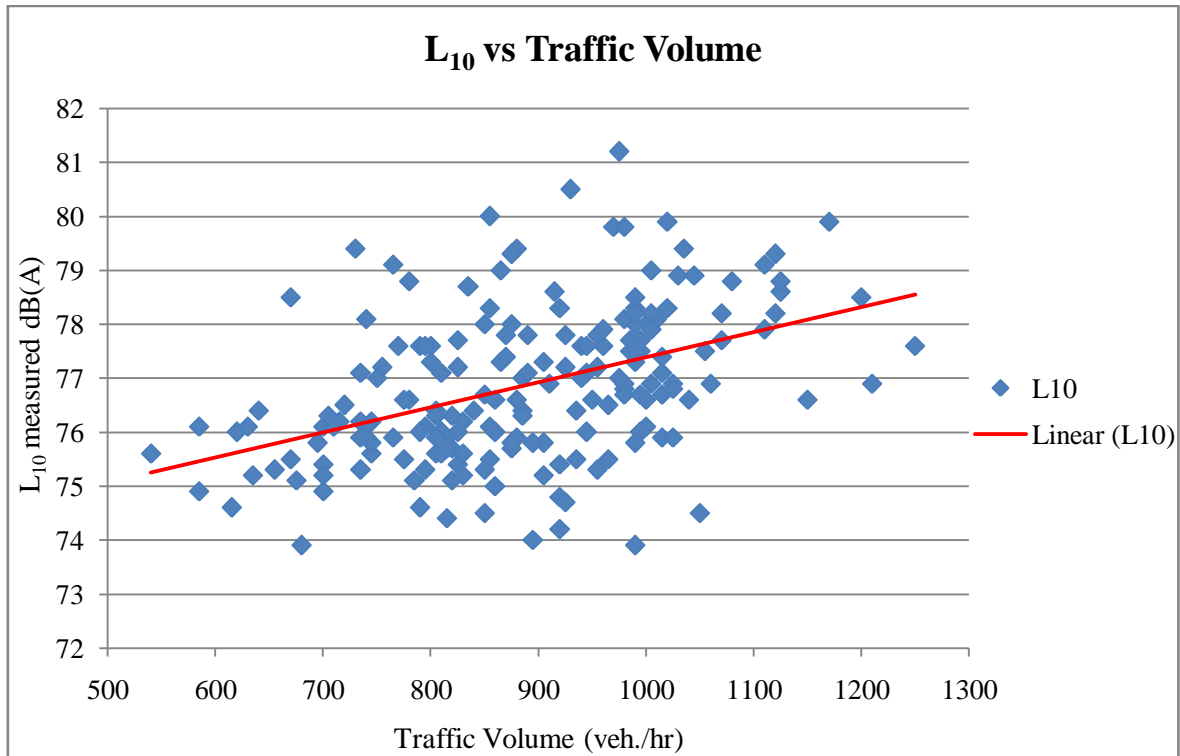


**Figure 4.7:**  $L_{eq}$  vs Mean Speed on Far Side

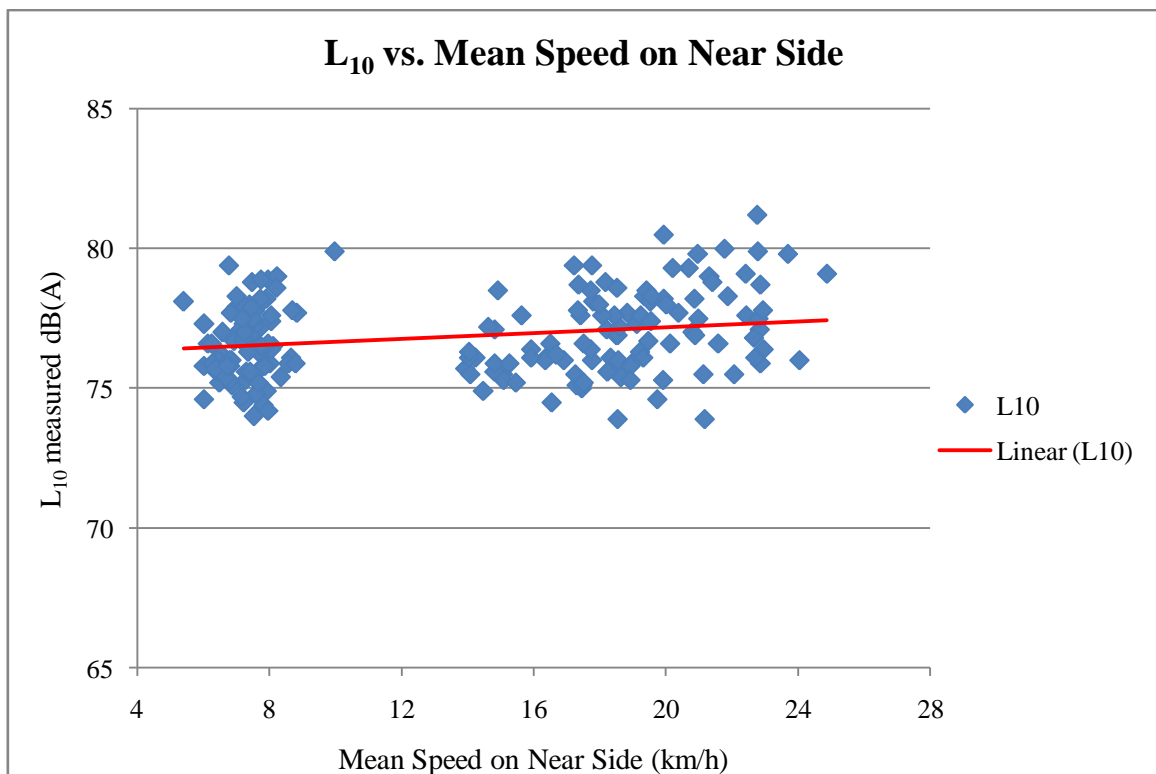
### Graph Interpretation for $L_{eq}$ :

From the graph (shown in Figure 4.5 to 4.7), it was found that, the sound level increased by 4 dB(A) as the number of vehicles varied from 700 to 900 (vehicles/hour). With an average increase in mean speed (near side) of 4 km/h there was an increase of 1.5 dB(A). With an average increase in mean speed (far side) of 4 km/h there was an increase of 1 dB(A). So, it can be said that the equivalent sound level was affected by the parameters of traffic volume for near side, traffic volume for far side, mean speed on near side and mean speed on far side.

