STUDY AND DEVELOPMENT OF ROAD TRAFFIC NOISE MODEL

A Thesis

Submitted in partial fulfillment of the requirement for the award of degree of

MASTER OF ENGINEERING

IN

CAD/CAM & ROBOTICS

Submitted By

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CERTIFICATE

This is to certify that the thesis entitled "**STUDY AND DEVELOPMENT OF ROAD TRAFFIC NOISE MODEL**", submitted by **Mr. Mukesh Chandra Mishra** in the partial fulfillment of the requirement for the award of the degree of **Master of Engineering in CAD/CAM & Robotics**, submitted in the **Mechanical Engineering Department, Thapar University, Patiala**, is an authentic record of candidate's own work carried out by him under our supervision and guidance. The matter embodied in this has not been submitted in part or full to any other university or institute for the award of any other degree.

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ABSTRACT

The major contribution of the traffic noise, towards overall noise pollution scenario, is a well known established fact. Traffic noise from highways creates problems for surrounding areas, especially when there are high traffic volumes and high speeds. Vehicular traffic noise problem is contributed by various kinds of vehicles like heavy, medium trucks/buses, automobiles and two wheelers. Many western countries have developed different prediction models based on L_{10}, L_{eq} and other characteristics.

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

The present work discusses the fundamentals of acoustics and analysis of vehicular traffic noise. A mathematical model is developed in Patiala city (Punjab) for a site at Patiala-Sangrur Highway (NH-64) (1.5Km from Rajindra Hospital). A large number of sets of data were recorded for 15 minutes duration at different dates/timings in a random/staggered manner in order to account for statistical temporal variations in traffic flow conditions. The noise measurement parameters recorded were L_{eq}, L_{10}, L_{max} and L_{min}. Sound level meter (CESVA SC 310) was used for these measurements.

A mathematical model was developed which is used for predicting L_{10} or L_{eq} level, included the following parameters:

1. Total vehicle volume/hr

2. Percentage of heavy vehicles

3. Average vehicle speed

The Noise levels L_{eq} and L_{10} were used in regression analysis for prediction. It was concluded that value of R^2 ranges from 0.1 to 0.7. The paired t-test was also carried out successfully for goodness-of-fitness.

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NOMENCLATURE

SYMBOLS	DESCRIPTIONS
D	Observer distance
D_E	Equivalent distance from roadways
D_f	Observer distance to the centre of far lanes
D_N	Observer distance to the centre of near lanes
dB	Decibel
f_{upper}	Upper limit frequency
f_{lower}	Lower limit frequency
f_{centre}	Centre frequency
Hz	Hertz
L_{eq}	Equivalent continuous sound level
L_{10}	10 percentile exceeded sound level
L_{90}	90 percentile exceeded sound level
L_{50}	50 median value of sound level
NPL	Noise pollution level
P	Percentage of heavy vehicles
Pa	Pascal
PTS	Permanent threshold shift
Q	Traffic Volume
SEL	Sound exposure level
SPL	Sound pressure level
TNI	Traffic noise index
TTS	Temporary threshold shift
V	Average speed of vehicles
σ	Standard deviation

CHAPTER-1
INTRODUCTION

1.1 INTRODUCTION TO NOISE

In our modern, rapidly expanding environment one of the developing problems is that of noise. This particular problem is becoming a Source of serious concern to industrial corporations, trades. Basically, noise is sound, while under some circumstances sound is noise. Noise is conveniently and concisely defined as “Unwanted Sound”, an essentially personal definition. The object of this part is to discuss the concept of noise, problems of noise and its effect on man and environment both as annoyance and as a danger to health [49].

The major sources of noise are:

1. Industrial noise
2. Traffic noise
3. Community noise

Out of above three parameters, the source that affects the most is traffic noise. In traffic noise, almost 70% of noise is contributing by vehicle noise. Vehicle noise, mainly, arises from two parameters i.e. engine noise and tyre noise. The major concern is to study and development of a road traffic noise model.

1.1.1 Harmful Effects of Noise on Human Beings

- Reduces work efficiency.
- May cause temporary threshold shift / permanent threshold shift.
- Induces loss of hearing ability.
- May damage the heart.
- Increases the cholesterol level in the blood.
- Dilates the blood vessels of the brain.
- Upsets the chemical balance of the body.
- Causes headache, nausea and general feeling of uneasiness.

- Induces errors in ‘motor’ performance, in visual perception.

1.1.2 Useful Applications of Noise

Noise is not only has harmful affects but sometimes it is very useful. Some of the examples when noise is useful:

1. **Study of heart beats:** Noise produced by the heart beats is very useful to diagnose the person’s health accordingly.
2. **Masking effects:** Sometimes, it is necessary that nobody should hear the conversation between the two persons. For this, masking effect is used. e.g. in the doctor’s chamber, doctor wants that nobody should hear his conversation with the patient so he uses masking effect by putting a more noisy exhaust fan which makes noise outside the room.

1.2 FUNDAMENTALS OF NOISE

Sound is produced as result of some mechanical disturbance creating pressure variations in an environment such as air or water, or in fact any elastic medium which can transmit a pressure wave. To be able to hear the sound there must always be air or other elastic medium at the ear. The magnitude of the pressure variations (The amplitude of the pressure oscillation) is proportional to the loudness of the sound. The number of pressure cycles per second determines whether we hear a sound of high pitch or of low pitch, the higher the frequency the higher the pitch.

1.2.1 Physical Properties of Sound

If a device, which can detect small pressure variations (microphone) is placed in the sound field, it will produce an electric signal proportional to the sound pressure. The unit of sound pressure is Pa (Pascal=N/m^2).The range of audible sound pressure variations is very wide ranging from $2x10^{-5}$ Pa=20μPa, which is threshold of hearing (P_t) to approximately 100 Pa, the threshold of pain (P_p).

The ratio between the threshold of hearing and the threshold of pain is 5000 000: 1 equivalent to 134 dB. dB is logarithmic ratio which defines the sound pressure level L as follows:

$L = 20 \times \log_{10} p/p_{ref}$

In this formula p is the sound pressure measured and p_{ref} is the reference sound pressure 20µPa. This logarithmic scale has several advantages over a linear scale. The most important advantages are:

1. A linear scale would lead to the use of some enormous and unwieldy numbers.

2. The ear responds not linearly, but logarithmically to stimulus.

Conversion from one scale (N/m^2) to the other scale (dB) can easily be done by use of the following table. (Table 1.1)

Table 1.1 Environmental conditions at different SPL

Sound Pressure (N/m^2)	Sound Pressure Level (dB)	Environmental Conditions
10^2	134 dB	Threshold of pain
10	114 dB	Loud Automobile horn (distance 1m)
1	94 dB	Inside subway train
10^{-1}	74 dB	Average Traffic on street corner
10^{-2}	54 dB	Living room, Typical business office
10^{-3}	34 dB	Library
10^{-4}	14 dB	Broadcasting Studio
$2x10^{-5}$	0 dB	Threshold of Hearing

1.2.2 Sound Sources

- Point Source
- Line Source
- Plane Source

Point Source: A sound source can be considered as a point source, if its dimensions are small in relation to the distance to the receiver and it radiates an equal amount of energy in all directions. Typical point sources are industrial plants, aircraft and individual road vehicles. The sound pressure level decreases 6 dB whenever the distance to a point source is doubled.

Line Source: A line source may be continuous radiation, such as from a pipe carrying a turbulent fluid, or may be composed of a large number of point sources so closely spaced that their emission may be considered as emanating from a notional line connecting them. The sound pressure level decreases 3 dB, whenever the distance to a line source is doubled.

Plane Source: A plane source can be described as follows. If a piston source is constrained by hard walls to radiate all its power into an elemental tube to produce a plane wave, the tube will contain a quantity of energy numerically equal to the power output of the source. In the ideal situation there will be no attenuation along the tube. Plane sources are very rare and only found in duct systems.

1.2.3 Audible Frequency Range

Human hearing responds to frequencies in the range approximately 20 cycles per second to 20,000 cycles per second (the unit “cycles per second” is also termed “Hertz” abbreviated Hz.

1.2.4 Frequency Spectrum

If a sound has components at one frequency only, it is said to be a pure tone. Such sounds are not very common in nature, however, and the only common example of a pure tone is the sound of a tuning fork. Most usually, sounds have components at several frequencies and the character or timbre of a steady sound is determined by the pressure amplitudes at the different component frequencies. We can therefore describe a steady sound by a graph of frequency against amplitude, and such a graph is referred to as the frequency spectrum of the sound. Sound measuring instruments are usually constructed to measure the frequency spectrum, but for measurement convenience and simplicity of the instrument in practice we measure the energy content in a particular range of frequencies. Some examples of the frequency spectra of particular sounds are shown in Fig 1.1.

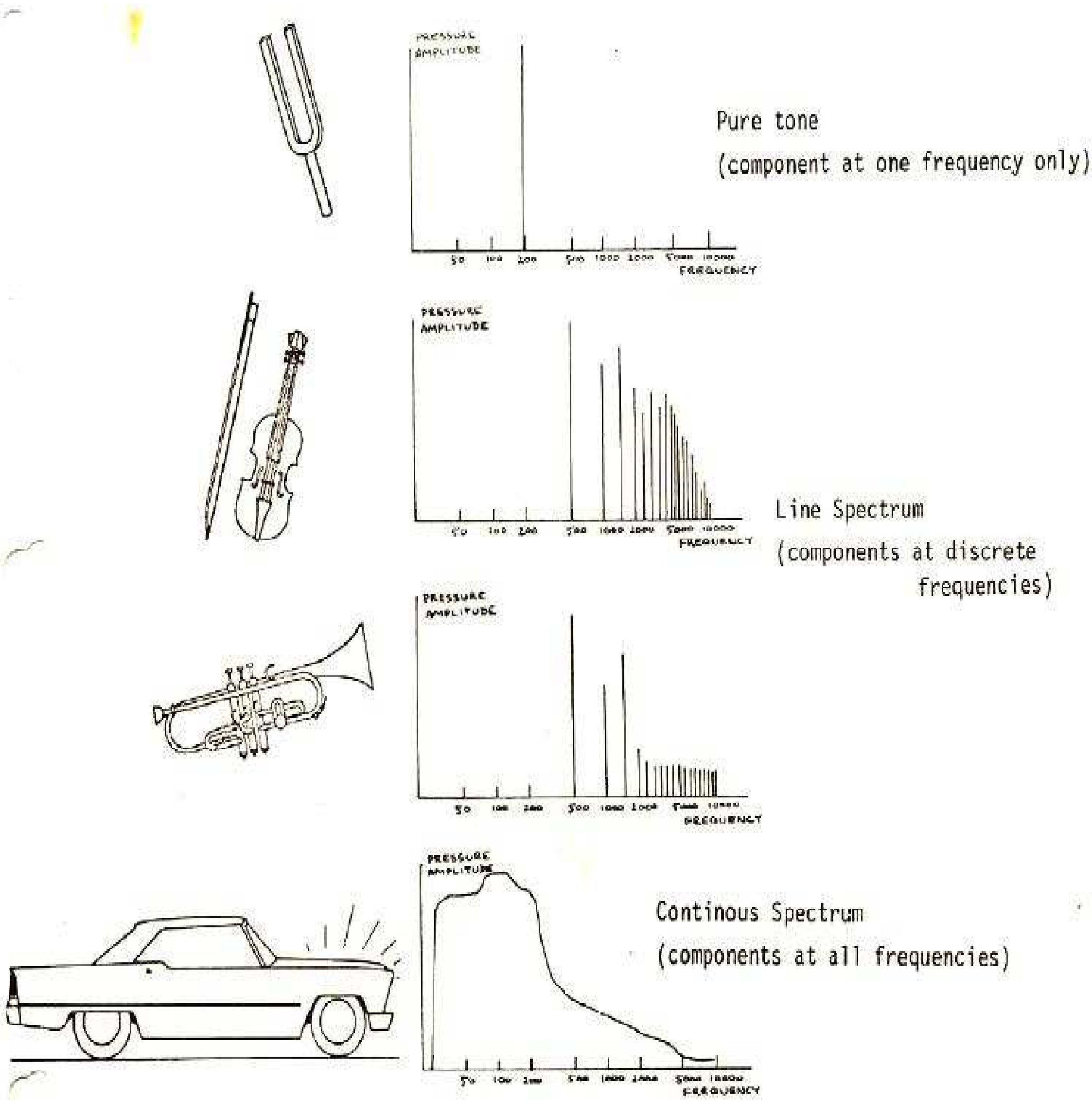

Fig 1.1 Examples of frequency spectra

1.2.5 Frequency Analyzers

The spectra in Fig. 1.1 are those which would be obtained from a narrow bandwidth analyzer, since the pure tone components appear as single lines of thickness equal to the frequency bandwidth of the analyzer. Such analyzers are not very common in practice because of the large number of frequency intervals which would be required to build up a complete spectrum and the consequent long time of analysis. The most common bandwidths being 1-1 octave bands and third octave bands. Octave bands contain a range of frequencies the upper limit of which is double the frequency of the lower limit (or f_{upper} = 2 f_{lower}). The third octave band is defined by the limits f_{upper} = $2^{1/3}f_{lower}$. All frequency bands are usually referred to a Centre Frequency which is the geometric mean frequency of the band;

($f_{entire}=\surd f_{upper}\surd f_{lower}$)

Frequency spectra such as those in Fig.1.1 take no account of variations with time and represent simply the average level of the sound over a particular interval.

1.2.6 Loudness

Loudness is the subjectively perceived attribute of sound which enables a listener to order their magnitude on a scale from soft to loud. It is defined as subjective intensity of sound.

Loudness Level in Phons

Human Perception of Loudness of pure tones of 1000 Hz was studied in the 1950s at various frequencies in the audible range.

•This established a set of curves defining Equal Loudness Contours. (Fig-1.2)

•Phon the unit used to express equal loudness levels.

•As per these contours, a 50 dB tone at 1000 Hz or a 73 dB tone at 50 Hz or a 42 dB tone at 4000 Hz has the same loudness level as 50 Phon.

Loudness Level in Sone

It is seen that Equal Loudness Contours show human ear response as non-linear in relation to both frequency and SPL.

- Due to this behavior a rise of 10 dB in SPL corresponds only to a doubling of subjective loudness nearly (Table 1.2).
- To represent this subjective behavior on a linear scale, Sone scale was developed.
- According to this scale one Sone is defined as the loudness of a sound of 40 Phon, 50 Phon are equal to 2 Sone, 60 Phon are 4 Sone and so on.

Table 1.2

Subjective Effect of Changes in Noise Levels

Change in levels in dB	Subjective Effects
3	Just Perceptible
5	Clearly Perceptible
10	Twice as Loud

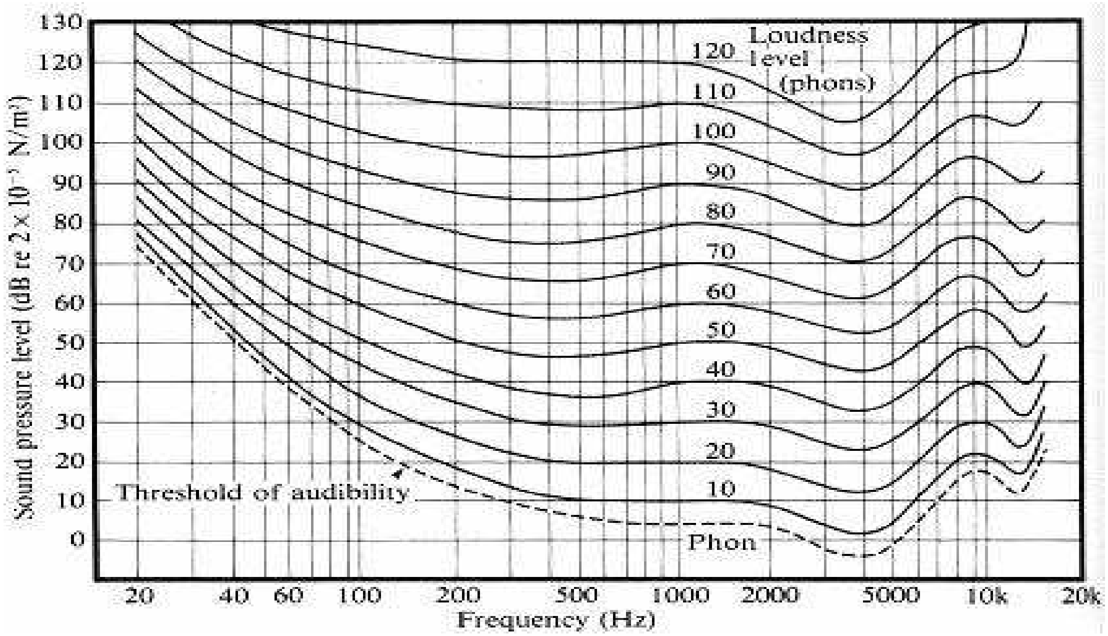

Fig 1.2 Equal loudness contours

1.2.7 Background Noise

When sound measurement for instance on a machine is carried out, it is important that the background noise level is so low, that it does not have any influence on the result. This can be tested in the following manner. Measure the sound at the position where it should be measured with the source (machine) running. Switch off the machine and measure the sound level without the machine running. If the difference is less then 3dB measurements should be stopped until the background noise has been reduced. If the difference is between 3 and 10 dB use the curve to correct the measured value. If the difference is more than 10 dB, the background noise may be ignored. (Fig-1.3)