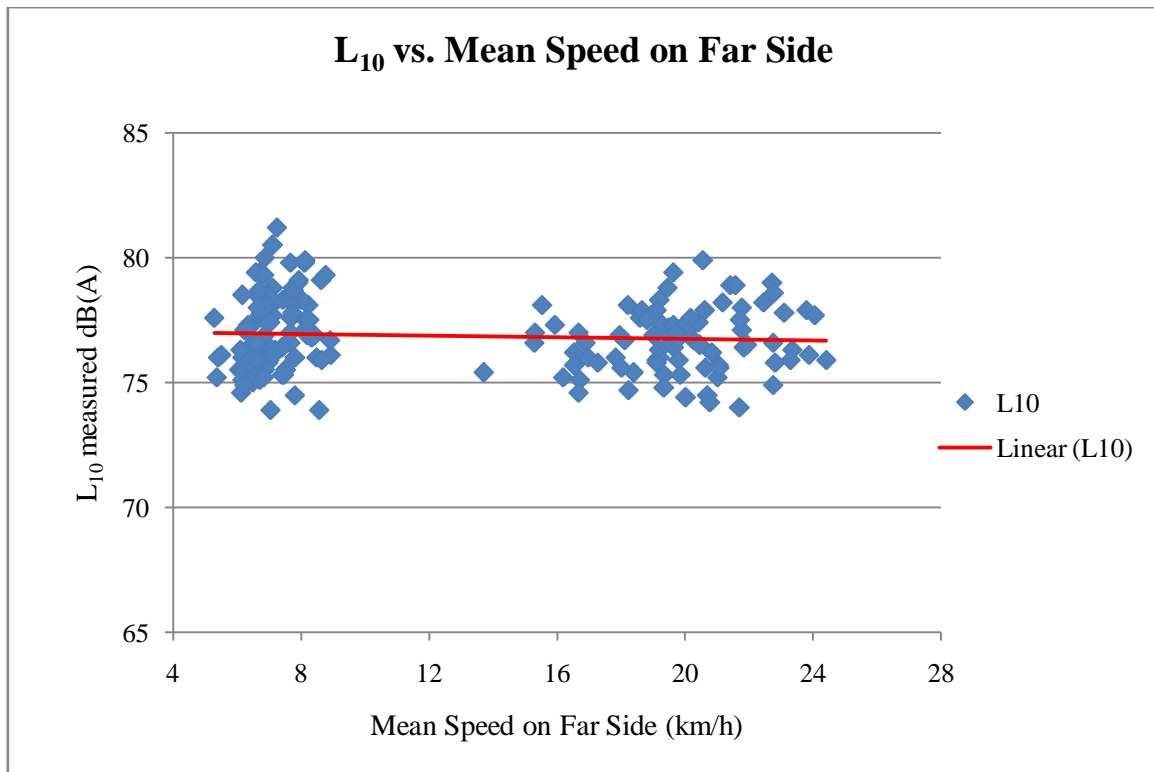
## Graphs for $L_{10}$



**Figure 4.08:**  $L_{10}$  vs Traffic Volume



**Figure 4.09:**  $L_{10}$  vs Mean Speed on Near Side

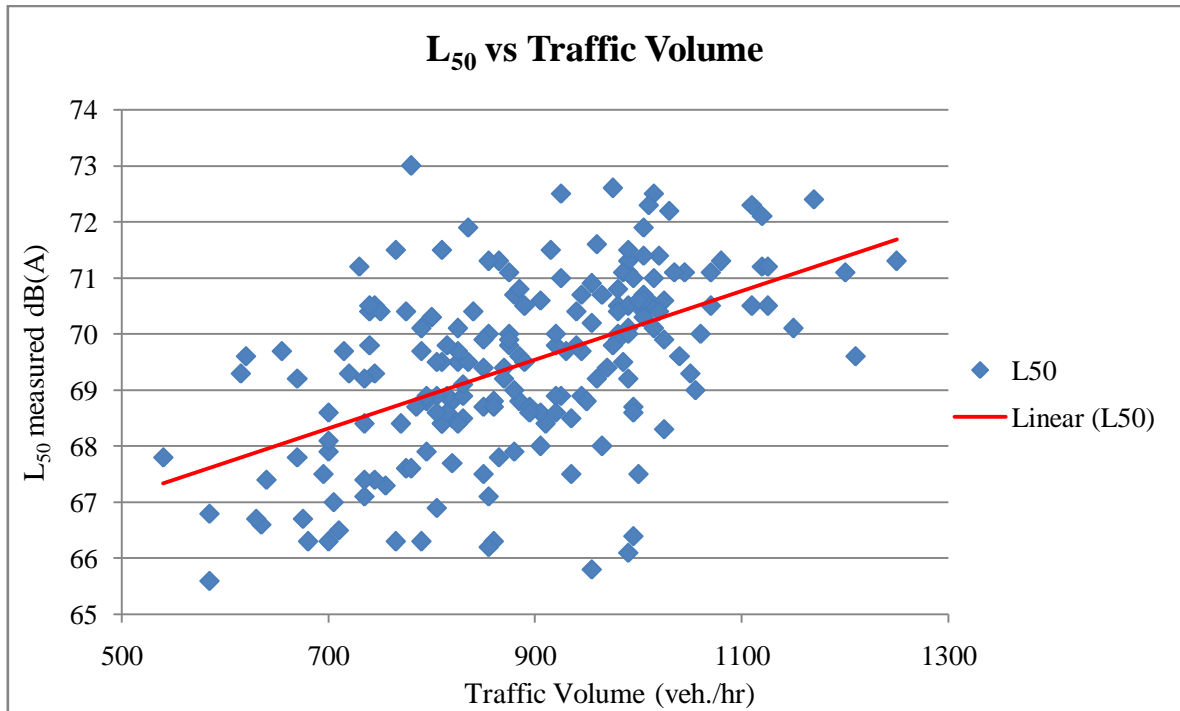


**Figure 4.10:** L<sub>10</sub> vs Mean Speed on Far Side

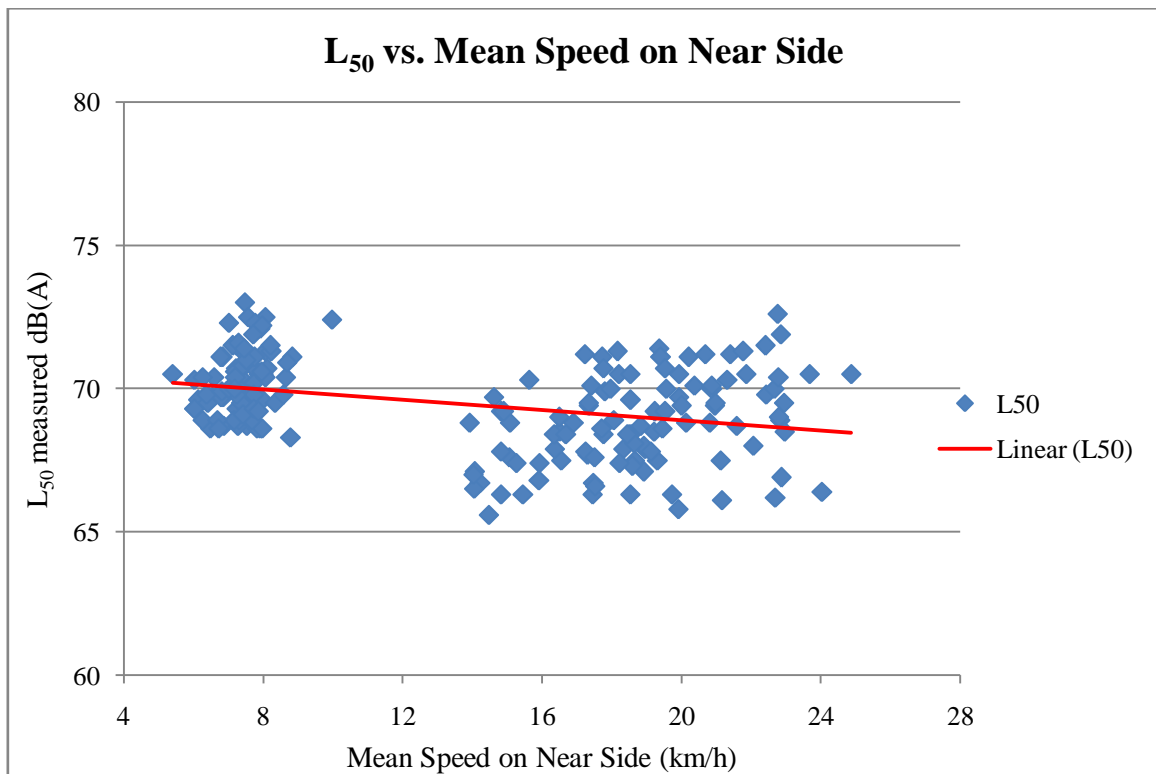
### Graph Interpretation for L<sub>10</sub>:

From the graph (shown in Figure 4.7 to 4.10), it was found that the sound level increased by 1.25 dB(A) as the number of vehicles varied from 600 to 800 (vehicles/hour). With an average increase in mean speed (near side) of 4 km/h there was an increase of 0.5 dB(A). There was a negative relation between sound level and mean speed on far side. The sound level dips by 0.25 dB(A) as there was an increase in mean speed (far side) of 4 km/h. So, it can be said that the equivalent sound level was affected by the parameters of traffic volume for near side, traffic volume for far side, mean speed on near side and mean speed on far side.