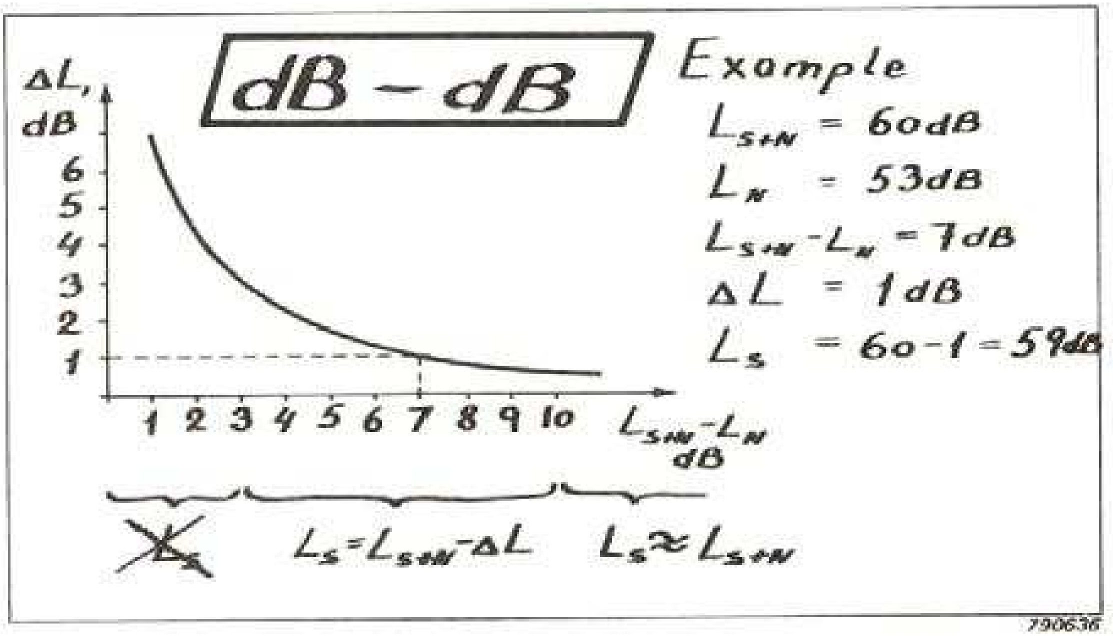

Fig 1.3 Curve for subtraction of background noise in dB

1.2.8 Weighting Curves

The nonlinear response of ear has lead to the introduction of weighting filters, which correlate well with the response of the ear. The instrument used weight the different frequency components taking into account the frequency sensitivity of the ear and thereby gives a better indication of annoyance than the dB. The most commonly used of these curves is the A-weighting curve as it gives the best correlation between the measured values and the annoyance and the harmfulness of the sound signal. It follows approximately the 40 phons curve. The B and C weighting curves follow more or less the 70 phon and the 100 phon curve respectively. The D weighting curve follows a contour of perceived noisiness and is used for aircraft noise measurement. In addition to these weightings sound level meters usually also have a Linear or zero weighting.

Weighting filters can easily be built into portable Sound Level Meters, and the sound level measured is then given in dB (A) in case where an A-weighting filter has been used etc. Some sound level meters also have octave filters built in, or provision for connection of external filters. (Fig 1.4)

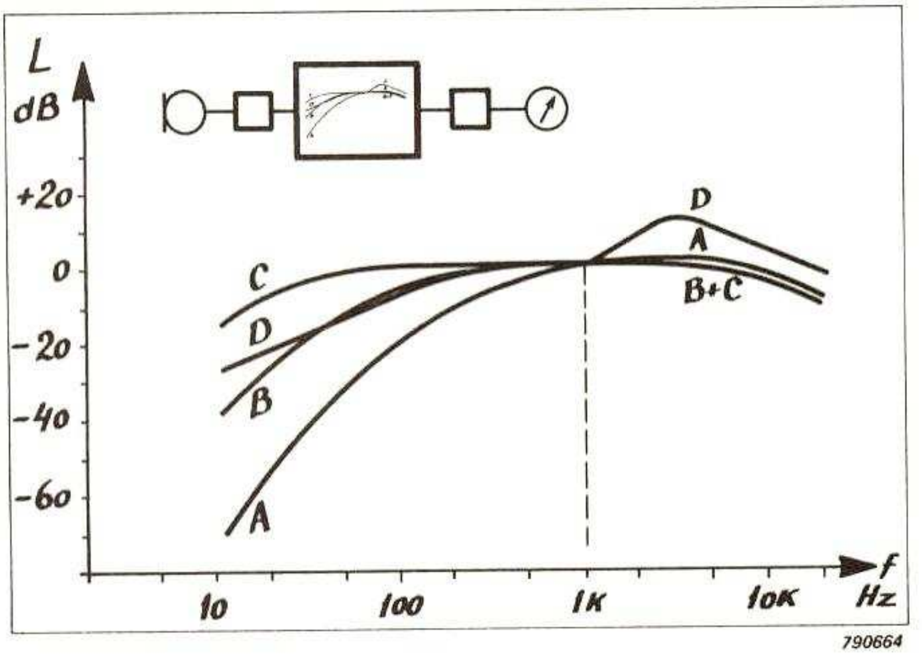

Fig 1.4 Weighting Curves

1.2.9 Percentile Exceeded Sound Levels

Percentile Exceeded Sound Levels:

L_{10} = 10 percentile exceeded Sound level (av. Peak level)

L_{90} = 90 percentile exceeded Sound level (av. Background level)

L_{50} = Median value of Sound level

$L_{10} - L_{90}$ = Noise climate

Equivalent continuous Sound level L_{eq}:

Continuous steady noise level which would have the same total A-weighted acoustic energy as the real fluctuating Noise measured over the same period of time.

$L_{eq}=10\log_{10}1/T_0\int^T(p/p_{ref})^2dt$

Where, T = Total measurement time

All these levels are in dB (A).

1.3 NOISE MEASUREMENT TECHNIQUES & INSTRUMENTS

Noise measuring devices typically use a sensor to receive the noise signals emanating from a source. The sensor, however, not only detects the noise from the source, but also any ambient background noise. Thus, measuring the value of the detected noise is inaccurate, as it includes the ambient background noise. Many different type of instruments are available to measure sound levels and the most widely used are sound level meters. (Fig. 1.5) [49].

1.3.1 Elements of sound level meter

1. Microphone: Most measurement microphones generate a voltage that is proportional to the sound pressure at the microphone and is the electrical analog of sound waves impinging on the microphone's diaphragm. The particular mechanism that converts the pressure variation into sound waves signal. Different types of microphones are:

a. Capacitor (Condenser) Microphone

b. Pre-polarized Microphone

c. Piezoelectric Microphone

2. Amplifier: It amplifies the signal from microphone sufficiently to permit measurement of low SPL. It amplifies sound over a wide frequency range. It maintains the amplification constant.

3. Rectifier: It rectifies the signal from analog signal to digital signal.

4. Smoothing circuit

5. Meter

Fig 1.5 Sound Level Meters

1.3.2 Steps of Measurement System

- Check the sensitivity (Calibration) of the measurement system.
- Measure the acoustical noise level.
- Apply all necessary correction to the observed measurement.
- Make a written record of all relevant data.

1.3.3 Outdoor Measurement Use of Windscreen

Wind can be significant influence on outdoor acoustical measurement

1. Wind effects can be minimized to protect microphone.

2. Wind generated Noise can be reduced significantly by fitting a wind screen.(fig.1.6)

Fig 1.6 Sound level meter with windscreen

1.3.4 Noise Measurement Procedure (Fig 1.7)

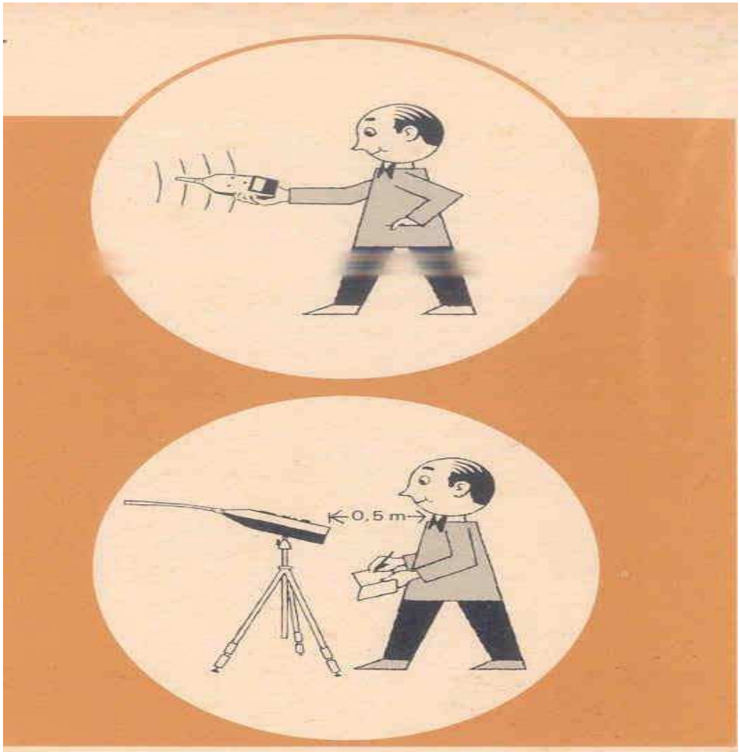

Fig 1.7 Noise Measurement Procedures

- SLM should be at least at a distance of 0.5 m from the body of the observer.
- Reflections from the body of the observer can cause an error of up to 6 dB at frequencies around 400 Hz.
- SLM should be at a height of 1.2 –1.5 m from the floor level.
- Preferred position from near buildings and windows is 1 –2 m away.
- Outdoor measurements to be made at least 3.5 m away from other reflecting structures.
- Within the room measurement should be made in the Free Field zone.

1.4 NOISE STANDARDS IN INDIA

Noise has been recognized as one of the unwanted by products of the industrialized society along with air, water and other pollutants. One of the earliest noise standards available is due to the Occupational Safety and Health Act (OSHA) enacted in USA in 1971 which happens to be a land mark step in the direction of Environmental Noise Control.

In India, noise figured only incidentally in general legislation of the Govt. of India as a Component in Indian Penal Code, Motor Vehicles Act (1939), and Industries Act (1951). Some of the states also had noise limits incorporated in certain manner in their legislation. In 1986, the Environment (Protection) Act was legislated.

A review of the status report indicates that noise surveys were made in India in the sixties by the National Physical Laboratory, New Delhi. The findings of this survey clearly established the existence of high noise levels in Delhi, Bombay and Calcutta.

An expert committee on noise Pollution was set up by the Ministry of Environment, Govt. of India, in early 1986 to look into the present status of Noise pollution in India Expert Committee submitted its report in June 1987.

The following have been identified as the Source of noise to which a man is exposed advertently or inadvertently on road, in the house, at work, in the factory, indoors or outdoors.

Table 1.3

Group 1	Industrial Noise Automobiles Noise Domestic Appliances Noise Public Address System Noise
Group 2	Aircraft Noise Railway Noise Construction Noise Noise from Crackers

1.4.1 Permissible sound levels for automotive vehicles in India

Table 1.4

Vehicle category	**Maximum permissible sound level in dB (A)**			
	1992	**1999**	**2002**	**2003**
(A) Two wheelers				
(i) Displacement upto 125 cc	80	80	75	75
(ii) Displacement 125-250 cc			77	77
(iii) Displacement 125-250 cc			80	80
(B) Three wheelers	80	80	77	77
(C) Passenger Cars	82	79	74	75
(D) Commercial vehicles				
(i) Light wt upto 4 tonnes	85	82	77	80
(ii) Light wt 4-12 tonnes	89	86	80	83
(iii) Light wt more than 12 tonnes	91	88	82	85

1.4.2 TYPICAL TRAFFIC NOISE LEVELS

- Areas with heavy traffic or close to blaring loud speakers: 80 –105 dB (A).
- Areas with over flying aircrafts: 90-100dBA.
- At Railway Stations, Traffic Junctions, Busy markets; 70 –90 dB (A).
- Residential Areas close to traffic, industries and markets: 60 –80 dB (A).
- Residential areas away from heavy traffic roads or other noisy Sources: 40 –60 dB (A).

CHAPTER-2

VEHICULAR TRAFFIC NOISE

2.1 INTRODUCTION TO VEHICULAR TRAFFIC NOISE

Highway noise is the sum of the total noise produced at the observer point by all the moving vehicles on the highway. Thus the fundamental component is the noise produced by the individual vehicles, which depend on the vehicle type and its mode of operation. The overall noise is also dependent on the characteristics of the vehicle flow and the relative proportions of the vehicle types included in the flow. Knowledge of these factors is thus necessary to define the characteristics of highway noise and to subsequently predict the associated noise level in the surrounding area. The amount of information required depends on the degree of accuracy desired in the predictions, which in turn is a function of the method selected to characterize the temporal variation of the noise. Thus the complexity of highway noise model will depend on the noise descriptor selected [48].

2.2 HIGHWAY NOISE DESCRIPTORS

2.2.1. Percentile Exceeded Sound Level, L_X

This defines the sound level that has been exceeded "X" percent of time in a measurement period. The value of the sound level history over a given period of time is presented in the form of a cumulative distribution. The percentile exceeded sound levels most commonly used are L_{10} and L_{50}.

2.2.2 Equivalent Continuous (A-Weighted) Sound Level, L_{eq}

Equivalent continuous (A-weighted) sound level is defined as the steady sound level that contains the same amount of acoustic energy as the fluctuating level over the prescribed period of time. Common prescribed periods are one hour (L1h), 24 hours (L24h), and the day time hours (7 A.M. to 10 P.M.) (Ld), and the night time hour (10 P.M. to 7. A.M.) (Ln),

$L_{eq}=10\log_{10} (1/T)_0\int^T[P/P_{ref}]^2$

Where,

T=Total measurement time

P=A-weighted instantaneous acoustic pressure

P_{ref}= Reference acoustic pressure=20µPa

2.2.3 Day Night Average Sound level, Ldn

This is an average sound level taken over a 24 hours period, 10 dB is added to account for the increased undesirable effect of noise at night. This is used to indicate the tolerance of peoples to noise at various times of the day.

2.2.4 Traffic Noise Index (TNI)

The traffic Noise index is used to describe community noise. The TNI takes into account the amount of variability in observed sound levels, is an attempt to improve the correlation between traffic noise measurements and subjective response to Noise. The traffic noise index is defined by

$TNI=4(L_{10}-L_{90}) +L_{90}-30$ dB where,

L_{10}= 10 percentile exceeded sound level

L_{90}=90 percentile exceeded sound level

All these are in dB and measured during 24 hours period.

2.2.5 Noise Pollution Level (NPL)

Noise pollution level is sometimes used to describe community noise which employs the equivalent continuous (A-weighted) sound level and the magnitude of the time fluctuations in levels.

$L_{NP}=L_{eq}+2.56\sigma$ dB

Where,

σ = standard deviation of the instantaneous sound level

L_{eq}= equivalent continuous sound level

Out of the above, the two noise descriptors which have been mostly used in many countries to describe highway noise are L_{10} and L_{eq} levels.

2.3 VEHICLE NOISE CHARACTERISTICS

Highway traffic consists of a large collection of vehicles of different types, makes and models. The relative proportion (mix) of which depends on the type of highway and the time of day, among other factors. In the assessment of highway noise by calculation it is convenient to assume that there are two main categories of vehicles. They are

- Automobiles

- Heavy trucks/buses

Automobiles are defined as transport vehicle with Gross Vehicle Weight Ratings (GVWR) of less than 4536 kg (includes the matadors, cars and three wheelers).Heavy trucks are defined as transport vehicle with Gross Vehicle Weight Ratings (GVWR) of more than 4536 kg. (Includes buses and heavy trucks).

2.4 VEHICLE NOISE SOURCES

It is well established fact that vehicular traffic noise is a major source of community annoyance especially near highway carrying fast traffic. Many people consider the truck noise to be the principal offender. Numerous components of noise sources contribute to the overall truck noise. These sources, however, can logically be grouped into the major categories as under.