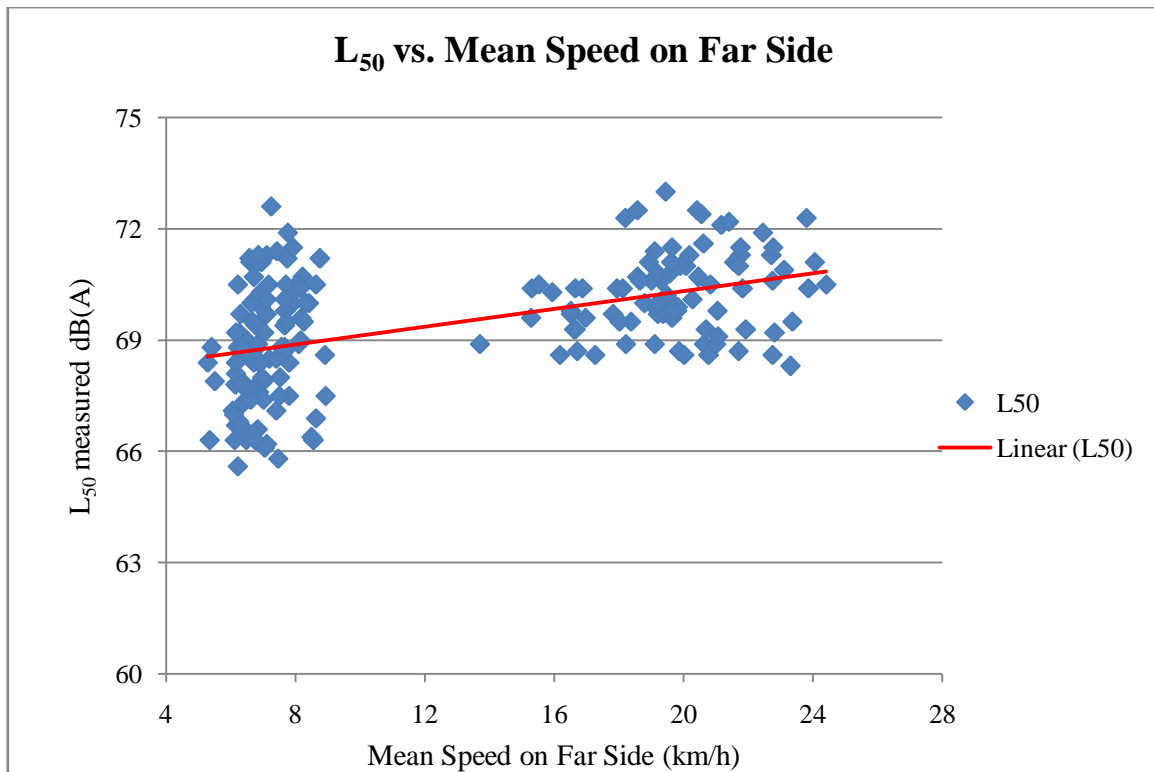
## Graphs for L<sub>50</sub>



**Figure 4.11:** L<sub>50</sub> vs Traffic Volume



**Figure 4.12:** L<sub>50</sub> vs Mean Speed on Near Side

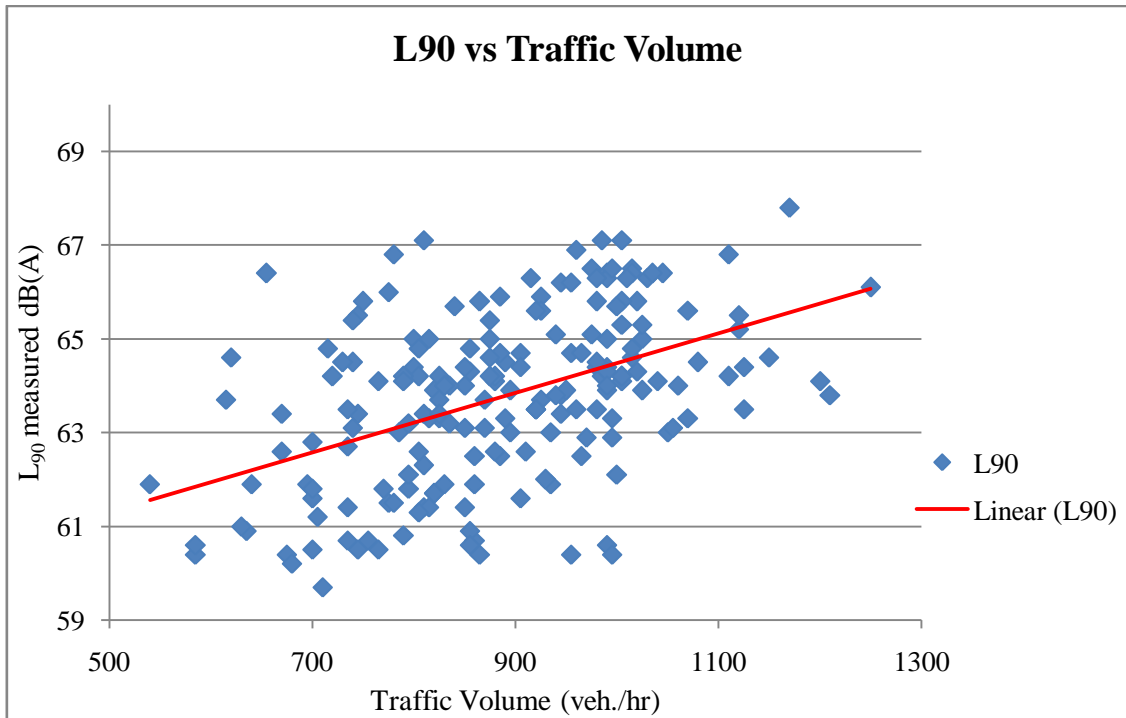


**Figure 4.13:** L<sub>50</sub> vs Mean Speed on Far Side

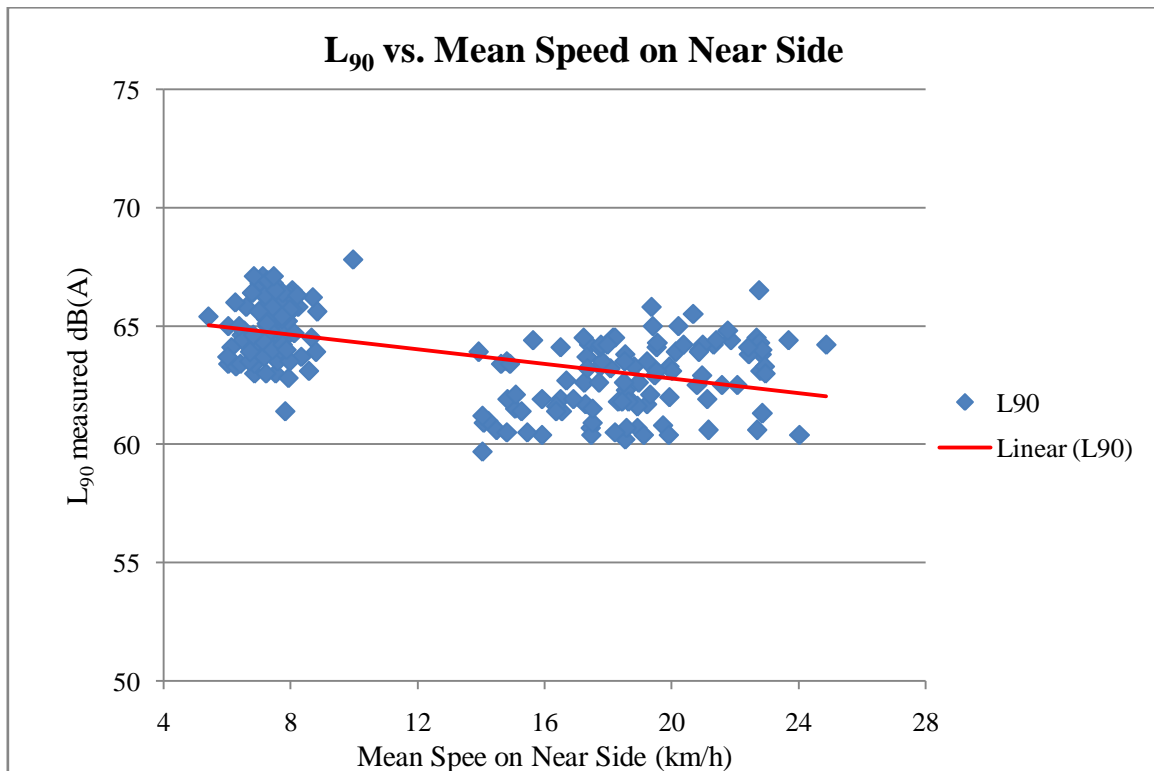
### Graph Interpretation for L<sub>50</sub>:

From the graph (shown in Figure 4.11 to 4.13), it was found that the sound level increased by 1.5 dB(A) as the number of vehicles varied from 700 to 900 (vehicles/hour). There was a negative relation between sound level and mean speed on near side. The sound level dips by 1 dB(A) as there was an increase in mean speed (far side) of 4 km/h. With an average increase in mean speed (far side) of 4 km/h there was an increase of 0.6 dB(A). So, it can be said that the equivalent sound level was affected by the parameters of traffic volume for near side, traffic volume for far side, mean speed on near side and mean speed on far side.

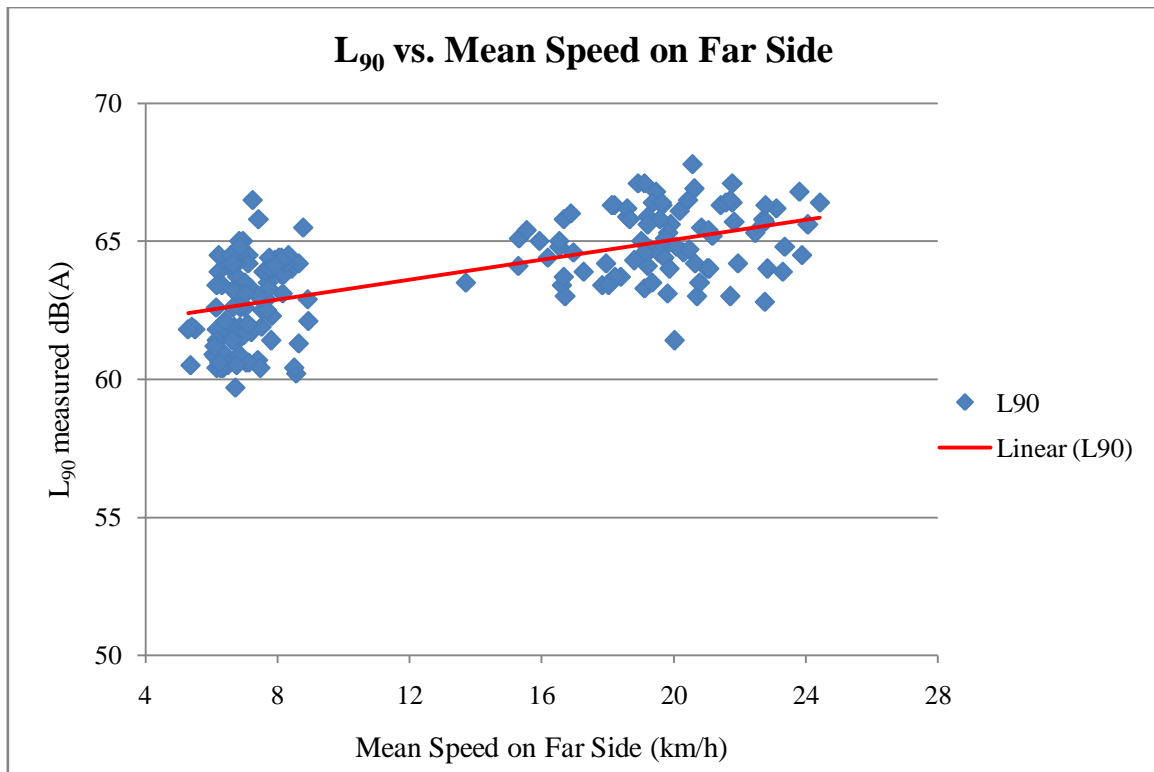
## Graphs for L<sub>90</sub>



**Figure 4.14:** L<sub>90</sub> vs Traffic Volume



**Figure 4.15:** L<sub>90</sub> vs Mean Speed on Near Side



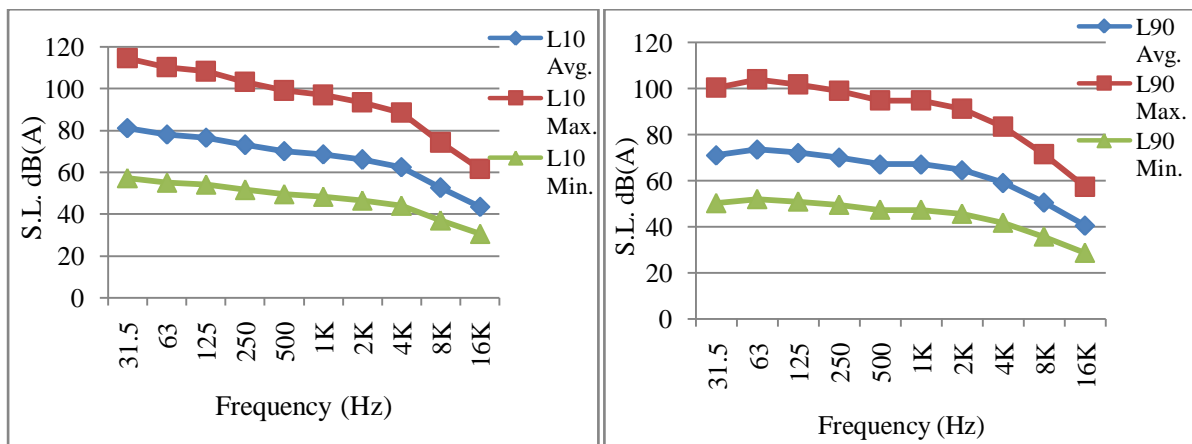
**Figure 4.16:** L<sub>90</sub> vs Mean Speed on Far Side

### Graph Interpretation for L<sub>90</sub>:

From the graph (shown in Figure 4.14 to 4.16), it was found that the sound level increased by 1.25 dB(A) as the number of vehicles varied from 700 to 900 (vehicles/hour). There was a negative relation between sound level and mean speed on near side. The sound level dips by 1 dB(A) as the increase in mean speed (far side) of 4 km/h. With an average increase in mean speed (far side) of 4 km/h there was an increase of 1.25 dB(A). So, it can be said that the equivalent sound level was affected by the parameters of traffic volume for near side, traffic volume for far side, mean speed on near side and mean speed on far side.

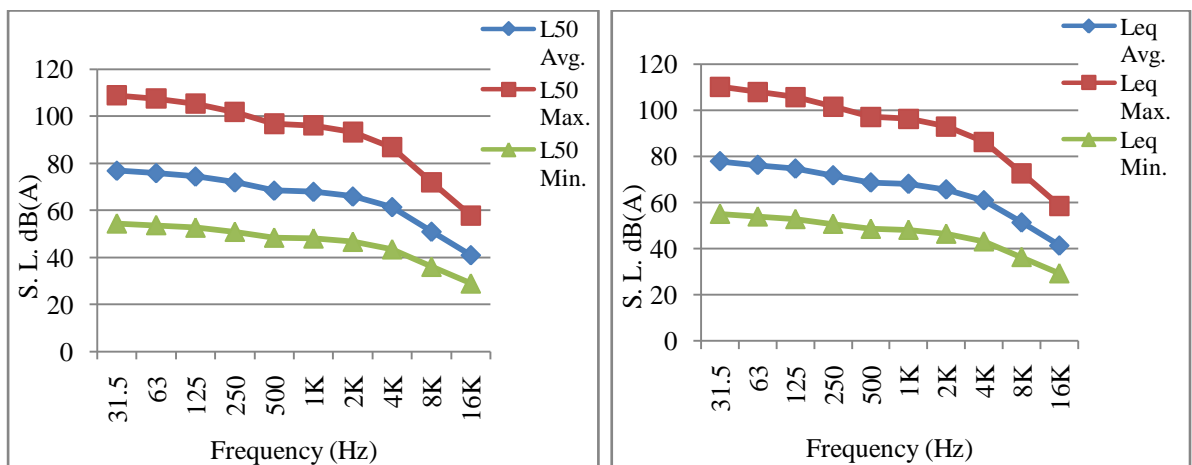
## 4.4 Frequency Analysis

Frequency analysis has been done for 1/1 Octave Band for traffic lights noise throughout a day. The data gathered for each frequency is then averaged and A-weight to each frequency band is applied. This results in a frequency spectrum that would be useful for traffic noise analysis for barrier design to reduce annoyance effect in surrounding areas and material suggestion that could be used in barriers to migrate the traffic noise level.



(a) L<sub>10</sub> (1 hour)

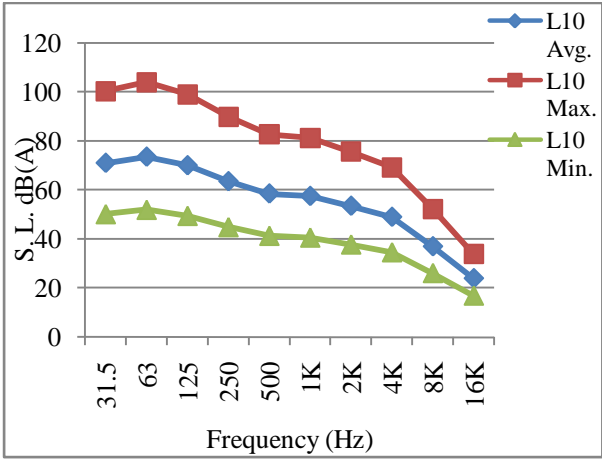
(c) L<sub>90</sub> (1 hour)



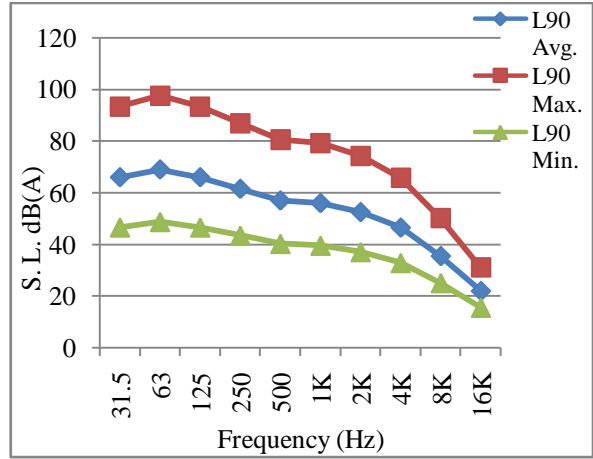
(b) L<sub>50</sub> (1 hour)

(d) L<sub>eq</sub> (1 hour)

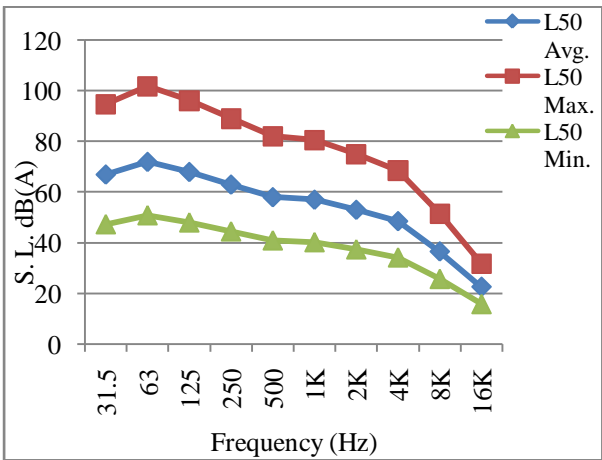
**Figure 4.17:** Sound Level vs. Frequency 1/1 Octave Band. (Position 1)



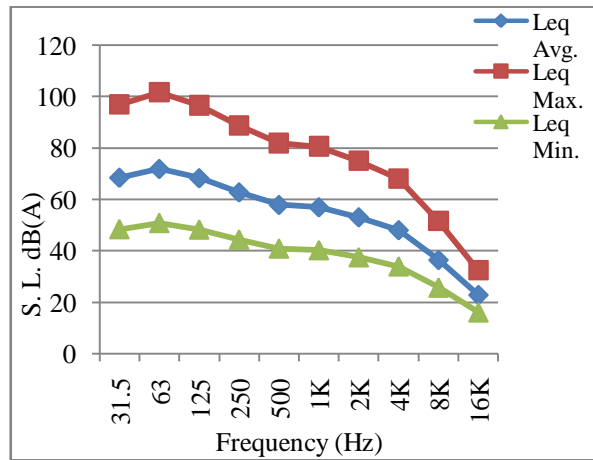
(a) L<sub>10</sub> (1 hour)



(c) L<sub>90</sub> (1 hour)

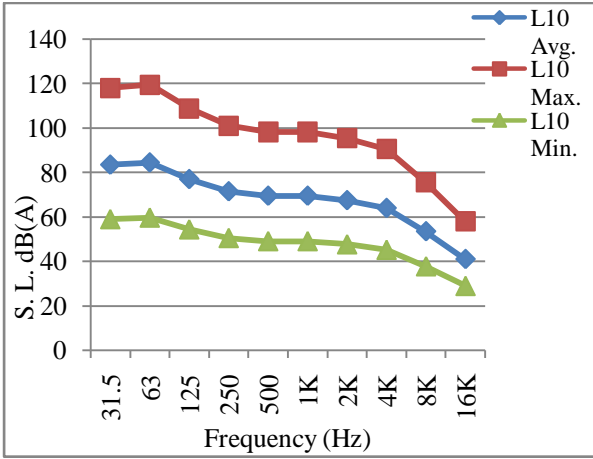


(b) L<sub>50</sub> (1 hour)

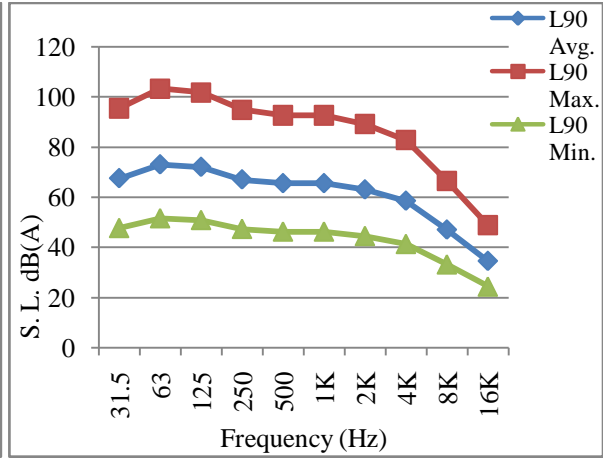


(d) L<sub>eq</sub> (1 hour)

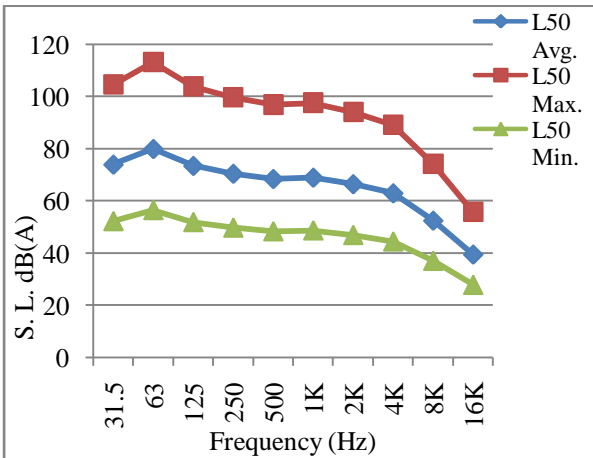
**Figure 4.18:** Sound Level vs. Frequency 1/1 Octave Band. (Position 2)



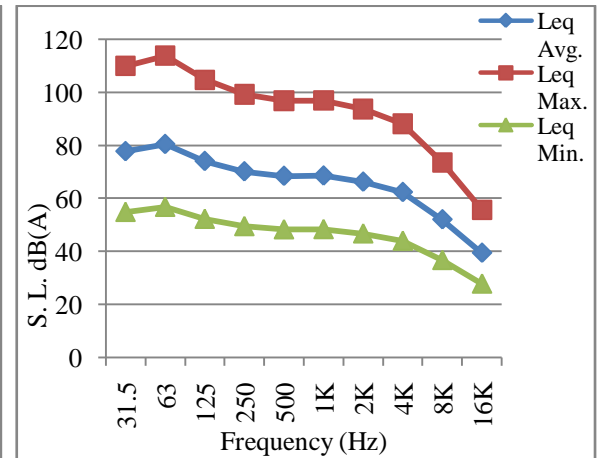
(a) L<sub>10</sub> (1 hour)



(c) L<sub>90</sub> (1 hour)

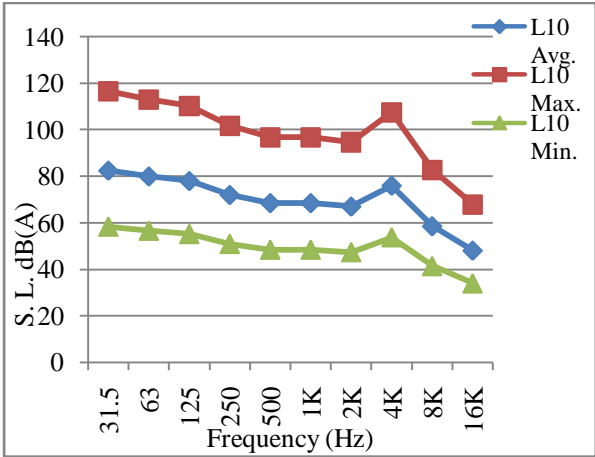


(b) L<sub>50</sub> (1 hour)

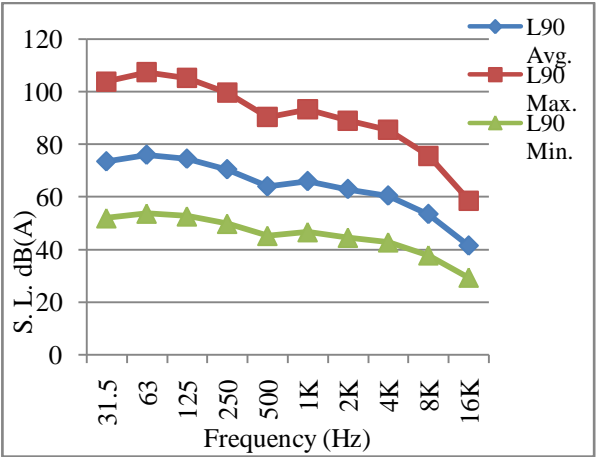


(d) L<sub>eq</sub> (1 hour)

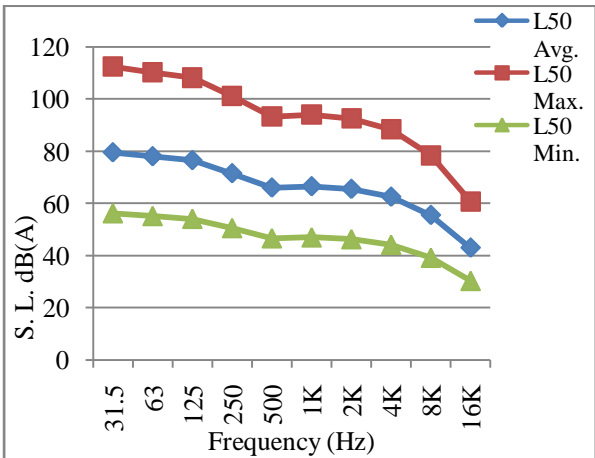
**Figure 4.19:** Sound Level vs. Frequency 1/1 Octave Band. (Position 3)



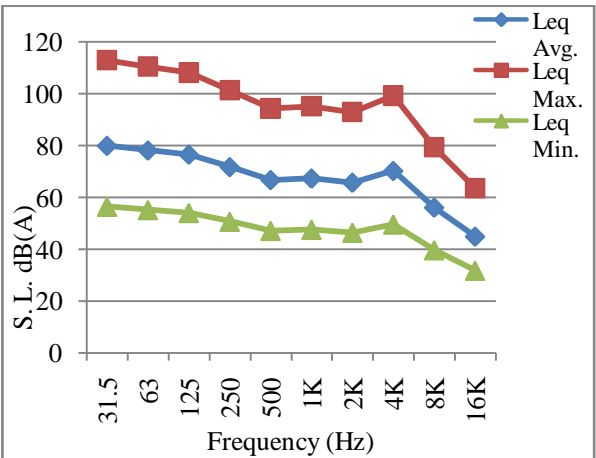
(a) L<sub>10</sub> (1 hour)



(c) L<sub>90</sub> (1 hour)



(b) L<sub>50</sub> (1 hour)



(d) L<sub>eq</sub> (1 hour)

**Figure 4.20:** Sound Level vs. Frequency 1/1 Octave Band. (Position 4)

From the frequency analysis, it was found that the main frequency (Hz) that has the most contribution to the noise and are dominating in noise spectrum are 31.5 Hz, 63 Hz, 125 Hz and 250 Hz. The data for the frequency spectrum graphs can be seen in APPENDIX-F.