1. Power Plant and Transmission Noise Sources- engine, exhaust, intake, cooling system, drive train and so on,

2. Running gear Noise Sources – tyre road interaction, differential, propeller shaft. Noise from the power-plant increases as engine speed increases. While noise from tyre increases as vehicle speed increases. Trucks tend to operate at a nominally constant engine speed, so that engine and exhaust noise do not vary appreciably with vehicle

speed. Therefore, at lower highway speeds the engine-exhaust noise is dominant, while at higher vehicle speeds tyre-pavement interaction becomes the dominant source of noise. The exact speed at which the tyre-roadway noise starts to dominate over the power-plant-associated noise is a highly complicated function of such variables as tyre characteristics, engine-exhaust characteristics, road surface, and vehicle design and condition.

As a tyre rolls over a road surface, it displaces macroscopic and microscopic volumes of air. The 'macroscopic' applies to volume displacements of the same order as the volume of the tyre itself, and 'microscopic' applies to much smaller volumes. These air displacements generated pressure disturbances in the surrounding air. Pressure disturbances in the audio frequency range and of sufficient amplitude are responsible for the production of noise along the roadway.

2.5 EFFECTS OF VARIOUS FACTORS ON TRAFFIC NOISE

Rapidly changing population patterns on the national scene and developed public expectancy in terms of environmental effects have generated the requirement to furnish environmental impact statement is the noise that my result from the traffic noise is more complicated due to the facts that highways are not flat, straight or free from natural terrain variation. The factors like vehicle speed, density, traffic mix, width of median and number of lanes are not constant. Therefore, for traffic noise each of these parameters is taken into account.

Traffic Noise depends on the following factors:

2.5.1 Traffic Parameters

(i) Vehicle volume

(ii) Vehicle mix

(iii)Average speed

2.5.2 Roadways characteristics

(i) Pavement width

(ii) Flow characteristics

(iii) Gradient

(iv) Surface finish

2.5.3 Observer characteristics

(i) Observer distance

(ii) Element size

(iii) Shielding

(iv) Observer relative height

2.5.4 Traffic Parameters

Traffic Volume, Q

The noise level near the highway depends on the number of vehicles. The noise level increases with an increase in traffic volume. Traffic volume is defined as the total number of vehicles flowing per hour. The number of vehicles passing through a fixed point on the road is to be counted. The traffic volume may be sub grouped into heavy vehicles and automobiles for duration of fifteen minutes. Several such samples are to be taken in different time slots ranging from 9.00 A.M. to 6.00 P.M.

Truck-Traffic Mix Ratio, P

Trucks and buses are contributing more noise to the environment, than compared to automobiles. The ratio of heavy trucks and buses to total traffic is called truck traffic mix ratio. This is computed in terms of percentage. An increase in this ratio will increase the noise level.

Speed of Vehicle, V

If the vehicle is traveling within the limited range of road speeds, the noise produced is related to the engine, which would vary with each vehicle type. Therefore, the term "V" is included in developing the model. Including vehicle speed as a parameter in the model has some approximation, because of the unavailability of speed measuring instrument ‘radar gun’ i.e. vehicle speed as a parameter is tried to be taken in the present work manually. Vehicle speed is taken as an average speed of all vehicles categories ranges 40-50 km/hr. Further, this parameter is included as a log term.

2.5.5 Roadway Characteristics

(i) Pavement width

(ii) Flow characteristics

(iii) Gradient

(iv) Surface finish

2.5.6 Observer Characteristics:

Equivalent Distance from Roadways, D_E

Traffic Noise diminishes from the Source at the rate of 3 to 4.5 dB (A) per doubling of distance on ground cover. Noise levels are computed on the basis of a single equivalent lane located at

$D_E = \sqrt{D_n}\,\sqrt{D_f}$ in meters, Where D_N and D_F are observer distance to the centre of the near and far lanes respectively.

2.6 METHODS OF PREDICTION

Several investigators have tried to estimate the traffic noise with the help of a mathematical expression in terms of the various parameters. Basically two approaches have been used for predicting the traffic noise:

1. Nomograph procedure

2. Computerized prediction

2.6.1 Prediction of highway noise by Nomograph Procedure

Nomograph procedure is valid for moderately high volume of freely flowing traffic on infinitely long, straight, level roadways. A curved road may be considered to be straight if it deviates from straight by less than 10 percent of the observer distance “D” for a distance “5D” from the nearest point. This tolerance is illustrated in Fig.2.1

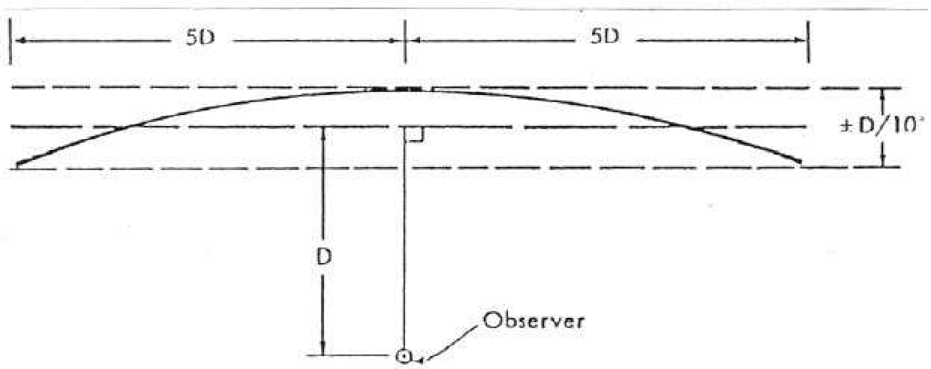

Fig. 2.1 Permissible curvature for approximately straight roads

A curved road may be divided into two or more approximately straight segments. If the highway is divided into sections or if there is more than one highway then the noise levels associated with each are combined, using the expression.

L_{10} total=10 $\log_{10}[10^{L1/10}+10^{L2/10}]$

Where, $L_1=L_{10}$ for section 1

$L_2=L_{10}$ for section 2

2.7 ADJUSTMENT TO THE NOMOGRAPH VALUE

2.7.1 Road Segment

For practical purposes, a road segment can be considered an infinitely long highway if it extends in each direction a distance of at least $4D_N$. If the segment does not meet this criterion, an adjustment is made to decrease the L_{10} level because the segment is finite. The amount of this decrease is obtained from Fig. (2.2)

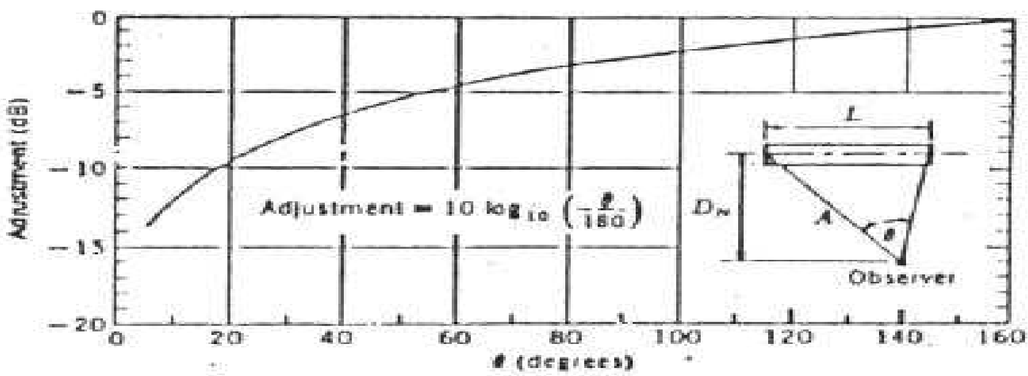

Fig 2.2 Adjustment of Nomograph values for finite length

2.7.2 Road Surface

For vehicles traveling on very rough or very smooth pavement, the basic noise level computations are adjusted upward or downward, as the case may be, by 5 dB, in accordance with Table 2.1. For the great majority of new surfaces, no adjustment is needed. Occasionally an old surface, worn badly by studded tyres, is encountered for which a 5 dB positive adjustment is justified. Less frequently, a very smooth coated surface warrants a 5 dB negative adjustment.

Table 2.1

Adjustments to vehicles noise levels for various road surfaces

Type of surface	Description	Adjustment (dB)
Smooth	very smooth, seal coated asphalt pavement	-5
Normal	moderately rough asphalt and concrete surface	0
Rough	rough asphalt pavement with large voids	+5

2.7.3 Road Gradient

The positive adjustments to account for the increased noise of trucks on gradients are shown in Table 2.2. These adjustments are made only to truck noise levels, and are never negative, that is there is no adjustment for a downhill gradient. In most situations where the two directional lanes appear together on a gradient, the adjustment may be applied equally to both sides of the highway without regard to whether the near lane is an up gradient or a down-gradient.