**Table 4.9:** Rank assigned various freq. according to each Sound level descriptor. (Position 1)

<b>Frequency (Hz)</b>	<b>L<sub>eq</sub></b>	<b>Rank</b>	<b>L<sub>10</sub></b>	<b>Rank</b>
<b>31.5</b>	<b>77.9</b>	<b>1</b>	<b>81</b>	<b>1</b>
<b>63</b>	76.3	2	78	2
<b>125</b>	74.7	3	76.5	3
<b>250</b>	71.8	4	73	4
<b>500</b>	68.7	5	70	5
<b>1k</b>	68.1	6	68.5	6
<b>2k</b>	65.7	7	66	7
<b>4k</b>	61	8	62.5	8
<b>8k</b>	51.4	9	52.5	9
<b>16k</b>	41.4	10	43.5	10

<b>Frequency (Hz)</b>	<b>L<sub>50</sub></b>	<b>Rank</b>	<b>L<sub>90</sub></b>	<b>Rank</b>
<b>31.5</b>	<b>77</b>	<b>1</b>	71	3
<b>63</b>	76	2	<b>73.5</b>	<b>1</b>
<b>125</b>	74.5	3	72	2
<b>250</b>	72	4	70	4
<b>500</b>	68.5	5	67	5
<b>1k</b>	68	6	67	6
<b>2k</b>	66	7	64.5	7
<b>4k</b>	61.5	8	59	8
<b>8k</b>	51	9	50.5	9
<b>16k</b>	41	10	40.5	10

**Table 4.10:** Rank assigned various freq. according to each Sound level descriptor (Position 2)

<b>Frequency (Hz)</b>	<b>L<sub>eq</sub></b>	<b>Rank</b>	<b>L<sub>10</sub></b>	<b>Rank</b>
<b>31.5</b>	68.5	2	71	2
<b>63</b>	<b>71.9</b>	<b>1</b>	<b>73.5</b>	<b>1</b>
<b>125</b>	68.3	3	70	3
<b>250</b>	62.8	4	63.5	4
<b>500</b>	57.9	5	58.5	5
<b>1k</b>	57	6	57.5	6
<b>2k</b>	53.1	7	53.5	7
<b>4k</b>	48.1	8	49	8
<b>8k</b>	36.5	9	37	9
<b>16k</b>	22.9	10	24	10

<b>Frequency (Hz)</b>	<b>L<sub>50</sub></b>	<b>Rank</b>	<b>L<sub>90</sub></b>	<b>Rank</b>
<b>31.5</b>	67	3	66	3
<b>63</b>	<b>72</b>	<b>1</b>	<b>69</b>	<b>1</b>
<b>125</b>	68	2	66	2
<b>250</b>	63	4	61.5	4
<b>500</b>	58	5	57	5
<b>1k</b>	57	6	56	6
<b>2k</b>	53	7	52.5	7
<b>4k</b>	48.5	8	46.5	8
<b>8k</b>	36.5	9	35.5	9
<b>16k</b>	22.5	10	22	10

**Table 4.11:** Rank assigned various freq. according to each Sound level descriptor (Position 3)

<b>Frequency (Hz)</b>	<b>L<sub>eq</sub></b>	<b>Rank</b>	<b>L<sub>10</sub></b>	<b>Rank</b>
<b>31.5</b>	77.8	2	83.5	2
<b>63</b>	<b>80.5</b>	<b>1</b>	<b>84.5</b>	<b>1</b>
<b>125</b>	74.1	3	77	3
<b>250</b>	70.2	4	71.5	4
<b>500</b>	68.2	6	69.5	5
<b>1k</b>	68.6	5	69.5	6
<b>2k</b>	66.3	7	67.5	7
<b>4k</b>	62.4	8	64	8
<b>8k</b>	52.1	9	53.5	9
<b>16k</b>	39.5	10	41	10

<b>Frequency (Hz)</b>	<b>L<sub>50</sub></b>	<b>Rank</b>	<b>L<sub>90</sub></b>	<b>Rank</b>
<b>31.5</b>	74	2	67.5	3
<b>63</b>	<b>80</b>	<b>1</b>	<b>73</b>	<b>1</b>
<b>125</b>	73.5	3	72	2
<b>250</b>	70.5	4	67	4
<b>500</b>	68.5	6	65.5	5
<b>1k</b>	69	5	65.5	6
<b>2k</b>	66.5	7	63	7
<b>4k</b>	63	8	58.5	8
<b>8k</b>	52.5	9	47	9
<b>16k</b>	39.5	10	34.5	10

**Table 4.12** Rank assigned various freq. according to each Sound level descriptor. (Position 4)

<b>Frequency (Hz)</b>	<b>Leq</b>	<b>Rank</b>	<b>L10</b>	<b>Rank</b>
<b>31.5</b>	<b>79.9</b>	<b>1</b>	82.5	1
<b>63</b>	78.1	2	<b>80</b>	<b>2</b>
<b>125</b>	76.5	3	78	3
<b>250</b>	71.7	4	72	5
<b>500</b>	66.7	7	68.5	6
<b>1k</b>	67.3	6	68.5	7
<b>2k</b>	65.7	8	67	8
<b>4k</b>	70.2	5	76	4
<b>8k</b>	56.1	9	58.5	9
<b>16k</b>	44.9	10	48	10

<b>Frequency (Hz)</b>	<b>L50</b>	<b>Rank</b>	<b>L90</b>	<b>Rank</b>
<b>31.5</b>	<b>79.5</b>	<b>1</b>	73.5	3
<b>63</b>	78	2	<b>76</b>	<b>1</b>
<b>125</b>	76.5	3	74.5	2
<b>250</b>	71.5	4	70.5	4
<b>500</b>	66	6	64	6
<b>1k</b>	66.5	5	66	5
<b>2k</b>	65.5	7	63	7
<b>4k</b>	62.5	8	60.5	8
<b>8k</b>	55.5	9	43.5	9
<b>16k</b>	43	10	41.5	10

From the 1/1 Frequency analysis it is found that the frequencies that affect the most the analyzed sound level were found to be 31.5Hz, 63Hz, 125Hz, 250 Hz. These are the one that affect most the areas next to the traffic road areas. Also the same frequencies are known to be annoying frequencies for human hearing. So there should be some preventive steps to lower their dominance in traffic noise or prevent them from annoying in the surrounding area. From barrier design perspective a material that has absorbing coefficient that of the required frequency absorbing coefficient can be used. Some of the materials that could be suggested in building barriers are shown in Table 4.13.

**Table 4.13:** Sound absorptive coefficient of constructive materials. [11]

Materials	Sound Absorption Coefficient					
	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz
Acoustic tile, ridged mount	0.2	0.4	0.7	0.8	0.6	0.4
Acoustic tile, suspended	0.5	0.7	0.6	0.7	0.7	0.5
Drapes, medium	0.07	0.3	0.5	0.7	0.7	0.6
Fiberglass boards	0.15	0.55	0.80	0.90	0.85	0.80
Vinyl on concrete	0.02	0.03	0.03	0.03	0.03	0.02
Window glass	0.3	0.2	0.2	0.1	0.07	0.04
Brick, painted carpet, Heavy form of rubber	0.08	0.24	0.57	0.69	0.71	0.73

# Chapter 5

## Findings, Conclusions and Scope

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### 5.1 Findings

From the site measurement, it was found that on the traffic lights  $L_{eq}$  noise level varied from 60 dB(A) to 80 dB(A),  $L_{10}$  varied from 74 dB(A) to 80 dB(A),  $L_{50}$  varied from 67 dB(A) to 73 dB(A),  $L_{90}$  varied from 61 dB(A) to 68 dB(A). Traffic composition for near side varied from 640 to 3480 vehicles/hour and for far side varied from 960 to 2880 vehicles/hour. The mean speed varied maximum between 13.7 to 24.8 km/hr and minimum between 5.2 to 13.9 km/hr.

### 5.2 Conclusions

On the basis of noise measurements recorded on the site, the results were generated with the help of regression analysis. The following conclusions were drawn from the study:

1. The percentage error was found to vary between  $\pm 5$  percent. The values for Multiple R were 0.87 for  $L_{eq}$ , 0.77 for  $L_{10}$ , 0.84 for  $L_{50}$  and 0.76 for  $L_{90}$  indicate that there was a good correlation between actual and the predicted values.
2. Correlation test was carried out to find which factor is impacting the most and ranks were assigned on the basis of correlation coefficient. The best correlation was obtained to be varying between 0.5 to 0.8.
3. A t-test was also implemented to check the significant difference between the measured sound level and predicted sound level. The test expressed no significant difference between the two and 't-critical' value was greater than 't-statistical'. The mean values of measured and predicted sound level were obtained much closer.
4. Frequency Analysis for 1/1 Octave band was performed for road traffic noise. The results indicated that the frequencies that were most influenced in sound level spectrum were 125, 250, 500 and 1k Hz. The barrier design analysis should consider such materials that have more absorption coefficient to reduce the peak noise level.
5. The peak value of sound level ( $L_{10}$ ) varied from 74 dB(A) to 80 dB(A), the average value of sound level ( $L_{50}$ ) varied from 61 dB(A) to 68 dB(A), the lower/background

value of sound level ( $L_{90}$ ) varied from 61 dB(A) to 68 dB(A) and the value of equivalent sound level ( $L_{eq}$ ) varied from 60 dB(A) to 80 dB(A)

### **5.3 Future Scope**

- The present study does not consider the composition of traffic in which two-wheeler, cars and 3-wheeler, SUV's, trucks and busses can be include for better results. Also the percentage of heavy vehicles can be included.
- The mean speed was accounted on an average of number of vehicles; however speed of individual vehicle can be considered.
- The timings of traffic lights (red and green waves) and its effect on the variation of noise level can be considered.

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## APPENDIX-A – Data Collected for Traffic Light at 4 Different Positions

Sr. No.	Date	Time	Volume of Traffic		Mean Speed (km/h)		Sound Level dB(A)			
			Near	Far	Near	Far	Leq	L10	L50	L90
At Position 1										
1	30-08-2014	09:10 - 09:25	450	370	19.2	7.2	66.8	76.3	68.5	61.7
2		09:25 - 09:40	375	320	18.6	6.6	62.1	75.8	67.5	61.9
3		09:40 - 09:55	415	380	18.3	5.5	62.6	76.1	67.9	61.8
4		09:55 - 10:10	470	340	18.5	7.8	64.8	76	68.4	62.3
5		10:10 - 10:25	470	380	16.5	7.8	61.6	74.5	67.5	61.4
6		10:25 - 10:40	395	490	20.8	7.6	72.2	77	68.8	62.5
7	01-09-2014	03:00 - 03:15	440	380	13.9	6.2	62	75.7	68.8	63.9
8		03:15 - 03:30	470	390	17.4	6.4	66.8	75	66.3	60.7
9		03:30 - 03:45	425	350	15.0	6.8	62.1	75.5	67.6	61.5
10		03:45 - 04:00	475	380	14.0	6.0	64.6	75.5	67.1	60.9
11		04:00 - 04:15	410	410	17.3	6.7	69.5	75.1	67.7	61.7
12		04:15 - 04:30	440	525	22.0	7.5	82.9	75.5	68	62.5
13		04:30 - 04:45	160	380	14.8	6.8	64.1	75.6	67.8	61.9
14	02-09-2014	09:00 - 09:15	510	490	19.3	8.9	73.8	76.1	67.5	62.1
15		03:00 - 03:15	520	310	16.5	6.2	59.8	76.2	68.5	61.9
16	03-09-2014	09:20 - 09:35	280	360	15.9	7.0	65.1	76.4	67.4	61.9
17		09:35 - 09:50	350	320	17.2	6.1	61.5	75.5	67.8	62.6
18		09:50 - 10:05	390	490	18.9	7.0	76.6	75.9	67.9	62.6
19		10:05 - 10:20	445	525	20.9	7.6	81.1	79.8	69.4	62.9
20		10:20 - 10:35	425	480	18.9	6.9	72.6	75.8	68	61.6
21		10:35 - 10:50	470	440	18.5	6.8	68.8	76.9	68.4	62.6
22		03:00 - 03:15	445	255	16.3	6.3	63.1	76.1	67.9	61.6
23		03:15 - 03:30	445	490	21.1	7.5	81	75.5	67.5	61.9
24	04-09-2014	10:00 - 10:15	425	520	22.8	8.1	87.4	77.1	68.9	63.8
25		10:15 - 10:30	470	525	18.8	6.7	72.8	77.7	68.7	63.3
26		10:30 - 10:45	470	480	20.1	7.5	69.4	76.6	68.8	63.9
27		10:45 - 11:00	490	390	16.5	6.5	66.5	76.6	69	64.1
28	05-09-2014	10:00 - 10:15	570	510	18.1	7.1	73.3	78.8	71.3	64.5
29		10:15 - 10:30	530	490	19.3	7.4	69.9	78.3	71.4	65.8

30		10:30 - 10:45	500	390	18.2	6.2	68.2	77.1	70.5	64.5
31		10:15 - 11:00	550	440	19.4	6.9	77.9	78.5	71.1	65
32	06-09-2014	09:00 - 09:15	370	330	18.6	6.1	63.5	75.4	68.1	61.8
33		09:15 - 09:30	520	540	20.8	8.4	81.6	76.9	70	64
34		09:30 - 09:45	480	320	15.6	6.9	63.3	77.6	70.3	64.4
35		09:45 - 10:00	530	540	19.9	7.1	71.4	78.2	70.5	63.3
36		10:00 - 10:15	510	495	19.5	8.2	75.7	78.1	70.7	64.1
37		10:15 - 10:30	550	660	18.5	8.1	74.8	76.9	69.6	63.8
38		03:30 - 03:45	480	345	17.7	6.7	64.8	76	68.4	63.3
39		03:45 - 04:00	485	370	19.5	7.9	68.1	78.3	70	64.3
40		04:00 - 04:15	515	480	19.4	8.9	74.8	76.7	68.6	62.9
41		04:15 - 04:30	480	330	16.3	6.1	62.4	76	68.4	61.4
42		04:30 - 04:45	480	380	16.9	5.4	65.1	76	68.8	61.9
43		04:45 - 05:00	480	315	15.0	6.4	60.2	75.3	68.8	62.1
44		07-09-2014	09:00 - 09:15	330	345	17.4	6.1	63.1	75.1	66.7
45	09:15 - 09:30		495	495	21.1	7.0	80.9	73.9	66.1	60.6
46	09:30 - 09:45		260	375	17.5	6.8	65.9	75.2	66.6	60.9
47	09:45 - 10:00		280	510	19.7	6.1	76.7	74.6	66.3	60.8
48	03:00 - 03:15		310	370	18.5	8.5	64.7	73.9	66.3	60.2
49	03:15 - 03:30		345	390	18.9	7.4	66.2	75.3	67.1	60.7
50	03:30 - 03:45		345	410	18.5	6.3	66.9	77.2	67.3	60.7
51	03:45 - 04:00		425	345	18.4	5.2	65.5	77.6	68.4	61.8
52	04:00 - 04:15		445	420	19.1	6.3	68	77.3	67.8	60.4
53	04:15 - 04:30		415	330	18.2	6.5	64.6	75.6	67.4	60.5
54	04:30 - 04:45	470	460	19.9	7.1	72.6	80.5	69.7	62	
At Position 2										
55	09-09-2014	10:00 - 10:15	550	465	7.4	20.2	69.3	76.7	70.1	64.6
56		10:15 - 10:30	525	490	7.6	20.0	69.3	77.1	71	64.8
57		10:30 - 10:45	430	510	7.3	15.3	65.7	77	70.4	65.1
58		10:45 - 11:00	400	345	7.8	20.8	68.7	76.2	70.5	65.5
59		03:00 - 03:15	400	315	6.5	16.5	63	76.2	69.7	64.8
60		03:15 - 03:30	415	330	6.0	16.6	62.3	75.8	69.3	63.4
61		03:30 - 03:45	275	345	6.4	16.9	63.6	76	69.6	64.6
62		03:45 - 04:00	495	390	7.9	19.6	71.6	76.4	69.6	64.7

63		04:00 - 04:15	475	480	7.7	19.5	69.6	77.2	70.2	64.7	
64		04:15 - 04:30	470	435	7.3	19.3	68	77.3	70.6	64.7	
65	10-09-2014	09:30 - 09:45	500	515	8.0	20.4	73.5	77.4	72.5	66.5	
66		09:45 - 10:00	525	480	7.3	17.9	69.8	76.9	70.4	64.2	
67		10:00 - 10:15	495	495	7.4	21.7	71.7	78	71.3	66.4	
68		10:15 - 10:30	540	240	7.4	19.4	71.5	78.8	73	66.8	
69		10:30 - 10:45	520	405	7.5	18.5	71.3	77.8	72.5	65.9	
70		03:30 - 03:45	430	720	7.2	19.5	70.5	76.6	70.1	64.6	
71		03:45 - 04:00	445	450	7.5	21.7	72	74	68.7	63	
72		04:00 - 04:15	495	410	6.4	16.1	65.4	75.2	68.6	64.4	
73		04:15 - 04:30	515	525	6.1	15.2	62.9	76.6	69.6	64.1	
74		04:30 - 04:45	560	405	8.1	20.4	74.8	76.5	70.7	64.7	
75		04:45 - 05:00	590	660	8.0	20.1	74.2	77.6	71.3	66.1	
76		11-09-2014	09:00 - 09:15	595	420	8.0	24.4	73.1	75.9	70.5	66.4
77			09:15 - 09:30	625	495	7.9	21.1	70.7	78.2	72.1	65.2
78			09:30 - 09:45	575	435	7.7	18.2	69.1	78.1	72.3	66.3
79	09:45 - 10:00		660	510	9.9	20.5	80.4	79.9	72.4	67.8	
80	10:00 - 10:15		550	480	7.9	21.4	72.1	78.9	72.2	66.3	
81	10:15 - 10:30		485	540	7.2	19.0	69.4	76.9	70.6	65	
82	03:30 - 03:45		365	420	6.8	16.7	65.3	75.1	68.7	63	
83	03:45 - 04:00		415	410	8.3	18.3	75	75.4	69.5	63.7	
84	04:00 - 04:15		380	435	6.2	19.1	65.6	75.9	68.9	63.3	
85	04:15 - 04:30		460	390	6.9	19.7	68.8	76.7	69.9	64.4	
86	04:30 - 04:45		430	420	7.2	19.8	72.4	75.3	68.7	64	
87	04:45 - 05:00	555	450	7.7	22.4	73	78.2	71.9	65.3		
88	12-09-2014	10:00 - 10:15	690	420	7.0	23.8	71.7	77.9	72.3	66.8	
89		10:15 - 10:30	570	420	7.2	19.6	69.8	77.3	71.5	66.3	
90		10:30 - 10:45	450	415	8.2	22.7	75.8	79	71.3	65.8	
91		10:45 - 11:00	420	390	7.1	21.7	71.9	77.1	71.5	67.1	
92	13-09-2014	03:00 - 03:15	350	390	8.6	23.8	75.7	76.1	70.4	64.5	
93		03:15 - 03:30	345	310	6.7	19.3	68.2	75.3	69.7	66.4	
94		03:30 - 03:45	385	315	7.9	22.7	73.8	74.9	68.6	62.8	
95		03:45 - 04:00	365	375	8.5	19.8	75.8	75.9	69.8	63.1	
96		04:00 - 04:15	415	390	7.3	20.6	69.5	75.6	68.9	64.2	

97		04:15 - 04:30	515	405	7.5	19.3	70.8	74.8	69.8	63.5
98		04:30 - 04:45	555	390	6.8	17.8	66.4	76	69.7	63.4
99		04:45 - 05:00	630	420	7.2	20.7	71.6	74.5	69.3	63
100	14-09-2014	10:00 - 10:15	370	555	7.1	18.2	69.6	74.7	68.9	63.7
101		10:15 - 10:30	430	380	6.4	18.0	66	75.6	69.5	63.4
102		10:30 - 10:45	350	465	7.8	20.0	72.6	74.4	68.6	61.4
103		10:45 - 11:00	395	525	7.9	20.7	74.6	74.2	68.6	63.5
104		03:00 - 03:15	250	365	6.0	16.6	63.4	74.6	69.3	63.7
At Position 3										
105	15-09-2014	03:00 - 03:15	600	510	24.8	8.6	80.1	79.1	70.5	64.2
106		03:15 - 03:30	500	480	23.6	8.1	78.7	79.8	70.5	64.4
107		03:30 - 03:45	380	355	14.8	6.2	61.3	77.1	69.2	63.5
108		03:45 - 04:00	475	465	22.4	7.7	74.1	77.6	69.8	63.8
109		04:00 - 04:15	525	465	21.8	8.0	72.8	78.3	70.5	64.4
110		04:15 - 04:30	540	465	21.3	7.9	71.4	79	70.3	64.2
111		04:30 - 04:45	515	540	22.8	8.1	74.4	77.5	69	63.1
112	04:45 - 05:00	535	585	20.6	8.7	70.9	79.3	71.2	65.5	
113	16-09-2014	03:00 - 03:15	480	310	17.4	6.7	66.1	77.6	70.1	64.2
114		03:15 - 03:30	440	385	14.6	6.3	62.7	77.2	69.7	63.4
115		03:30 - 03:45	300	495	18.0	6.8	67.7	77.6	68.9	63.2
116		03:45 - 04:00	515	465	17.8	6.9	66.6	78.1	69.9	63.5
117		04:00 - 04:15	515	470	20.9	8.2	74.2	77.5	69.5	64.2
118		04:15 - 04:30	480	500	22.6	8.3	78.3	76.8	70	64.5
119		04:30 - 04:45	525	345	17.3	6.7	65	77.8	69.4	63.7
120	17-09-2014	09:30 - 09:45	780	345	18.5	7.7	68.9	78.6	70.5	63.5
121		09:45 - 10:00	870	255	21.4	7.7	72	78.8	71.2	64.4
122		10:00 - 10:15	870	330	17.7	6.6	65.6	78.5	71.1	64.1
123		10:15 - 10:30	525	300	20.3	7.1	70.8	77.7	70.1	64.2
124		10:30 - 10:45	675	285	19.2	7.0	68.8	77.6	69.2	63.5
125		10:45 - 11:00	720	300	22.7	8.1	78.9	79.9	70.4	64.3
126		11:00 - 11:15	475	375	20.0	6.8	69.5	78	69.4	63.1
127		11:15 - 11:30	530	350	17.7	6.7	65.6	79.4	70.7	64.2
128	18-09-2014	09:45 - 10:00	415	255	14.9	6.1	62	78.5	69.2	63.4
129		10:00 - 10:15	415	315	17.2	6.5	66.2	79.4	71.2	64.5