Table 2.2

Adjustments to truck noise levels for various road gradients

Gradient (%)	Adjustment (dB)
<2	0
3-4	+2
5-6	+3
>7	+5

As is seen from above discussions any mathematical model which is to be used for predicting L_{10} or L_{eq} level must include the following parameters:

1. Total vehicle volume/hr
2. Percentage of heavy vehicles
3. The distance of the measurement point from the roadway
4. Average vehicle speed

Inclusion of vehicle speed as a parameter may be a difficult task and many models do not include this. But in the present work vehicle speed as a parameter is included as a log term. The distance parameter can be ignored if the measurement/reference point is not varied. Further, vehicle flow parameter is included as a log term.

2.8 NOISE PREDICTION MODELS

It is evident that the overall traffic noise level is being contributed by the type of individual vehicles and the road conditions. Noise prediction models have been developed in many countries. These include different parameters like L_{10} and L_{eq}, etc. Traffic volume, traffic mix ratios and vehicle speed, need to be included in any modeling analysis. The road surface, the road gradient, surface finish conditions also affect the noise level at any observation point, hence need to be considered. Countries like USA, UK, and other European Union members have developed and evolved their own vehicular traffic noise prediction models and standards. Out of these the most popular being FHWA (Federal Highway Administration) model of USA and CRTN (Calculation of Road Traffic Noise) model of UK which have been adopted by many other countries including India.

CHAPTER-3
LITERATURE REVIEW

A lot of time and effort has been devoted 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. From a long time, work is continued in this field. Some important works are as follows:

Stephenson R. J. et al. [1] confirmed that traffic was the main source of noise in Central London, and details are given of two experiments on measuring the noise contributions made by different types of vehicle. In the first investigation the noise levels due to 1100 vehicles were measured individually under similar conditions, and in the second case, traffic noise was measured at 140 sites, note being taken of traffic volume and composition. The importance of lorries and buses in contributing to high noise levels is discussed, as are the effect of gradients and speed. Urban motorways will have a major influence on the noise environment of the future, and measurements near existing motorways are reported, both with respect to traffic volume and to distance from the motorway. In existing roads the effects of the introduction of one-way schemes, and of road widening programs are also described. Planning to mitigate the effect of traffic noise on the environment is discussed, with special reference to the use of barriers. The paper concludes with a summary of the Greater London Council's policy on traffic Noise.

Johnson D.R. et al [2] described road side surveys of the noise emitted by freely flowing traffic on sites ranging from motorways to urban roads. Sites were generally unobstructed but a few tests were made in places with buildings adjacent to the roadway. The survey also included measurements on two sites involving road gradients. The results provide an indication of present day traffic noise conditions against which future comparisons may be made and also show how basic variables such as traffic density, speed an composition, and distance from roadside affect the observed patterns of noise. Agreement between the experimental data and theoretical analysis of simplified traffic flow forms the basis of a method for predicting the median Sound level produced under any given set of traffic conditions. The reliability of the method, provided that due allowance is made for possible ground attenuation effects, is demonstrated using the results of the survey.

Scholes W.E. [3] summarized that traffic noise needs to be described in physical terms such that measurements or predictions of noise exposure in these units are effectively measurements or predictions of nuisance. Such units are developed by the means of social surveys, and typical survey techniques are briefly described of the three current proposals: Wilson proposals, traffic noise index and mean energy level; the Wilson proposals fail the requirements of a physical unit intended to be the basis of traffic noise control because of the lack of demonstrated correlation of noise levels with nuisance. Both traffic noise index and mean energy level have been shown to correlate well with nuisance but nevertheless the formulations of these two units are, in some respects, conflicting. The development and the relative merits of the two units are discussed, and the direction of further research into traffic noise is outlined.

Harman D.M. et al [4] summarized the results of a noise survey made within the Portsmouth City boundaries are outlined. Measurements were made throughout the 18-hour day at 33 sites which covered a wide range of traffic conditions. Comparisons were made between the published noise prediction methods and the measured results for sites adjacent to roads carrying free-flowing traffic. A modification is introduced to allow the design parameter employed by traffic engineers to be used in the prediction formula. The fall-off of noise levels with distance was also examined. An area classification is suggested for situations where the prediction formulae are not able to be applied.

Oakes B. et al [5] reviewed the various positions adopted in the past for the measurement of traffic noise levels in different situations. The use of kerbside measurements is justified for congested urban situations where the interference from pedestrians and the obstruction caused by the measuring and recording equipment can present serious problems.

Cannelli G.B. [6] described that an objective survey was made of rush-hour traffic noise in Rome, on a statistically representative number of sites included in an area covering the historical centre. The mean values of the statistical noise levels L_{90}, L_{50} and L_{10} i.e. of the noise levels exceeded for 90 per cent, 50 per cent and 10 per cent, respectively, of measuring time, were very close to those obtained during an investigation in Madrid and much higher than data from a 'London Noise Survey'. For the purposes of a subjective evaluation of noise in various types of site in Rome, the nuisance indices of noise proposed by a few investigators were also determined and compared against each other.

Williams D. et al [7] presented that data are given of noise spectra obtained in the cabs of new, and in-service, heavy goods vehicles having gross vehicle weights up to 40 tons. Comparisons are made between dB (A) and linear sound pressure levels under motorway conditions at 30, 40 and 50 mile/h. The emphasis has been on the collection of data, particularly in the infrasonic region, which lies in the octave bands between 2-20 Hz. The results confirm that high levels of infrasound exist in the cabs and these levels are, possibly, influenced by the ventilation of the cab and the road speed. The data obtained are discussed from the points of view of hearing hazard, impaired vigilance, and possible dangers arising from infrasound. It is concluded that in the noisier vehicles there is certainly a danger to hearing, and from available data on the effects of noise in the laboratory and in industry, there is probably some effect on vigilance. The extent of the possible hazard of infrasound is less well established and a need for further research is pointed out.

Clayden A.D. et al [8] described a mathematical model for the prediction of traffic noise levels in an urban or suburban situation. At the present time, only noise levels produced by stationary sound sources have been considered. Any paint in a chosen area is described by its grid co-ordinates. A detailed plan of the buildings or other structures in the area and the position(s) of the sound source(s) are needed as input to the model. Noise levels at all grid positions in the area are then calculated on the basis of the attenuation of sound due to direct propagation, diffraction and reflection. The results obtained, so far are given and since the model is in an early stage of development, and has yet to be proved against measurements in real situations, possible refinements and future developments are discussed in some detail.

Delany M.E. et al [9] have developed an improved procedure for predicting noise levels L_{10} from road traffic. The new method has been adopted for use within England and Wales in connection with the noise Insulations Regulations 1975 and for other aspects of planning.

Benedetto G. et al [10] described an objective traffic noise survey of Turin, an industrial town in north Italy. The main objects of the investigation were to determine the nature and level of outdoor traffic noise in an actual urban situation and to verify the relationships between level of traffic noise, traffic volume and traffic composition. Noise measurements were performed at 70 locations uniformly distributed over the town, in the autumn of 1974. A ten-minute record was made at each site ever), hour for 23 hours. The results are presented and compared with published data from previous surveys carried out in other European and North American towns.

Burgess M.A. [11] summarized a method for the prediction of the noise levels from road traffic, developed at the National Physical Laboratory (NPL), and has been used for comparison with measured values of road traffic noise in the Sydney Metropolitan Area. As the comparison was not good, multiple regression analysis, using the basic format of the NPL formula, was performed. A better comparison was obtained from a formula in which the term relating to the average road speed of the vehicles was excluded. This new formula permits a simple graphical representation for the determination of L_{10} for urban traffic. A similar formula and graph for the determination of L_{eq} is also provided.

Ko N.W.M. [12] introduced the extensive roadside noise measurements of 20000 vehicles in 100 measurement sites in the high-rise city, Hong Kong. The vehicles are classified into petrol-powered saloon, diesel-powered saloon, mini-bus and small lorry, and bus and big lorry. The survey was mainly concentrated in the urban areas. However, rural areas were also included in the investigation such that comparison with the urban areas could be made. The results obtained illustrate the effect of enclosed environment on the noise emitted by the vehicles and support the simple classification of the sites into closed, semi-closed and open environments. Distinct differences in the sound pressure levels observed in these environments have been found.

Yeow K.W. et al [13] determined the time-averaged overall mean-square sound pressure created by statistically stationary traffic traveling a finite, straight road segment explicitly. This result is extended to a system of roads by using digital simulation. Theoretical predictions for a typical urban conurbation show encouraging agreement with measured values. Therefore the technique appears to offer a practical means of evaluating community plans before the introduction of road systems and changes in trunk routes and traffic controls, etc., are realized.