130		10:15 - 10:30	660	330	20.8	7.6	71.3	78.2	70.1	63.9
131		10:30 - 10:45	525	310	17.3	6.6	65.6	78.7	69.5	63.2
132		10:45 - 11:00	480	395	17.9	6.6	66.6	78	70	64.2
133		11:00 - 11:15	495	380	20.2	6.8	70	79.3	71.1	65
134		03:15 - 03:30	300	435	16.6	6.9	64.8	76.2	68.4	62.7
135		03:30 - 03:45	435	370	17.7	6.6	65.6	76.4	68.6	62.6
136		03:45 - 04:00	425	465	22.9	7.7	78.5	77.8	69.5	63.3
137		04:00 - 04:15	395	465	21.5	7.6	71.8	76.6	68.7	62.5
138		04:15 - 04:30	470	465	22.9	7.4	75.9	76.4	68.5	63
139		04:30 - 04:45	440	430	19.5	7.0	69.1	77.4	69.2	63.1
140	19-09-2014	10:30 - 10:45	525	310	22.8	7.7	76.5	78.7	71.9	64
141		10:45 - 11:00	480	285	22.4	7.9	76.2	79.1	71.5	64.1
142		11:00 - 11:15	615	240	21.7	6.8	76.5	80	71.3	64.8
143		11:15 - 11:30	735	240	22.7	7.2	78.1	81.2	72.6	66.5
144	21-09-2014	09:30 - 09:45	415	580	24.0	8.5	82.3	76	66.4	60.4
145		09:45 - 10:00	375	255	14.2	6.3	62.6	76.1	66.7	61
146		10:00 - 10:15	380	330	14.0	6.7	61.2	76.1	66.5	59.7
147		10:15 - 10:30	395	410	22.8	8.6	76.1	75.9	66.9	61.3
148		10:30 - 10:45	300	285	15.9	6.2	63.5	76.1	66.8	60.4
149		10:45 - 11:00	400	300	15.4	5.3	62.1	75.2	66.3	60.5
150		11:00 - 11:15	420	360	17.5	6.6	66.3	76.6	67.6	61.5
151		03:00 - 03:15	300	285	14.4	6.2	63.3	74.9	65.6	60.6
152		03:15 - 03:30	435	420	22.7	7.1	78.1	76.1	66.2	60.6
153		03:30 - 03:45	460	495	19.9	7.4	69.2	75.3	65.8	60.4
154		03:45 - 04:00	445	320	14.8	6.7	62.5	75.9	66.3	60.5
155		04:00 - 04:15	380	325	14.0	6.1	60.9	76.3	67	61.2
156		04:15 - 04:30	300	435	15.2	6.6	63.4	75.9	67.4	61.4
At Position 4										
157	23-09-2014	03:30 - 03:45	555	330	7.6	19.2	72	76.3	70.8	65.9
158		03:45 - 04:00	510	435	7.2	18.5	70.7	77.6	70.7	66.2
159		04:00 - 04:15	485	315	6.0	15.9	63.6	77.3	70.3	65
160		04:15 - 04:30	385	540	7.5	19.9	71.3	77.2	71	65.6
161		04:30 - 04:45	510	495	7.2	18.6	69	77.9	70.6	65.8

162	24-09-2014	03:00 - 03:15	350	570	6.6	13.7	65	75.4	68.9	63.5
163		03:15 - 03:30	420	420	8.0	21.8	74	76.4	70.4	65.7
164		03:30 - 03:45	510	240	6.5	16.6	65.1	77	70.4	65.8
165		03:45 - 04:00	500	480	7.4	19.5	69.4	76.9	70.8	65.8
166		04:00 - 04:15	500	480	7.2	18.1	69.4	76.7	70.4	66.3
167		04:15 - 04:30	510	490	7.9	22.7	73	76.6	70.6	65.7
168	25-09-2014	09:30 - 09:45	400	390	6.7	19.2	67.7	76	69.7	64.1
169		09:45 - 10:00	400	475	7.7	21.0	72.5	75.7	69.8	65.4
170		10:00 - 10:15	395	420	6.3	16.5	64.3	75.7	69.8	65
171		10:15 - 10:30	350	525	6.8	19.1	68.2	75.8	69.9	64.6
172		10:30 - 10:45	350	675	7.2	19.8	69.3	76.8	69.9	65.3
173		10:45 - 11:00	350	720	8.8	24.0	82.6	77.7	71.1	65.6
174		04:00 - 04:15	415	480	6.7	17.2	65.6	75.8	68.6	63.9
175		04:15 - 04:30	350	480	7.6	21.0	72.8	75.2	68.9	64
176		04:30 - 04:45	385	420	7.3	23.3	70.4	76.3	69.5	64.8
177		04:45 - 05:00	480	495	7.2	19.7	69.5	77	69.8	65.1
178	26-09-2014	10:00 - 10:15	395	560	8.6	23.1	84.8	77.8	70.9	66.2
179		10:15 - 10:30	385	660	7.7	21.5	73.2	78.9	71.1	66.4
180		10:30 - 10:45	475	510	6.8	18.9	67.2	77.7	71.1	67.1
181		10:45 - 11:00	450	510	7.2	20.6	71	77.9	71.6	66.9
182		03:00 - 03:15	475	520	7.5	21.7	72.1	77.5	71	66.5
183		03:15 - 03:30	415	325	5.4	15.5	60.4	78.1	70.5	65.4
184		03:30 - 03:45	445	330	6.2	16.8	64.1	76.6	70.4	66
185		03:45 - 04:00	485	435	7.0	19.2	68.7	78.3	70	65.6
186		04:00 - 04:15	465	525	7.1	18.8	68.9	77.5	70	64.3
187		04:15 - 04:30	465	540	7.4	19.1	71.7	77.9	71.4	67.1
188		04:30 - 04:45	540	495	6.7	19.6	67.2	79.4	71.1	66.4
189		04:45 - 05:00	585	330	8.2	22.7	73.3	78.6	71.5	66.3
190		28-09-2014	10:00 - 10:15	415	610	8.7	23.3	78	75.9	68.3
191	10:15 - 10:30		485	345	7.4	21.0	69.1	75.6	69.1	64
192	10:30 - 10:45		480	240	7.7	21.9	72.3	76.5	69.3	64.2
193	10:45 - 11:00		510	480	7.8	22.8	73.2	75.8	69.2	64

## APPENDIX-B – Data Samples ‘t-test’ & Percentage Error for $L_{eq}$

S. No.	Measured $L_{eq}$ dB(A)	Predicted $L_{eq}$ dB(A)	Percentage (%) Error
1	64.1	68.0	6.2
2	66.9	70.2	4.9
3	63.9	63.1	-1.2
4	72.2	68.9	-4.6
5	73.8	73.9	0.1
6	59.8	64.2	7.4
7	67.7	66.8	-1.4
8	74.2	71.6	-3.5
9	72.1	68.9	-4.4
10	74.0	71.8	-3.0
11	72.3	70.2	-3.0
12	70.0	70.0	0.1
13	75.3	73.6	-2.2
14	66.5	69.2	4.1
15	65.6	66.2	0.9
16	72.0	69.3	-3.8
17	65.8	68.6	4.3
18	68.4	69.4	1.5
19	68.3	69.7	2.1
20	65.1	64.9	-0.4
21	70.6	70.0	-0.9
22	71.7	70.6	-1.5
23	71.5	69.8	-2.4
24	71.3	72.9	2.3
25	69.3	68.4	-1.3
26	73.3	73.8	0.7
27	70.8	71.9	1.6
28	70.2	67.1	-4.4
29	70.0	70.0	0.1
30	72.3	72.7	0.6
31	73.4	71.8	-2.2
32	69.6	69.3	-0.3
33	70.7	69.7	-1.4
34	63.4	62.8	-0.9
35	73.6	74.8	1.7
36	72.4	76.6	5.9
37	65.8	66.6	1.2

S. No.	Measured $L_{eq}$ dB(A)	Predicted $L_{eq}$ dB(A)	Percentage (%) Error
38	72.5	73.2	0.9
39	69.3	70.2	1.3
40	70.7	70.7	0.0
41	66.5	66.4	-0.1
42	67.4	68.3	1.4
43	69.6	70.2	0.8
44	72.3	74.2	2.6
45	76.8	73.9	-3.8
46	68.7	67.4	-1.9
47	67.0	66.0	-1.5
48	68.3	67.8	-0.7
49	62.2	62.2	0.1
50	71.4	68.5	-4.0
51	68.0	67.5	-0.7
52	68.4	67.3	-1.6
53	71.2	71.8	0.8
54	70.1	70.1	0.0
55	71.1	71.7	0.8
56	69.6	70.9	1.8
57	74.1	73.5	-0.8
58	66.3	66.6	0.3
59	70.3	71.0	1.1
60	73.2	74.0	1.1

### APPENDIX-C – Data Samples for ‘t-test’ & Percentage Error for L<sub>10</sub>

S. No.	Measured L <sub>10</sub> dB(A)	Predicted L <sub>10</sub> dB(A)	Percentage (%) Error
1	76.1	76.5	0.6
2	75.8	76.8	1.3
3	75.4	76.5	1.4
4	75.4	76.9	2.0
5	76.1	77.6	2.0
6	76.2	77.2	1.3
7	75.9	76.1	0.2
8	77.5	77.0	-0.6
9	75.8	76.8	1.3
10	77.0	77.1	0.1
11	78.2	77.6	-0.8
12	77.0	77.1	0.1
13	77.5	77.8	0.3
14	77.2	77.1	0.0
15	76.0	77.0	1.3
16	74.5	76.1	2.2
17	76.0	76.2	0.3
18	77.8	76.8	-1.3
19	76.8	76.7	0.0
20	76.1	75.9	-0.2
21	76.8	76.7	-0.2
22	77.2	77.2	0.0
23	78.2	77.0	-1.5
24	75.3	76.6	1.8
25	76.5	77.2	1.0
26	78.0	78.0	-0.1
27	77.9	77.2	-1.0
28	75.3	76.0	1.0
29	76.5	76.6	0.1
30	77.8	77.3	-0.7
31	75.6	75.9	0.5
32	75.2	77.2	2.6
33	74.7	76.1	1.8
34	74.6	74.8	0.2
35	78.4	77.5	-1.2
36	78.5	77.9	-0.7
37	77.6	76.6	-1.3

S. No.	Measured L <sub>10</sub> dB(A)	Predicted L <sub>10</sub> dB(A)	Percentage (%) Error
38	77.4	77.4	0.1
39	78.4	79.1	0.9
40	78.7	78.1	-0.8
41	78.7	77.1	-2.0
42	78.7	77.4	-1.7
43	76.8	76.4	-0.5
44	76.8	76.9	0.2
45	79.8	78.2	-2.0
46	76.1	76.2	0.2
47	76.0	76.2	0.3
48	75.6	76.4	1.2
49	76.1	75.7	-0.5
50	77.0	77.2	0.4
51	77.5	76.6	-1.2
52	76.4	76.5	0.1
53	76.7	76.9	0.3
54	75.9	76.0	0.1
55	76.5	76.0	-0.7
56	76.1	76.3	0.3
57	78.1	76.6	-1.9
58	77.6	76.5	-1.5
59	78.4	77.3	-1.4
60	76.0	76.7	1.0

## APPENDIX-D – Data Samples for ‘t-test’ & Percentage Error for L<sub>50</sub>

S. No.	Measured L <sub>50</sub> dB(A)	Predicted L <sub>50</sub> dB(A)	Percentage (%) Error
1	68.1	68.2	0.1
2	68.2	68.6	0.6
3	67.5	68.4	1.4
4	67.8	68.7	1.3
5	67.5	69.6	3.1
6	68.5	69.2	0.9
7	67.7	67.8	0.2
8	68.6	68.7	0.2
9	67.7	68.5	1.2
10	68.9	68.8	0.0
11	71.1	69.4	-2.3
12	69.7	68.9	-1.2
13	70.2	69.7	-0.7
14	69.2	69.0	-0.3
15	68.7	68.9	0.3
16	66.4	67.7	2.0
17	67.3	67.9	0.9
18	68.3	68.5	0.3
19	70.5	70.3	-0.3
20	69.6	69.3	-0.3
21	69.9	70.2	0.4
22	71.5	70.7	-1.0
23	72.3	70.7	-2.2
24	69.4	70.2	1.2
25	70.1	70.7	1.0
26	71.8	71.8	-0.1
27	71.4	70.8	-0.8
28	69.1	69.3	0.3
29	69.9	70.2	0.6
30	71.7	71.2	-0.7
31	69.6	69.5	-0.2
32	69.4	70.8	2.0
33	68.9	69.5	0.9
34	69.3	68.0	-1.9
35	70.0	69.2	-1.2
36	70.3	69.7	-0.8
37	69.7	68.5	-1.7

S. No.	Measured L <sub>50</sub> dB(A)	Predicted L <sub>50</sub> dB(A)	Percentage (%) Error
38	69.6	69.2	-0.6
39	70.7	71.2	0.7
40	69.9	70.0	0.1
41	70.2	69.0	-1.6
42	70.2	69.2	-1.4
43	68.8	68.1	-1.1
44	68.8	68.5	-0.4
45	71.8	69.9	-2.6
46	66.5	68.0	2.2
47	66.9	67.8	1.4
48	66.0	68.2	3.4
49	67.2	67.6	0.6
50	70.8	70.9	0.2
51	70.6	70.0	-0.8
52	70.1	69.9	-0.3
53	70.5	70.5	0.0
54	69.8	69.5	-0.4
55	70.2	69.4	-1.1
56	69.2	69.8	0.9
57	71.2	70.2	-1.4
58	70.5	70.0	-0.7
59	71.0	71.0	-0.1
60	69.0	70.5	2.1

## APPENDIX-E – Data Samples for ‘t-test’ & Percentage Error for L<sub>90</sub>

S. No.	Measured L <sub>90</sub> dB(A)	Predicted L <sub>90</sub> dB(A)	Percentage (%) Error
1	61.9	62.1	0.3
2	62.0	62.6	1.1
3	61.8	62.4	1.1
4	62.0	62.7	1.1
5	62.1	63.6	2.4
6	61.9	63.0	1.7
7	62.4	61.9	-0.7
8	62.4	62.7	0.6
9	61.8	62.5	1.2
10	63.8	62.8	-1.5
11	65.0	63.3	-2.5
12	63.4	62.9	-0.8
13	64.0	63.7	-0.3
14	63.8	62.9	-1.4
15	62.1	62.8	1.2
16	60.5	61.8	2.2
17	60.9	61.9	1.8
18	61.0	62.5	2.5
19	65.0	65.0	0.0
20	64.4	64.0	-0.6
21	64.7	64.9	0.4
22	65.4	65.4	0.1
23	66.4	65.3	-1.6
24	63.8	65.2	2.1
25	64.8	65.4	0.9
26	66.4	66.4	-0.1
27	65.7	65.6	-0.1
28	63.4	64.0	1.1
29	64.3	65.0	1.2
30	66.5	65.9	-1.0
31	64.2	64.3	0.2
32	63.5	65.4	3.0
33	63.0	64.4	2.2
34	63.7	62.8	-1.4
35	64.0	63.1	-1.4
36	64.3	63.6	-1.1
37	63.6	62.5	-1.7

S. No.	Measured L <sub>90</sub> dB(A)	Predicted L <sub>90</sub> dB(A)	Percentage (%) Error
38	64.1	63.1	-1.6
39	64.1	64.7	1.1
40	63.8	63.6	-0.2
41	63.9	62.9	-1.7
42	64.1	63.0	-1.7
43	62.9	62.2	-1.1
44	62.9	62.5	-0.6
45	64.9	63.5	-2.1
46	60.4	62.1	2.8
47	60.9	61.8	1.4
48	60.5	62.2	2.8
49	61.3	61.8	0.8
50	66.1	65.4	-1.0
51	65.5	64.8	-1.1
52	65.2	64.6	-0.9
53	66.0	65.3	-1.1
54	64.8	64.3	-0.7
55	65.1	64.4	-1.1
56	64.5	64.7	0.4
57	66.7	65.1	-2.3
58	65.9	64.7	-1.8
59	66.0	65.6	-0.6
60	64.0	65.3	1.9

## APPENDIX-F

### DATA FOR DIFFERENT SOUND LEVELS FOR 1/1 OCTAVE BAND

			Frequency (Hz)									
			31.5	63	125	250	500	1K	2K	4K	8K	16K
Day 1	L10 (dB)	Avg.	81	78	76.5	73	70	68.5	66	62.5	52.5	43.5
		Max.	114.6	110.3	108.2	103.2	98.99	96.87	93.34	88.39	74.25	61.52
		Min.	57.28	55.15	54.09	51.62	49.5	48.44	46.67	44.19	37.12	30.76
	L90 (dB)	Avg.	71	73.5	72	70	67	67	64.5	59	50.5	40.5
		Max.	100.4	103.9	101.8	98.99	94.75	94.75	91.22	83.44	71.42	57.28
		Min.	50.21	51.97	50.91	49.5	47.38	47.38	45.61	41.72	35.71	28.64
	L50 (dB)	Avg.	77	76	74.5	72	68.5	68	66	61.5	51	41
		Max.	108.9	107.5	105.4	101.8	96.87	96.17	93.34	86.97	72.12	57.98
		Min.	54.45	53.74	52.68	50.91	48.44	48.08	46.67	43.49	36.06	28.99
	Leq (dB)	Avg.	77.9	76.3	74.7	71.8	68.7	68.1	65.7	61	51.4	41.4
		Max.	110.2	107.9	105.6	101.5	97.16	96.31	92.91	86.27	72.69	58.55
		Min.	55.08	53.95	52.82	50.77	48.58	48.15	46.46	43.13	36.35	29.27
Day 2	L10 (dB)	Avg.	71	73.5	70	63.5	58.5	57.5	53.5	49	37	24
		Max.	100.4	103.9	98.99	89.8	82.73	81.32	75.66	69.3	52.33	33.94
		Min.	50.21	51.97	49.5	44.9	41.37	40.66	37.83	34.65	26.16	16.97
	L90 (dB)	Avg.	66	69	66	61.5	57	56	52.5	46.5	35.5	22
		Max.	93.34	97.58	93.34	86.97	80.61	79.2	74.25	65.76	50.2	31.11
		Min.	46.67	48.79	46.67	43.49	40.31	39.6	37.12	32.88	25.1	15.56
	L50 (dB)	Avg.	67	72	68	63	58	57	53	48.5	36.5	22.5
		Max.	94.75	101.8	96.17	89.09	82.02	80.61	74.95	68.59	51.62	31.82
		Min.	47.38	50.91	48.08	44.55	41.01	40.31	37.48	34.3	25.81	15.91
	Leq (dB)	Avg.	68.5	71.9	68.3	62.8	57.9	57	53.1	48.1	36.5	22.9
		Max.	96.87	101.7	96.59	88.81	81.88	80.61	75.09	68.02	51.62	32.39
		Min.	48.44	50.84	48.3	44.41	40.94	40.31	37.55	34.01	25.81	16.19
Day 3	L10 (dB)	Avg.	83.5	84.5	77	71.5	69.5	69.5	67.5	64	53.5	41
		Max.	118.1	119.5	108.9	101.1	98.29	98.29	95.46	90.51	75.66	57.98
		Min.	59.04	59.75	54.45	50.56	49.14	49.14	47.73	45.26	37.83	28.99
	L90 (dB)	Avg.	67.5	73	72	67	65.5	65.5	63	58.5	47	34.5
		Max.	95.46	103.2	101.8	94.75	92.63	92.63	89.09	82.73	66.47	48.79
		Min.	47.73	51.62	50.91	47.38	46.32	46.32	44.55	41.37	33.23	24.4
	L50 (dB)	Avg.	74	80	73.5	70.5	68.5	69	66.5	63	52.5	39.5
		Max.	104.7	113.1	103.9	99.7	96.87	97.58	94.04	89.09	74.25	55.86
		Min.	52.33	56.57	51.97	49.85	48.44	48.79	47.02	44.55	37.12	27.93
	Leq (dB)	Avg.	77.8	80.5	74.1	70.2	68.5	68.6	66.3	62.4	52.1	39.5
		Max.	110	113.8	104.8	99.28	96.87	97.01	93.76	88.25	73.68	55.86
		Min.	55.01	56.92	52.4	49.64	48.44	48.51	46.88	44.12	36.84	27.93

Day 4	L10 (dB)	Avg.	82.5	80	78	72	68.5	68.5	67	76	58.5	48
		Max.	116.7	113.1	110.3	101.8	96.87	96.87	94.75	107.5	82.73	67.88
		Min.	58.34	56.57	55.15	50.91	48.44	48.44	47.38	53.74	41.37	33.94
	L90 (dB)	Avg.	73.5	76	74.5	70.5	64	66	63	60.5	53.5	41.5
		Max.	103.9	107.5	105.4	99.7	90.51	93.34	89.09	85.56	75.66	58.69
		Min.	51.97	53.74	52.68	49.85	45.26	46.67	44.55	42.78	37.83	29.35
	L50 (dB)	Avg.	79.5	78	76.5	71.5	66	66.5	65.5	62.5	55.5	43
		Max.	112.4	110.3	108.2	101.1	93.34	94.04	92.63	88.39	78.49	60.81
		Min.	56.22	55.15	54.09	50.56	46.67	47.02	46.32	44.19	39.24	30.41
	Leq (dB)	Avg.	79.9	78.1	76.5	71.7	66.7	67.3	65.7	70.2	56.1	44.9
		Max.	113	110.4	108.2	101.4	94.33	95.18	92.91	99.28	79.34	63.5
		Min.	56.5	55.23	54.09	50.7	47.16	47.59	46.46	49.64	39.67	31.75

## APPENDIX-G

### CALCULATION FOR TRAFFIC VOLUME AND MEAN SPEED

Date.....

Site.....

Sr. No.	Date	Time	Traffic Volume		Mean Speed	
			Near	Far	Near	Far
1						
2						
3						
4						
5						
6						
7						

## APPENDIX-H

### CALCULATION FOR SOUND LEVELS

Date: .....

Site: .....

Measurement period: 1 Hour

Sound Level Meter Microphone: .....

Distance from Center of the Road (meter): .....

Temperature: ..... °C

Sr. No.	Date	Time	Sound Pressure Level dB(A)			
			L <sub>eq</sub>	L <sub>10</sub>	L <sub>50</sub>	L <sub>90</sub>
1						
2						
3						
4						
5						
6						
7						