Yeowart N.S. et al [14] collected responses to a social survey were from residents of 27 different sites in the Greater Manchester area. The sites were exposed to noise emanating from (a) freely flowing traffic on urban roads, or (b) motorway traffic, or (c) congested or disturbed traffic flow on urban roads. Existing noise indices were tested on this general sample of traffic flow situations to determine their efficacy in the prediction of community dissatisfaction to traffic noise. No existing index could handle adequately all the traffic flow conditions. When the indices were combined with measures of traffic volume flow between midnight and 6 a.m. a marked improvement in their predictive capability was noted. In particular, extended indices based on L_{10} (18 hour) and L_{eq} appeared to be useful predictors of community response to all of the traffic flow situations studied in this project.

Gilbert D. [15] has developed an equation for predicting L_{10} noise levels for roads where interrupted flow traffic exits. This summarizes the initial work carried out at Imperial College to develop provisional prediction equation. It then describes how the equation was tested and modified by using data recently acquired at Sheffield and Rotherham. The provisional equation includes a variable, the index of dispersion, whose value cannot at present be predicted. But an alternative equation is described which uses only currently predictable variables. It is based on the data from Sheffield and Rotherham.

Ko N.W.M. [16] reported extensive results of traffic noise measured at 258 roadside sites in the high-rise city of Hong Kong. From the results of this investigation the measurement sites can be very simply classified into three categories: enclosed, semi-enclosed and open. Distinct differences were found in the sound pressure levels L_{10}, L_{50} and L_{90} and in the standard deviations obtained at the enclosed site and at the semi-enclosed and open sites.

Bodsworth B. et al [17] established the dominating influence of road traffic on the noise climate of the world's cities and attempts to reduce the problem follow two main lines: The first involves ameliorating the effects of traffic stream noise; the second an attack on the noise levels of individual vehicles. The great expense involved in developing and building quieter vehicles justifies expending considerable effort in establishing the relative noise contribution of the vehicle types found in typical urban traffic mixtures. This paper describes the development of a field method for examining the effects of heavy vehicles such as trucks and buses on the noise profile of the traffic stream. The essential feature of the method involves synchronization of a recorded voice commentary with the traffic noise. The graphical record of this noise can then be annotated to show what type of vehicles cause the peaks in the overall noise profile.

Mulholland K. A. [18] describe the development of means of using a scale model of a road and its surrounding urban environment to predict L_{eq}, L_{10} and other measures of traffic noise. The model described is that of the Centre Scientific Technique du Batiment, Grenoble, France. The problems involved in the development include allowance for relative sound absorption between real life and the model situation, the constraints on the accuracy of the results due to noise source variations on the model and the effects of the finite size of the model.

Kerber Gabriela et al [19] describe principles of modeling traffic noise using an optical scale model. The main difference between this model and the widely used 'acoustical' scale model is that it makes use of light instead of sound. There were four phases to the study. The first of these involved the propagation of single vehicle noise over ground and its dependence upon distance and vehicle velocity. The second phase was concerned with light emitted by a small lamp, which imitated a single vehicle. The third part of the work dealt with the principles of the optical model, its construction and use in predicting the equivalent level, L_{eq}, of traffic noise. Finally, a model of a part of a residential area of Poznati, Poland, was built and values of L_{eq} computed. These results were compared with field measurements.

Ko N.W.M. [20] presents the findings of a further analysis of the results of road traffic noise measurements made in a high-rise city. The means and standard deviations of the sound pressure levels within the industrial, commercial, commercial/residential and residential areas are only very marginally different from one another.

El-Sharkawy A.I. et al [21] presented measurements and analysis of traffic noise in the residential area of Jeddah city. These measurements are aimed to help in predicting the subjective response to noise as a function of measured predicted sound levels. L_{10}, L_{50} and L_{90} were predicted for different sites, the traffic noise index and the noise pollution index, LNP, were estimated. Noise data were correlated to the individual respondent's reaction. Linear regression analyses were performed between noise exposure and dissatisfaction response.

Tang S .H. et al [22] carried out a comprehensive survey and statistical analysis of daytime traffic noise in Singapore. The results are presented in terms of average L_{10}, L_{50} and L_{90} for four different classes of sites. By clearly distinguishing between temporal and spatial noise fluctuations, it is possible, on the basis of the Gaussian noise distributions obtained, to verify that the overall noise fluctuation can also be derivable from the respective temporal and spatial noise fluctuations. The traffic noise index (TNI) and the noise pollution index (LNP) are determined and a correlation is established between the traffic noise levels and the corresponding volume of traffic.

Hood R.A. [23] prescribed the method of calculating road traffic noise in order to determine entitlement to noise insulation, the method described is now frequently used to determine the impact of new roads at the Public Inquiry stage. Since publication, vehicle regulations have changed, as has tyre design. The accuracy of the calculation method is examined, taking into account these factors, and also possible errors owing to meteorological and road-surface effects.

Radwan M.M. et al [24] described a computer model for predicting noise levels generated by urban road traffic under interrupted flow conditions. The model is composed of two subsections. The first predicts the propagation characteristics of sound in typical street configurations and the second simulates the flow of road traffic in urban areas. The two subsections are combined to yield a model capable of predicting traffic noise levels in urban conditions. Predictions obtained from application of this model are compared with those given from application of predictive models based upon field measurements. The agreement between the predictions is good. It is shown that the model described in this paper can predict noise levels for situations which existing field-based models cannot handle.

Sandburg Ulf [25] described that unacceptable errors in the prediction of traffic noise occur in some cases when the road surface is largely different from that on which the prediction model is based. The reason is that tyre/road noise has appeared to be the dominating component of the noise from free-flowing traffic and that this noise is to a substantial extent dependent on the road surface. The mechanisms for tyre/road noise generation and its relation to road characteristics are described. Relevant road surface characterization methods are suggested. The major method is the measurement of the road texture profile and subsequent spectral analysis of the profile curve. Supplementary methods concern the measurement of acoustical and mechanical impedances. It is concluded that the road surface effect on traffic noise is extremely complicated and that it is very difficult to generalize any simple relations. For free-flowing traffic it is shown that the tested road surface types and conditions may influence the traffic noise by up to 11 dB (A). This calls for a correction term for the road surface in the prediction models. Despite the complicated relations, it appears feasible---within stringent limitations—to use a table where the correction term is a variable of vehicle type, vehicle speed as well as road surface type and condition.

Hammad R.N.S. et al [26] have developed the measured values of the sound pressure level (L_{10}) resulting from traffic noise measurements over periods of 1 h and 18 h. These measurements were done daily over long and difficult periods, and at different periods and at different locations, in the greater Amman (Jordan) area. Measured values are presented versus the numbers of vehicles accounted for at the time of measurement. Comparisons between calculated and measured levels for both Amman and other cities are given. Annoyance, from the traffic noise, to the people living around the measurement sites is given in a percentage form.

Bjorkman M. [27] developed certain field investigations which have shown that the correlation between the extent of annoyance due to road traffic noise and the noise dose expressed in Leq is rather poor. A higher correlation was found when the expression of the noise dose was based upon the maximum noise level (MNL) from the single noisiest event. To determine the relation between L_{eq} and MNL according to different principles, 24-h measurements were made for a period of 5 days in 18 streets with various types of traffic noise exposure. Analyses were made of the variation in MNL during different times of day and of the correlation between MNL during different times of day and of the correlation between MNL and other noise indices. L_{eq}, and MNL during day, evening and night were not related. It is suggested that investigations be performed focusing on the extent of annoyance in streets with similar L_{eq} values where the MNL for day, evening and night is different.

Ramalingeswara Rao P. et al [28] described that the environmental noise level due to motor vehicle traffic to a first approximation is a function of traffic volume. The values of sound pressure level (L_{10}) resulting from traffic noise measurements over one-hour periods have been correlated with the equivalent measured numbers of heavy, light vehicles per hour (traffic density). A statistical analysis of the data has been made to enable L_{10} be expressed in terms of the traffic density in the city of Visakhapatnam, India in 1986 and 1987. Plots of L_{10} against logarithm Nh (equivalent heavy vehicle density) and logarithm N1 (equivalent light vehicle density) for the different zones, as well as for the entire city have been made. The validity of these equations is tested by computing the values of the noise indices from these equations, using the traffic density data and comparing them with the measured values. The difference between the measured and calculated values is very small.

Kumar Krishan et al. [29] carried out a survey of traffic noise in the city of Delhi in order to examine the nature and levels of noise inside various types of vehicle. The study involved measurements of average A-weighted levels and power spectra of noise inside buses, auto-rickshaws, cars and trucks from which L_{10}, L_{50}, L_{90} and L_{eq} levels were estimated. It is found that noise levels in auto-rickshaws are the highest, followed by trucks, buses and cars. The power spectra o fall four types of vehicle exhibit rather similar behavior.

Bjorkman M. et al [30] performed manual and automatic noise measurements made along 13 streets in Gothenburg, Sweden to explore sources of maximum noise levels. Noise from different types of vehicles driven in a realistic way in inner city traffic was measured. In summary, the result show that the most important vehicle component as regards the maximum noise level in inner city traffic was a medium weight truck "delivery truck'. Among the higher noise levels measured (>80 dB (A)) this type of vehicle is dominant. This is supported by tests that demonstrated that the noise level of a light truck, driven in a realistic way, exceeds that of cars and is on the same level as heavy trucks .Measures can be taken against the noisiest vehicle types specifically, and the noise load can be limited by introducing noise bans for particular streets in which vehicles that emit greater than a certain noise level would not be allowed use of the street.

Cvetkovic Dragan,et al [31] introduced the results of traffic noise prediction based on NAISS-model obtained by trending of the experimental data collected by systematic noise measurement in urban areas of Nis as well as comparative analysis with other models will be shown.

Thanaphan suksaard et al [32] developed a road traffic noise prediction model for environmental impact assessment in Thailand. The model was made under assumptions; vehicles were classified into two groups and the average stationary noise level of each group was then determined from measurement of many vehicles. The power level of each group was determined by measuring the noise level of running vehicles. The average power level of running vehicles was subsequently described by a relationship between power level and the logarithm of the vehicle speed. Predicted noise levels were then compared with measured traffic noise levels from different roads involving 2,4,6,8, and 10 lanes. The model is found accurate within +/- 3 dB (A) and it can be used for flat road traffic noise prediction in the cases of 2, 4, 6,8,10 lane roads.

Moehler U. et al [33] carried out a field study between 1994 and 1998; the noise impact as well as psychological reactions in four areas exposed either to railway or to road traffic noise were measured for 1600 persons. Furthermore, body movements during sleep were assessed for about 400 persons by actimeters. The noise impact was determined by noise measurements and calculations inside and outside the bedrooms of all persons concerned and was described by different acoustical indices. The psychological reactions were recorded by questionnaires. The analyses show typical differences in the acoustical and psychological factors between road and rail traffic noise; on the other hand, the differences with regard to body movements are rather low. There is also a high correlation between the acoustical and psychological variables for both road and rail traffic Sources, whereas the correlations between the body movements on the one hand and the acoustical and psychological variables on the other are rather low.

Campbell Steele [34] reviewed that traffic noise prediction models in the 1950s and 1960s were designed to predict a single vehicle sound pressure level L_p at the road side. These models were based on constant speed experiments, the predicted levels then being expressed as functions of speed, and with zero acceleration. Later models were not intended to predict single vehicle levels but to predict the equivalent continuous level L_{eq} for traffic over a chosen period. Still later models predicted L_{eq} under interrupted and varying flow conditions. Early models predicted linear levels whereas the later models predicted A-weighted levels. Several more recent models predict one-third octave band spectra. Six commonly used models and others under development are reviewed.

Bengang Li et al [35] predicted a suitable road traffic model for use in China. This model is based on local environmental standards, vehicle types and traffic conditions. The model was accurate to 0.8 dB (A) at locations near the road carriage way and 2.1 dB (A) within the housing estate, which is comparable to the FHWA model. An integrated Noise-GIS system was developed to provide general functions for noise modeling and an additional tool for noise design, where a new interaction mode in ''WHAT IF Question/Explanation'' format was used. Application of this system offered improvements in the efficiency and accuracy of traffic noise assessment and noise design.

Bengang Li et al [36] performed a survey and analysis of traffic noise along three main roads in the Beijing urban area—the 2nd and 3rd ring roads circling the central downtown area and Chang-An Avenue, a major east—west corridor road through the heart of the city. The results indicate that these main roads are overloaded by traffic flow during daytime and noise levels due to road traffic along these roads are above relevant environmental standards by 5 dB (A). The spatial variance of traffic noise was also analyzed, with the results indicating that the spatial differences result primarily from the unbalanced development of Beijing's urban districts.

Pamanikabud Pichai et al [37] formulated a model of highway traffic noise based on vehicle types. The data were collected from local highways in Thailand with free flow traffic conditions. First, data on vehicle noise was collected from individual vehicles using sound level meters placed at a reference distance. Simultaneously, measurements were made of vehicles-spot speeds. Secondly, are data for building the highway traffic noise model. This consists of traffic noise levels, traffic volumes by vehicle classification, average spot speeds by vehicle type, and the geometric dimension of highway sections. The free-flow traffic noise model is generated from this database. A reference energy mean emission level (the basic noise) level for each type of vehicles is developed based on direct measurement of L_{eq} (10 s) from the real running condition of each type of vehicles. Modification of terms and parameters are used to make the model fit highway traffic characteristics and different types of vehicle.

Rylander R. et al [38] measured noise levels from different kinds of vehicles on streets close to road bumps. In comparison with free flowing traffic, the acceleration after road bumps increased peak noise levels from 1 to 13 dB (A) max. Although the results are of a pilot nature, it is suggested that noise consequences should be included in the planning of road bumps.

Gaja E. et al [39] summarized 5 years of continuous noise measurements carried out at one of the most important squares in Valencia (Spain). The chosen square is a clear hotspot for traffic noise in a large city. The aim of this study is to determine the appropriate measuring time in order to obtain a 24-h noise level suitable to represent the annual equivalent level. Our findings allow us to reach a number of conclusions in terms of the most suitable urban traffic noise measurement techniques. If the sampling strategy involves measurements on randomly-chosen days, then at least 6 days should be used.

Tang S.K. and Tong K.K. [40] carried out traffic noise measurements on the kerbs of 19 independent inclined trunk roads with freely flowing traffic within the residential areas of Hong Kong are carried out in the present investigation. The performance of the existing noise prediction models in predicting traffic noise from inclined roads is evaluated. By regression analysis and simple physical consideration of the traffic noise production mechanisms, formulae for the prediction of the L_{10}, L_{50}, L_{90} and L_{eq} are developed or recalibrated. Results suggest tire noise has the major contribution to the overall noise environment when the Source is an inclined trunk road. Also, the road gradient is found to have a higher contribution to the traffic noise than assumed in the existing models, but becomes unimportant when the background noise level L_{90} is concerned.

Paoprayoon Suwajchai et al [41] modeled an interrupted flow traffic noise at a signalized intersection. The models are mathematically derived by applying the inverse square law of sound pressure incorporating with theories of traffic flow at an intersection. The traffic flow theories utilized for developing the model consist of characteristics of individual vehicle motion at intersection, shock wave model, and queuing analysis. The model formulation is divided into two different approaches and takes into account of all regimes of vehicle movement while traversing an intersection (i.e. idling, decelerating, accelerating, and cruising conditions). The first approach assumes a constant acceleration/deceleration rate for each type of vehicle. Another applies inconstant acceleration/deceleration which comes from speed-distance relationship. The final models are expressed in L_{eq} (1 hr).Eventually; the developed models are validated by collecting equivalent continuous noise level in 1 min as well as traffic parameters (i.e. red time, number of vehicle in the queue, queue length, time of queue dissipation, and final cruise speed) from fifteen vehicle platoons. The noise levels predicted from the developed models are compared with the measured ones. The results show that the inconstant acceleration model gives the predicted levels closer to the measured ones than constant acceleration model. It might be concluded that movement characteristic of vehicle is an important factor that apparently affects the accuracy of traffic noise prediction at an intersection.

Tansatcha M. et al [42] obtained a model for motorway traffic noise from measurements along the Bangkok–Chonburi motorway. The model’s parameters include traffic volume and combination, the average spot speed of each type of vehicle and the physical conditions of the motorway in terms of right-of-way width, number of lanes, lane width, shoulder width, and median width for both of the main carriageways and frontage roads. The noise level that is generated by each type of vehicle has been analyzed according to the propagation in the direction perpendicular to the center line of motorway's carriageway. The total traffic noise is then analyzed from traffic volume of all vehicle types on both sides of carriageways and frontage roads. The basic noise levels used in the motorway traffic noise model are modified according to the effective ground effect along the propagation path. The final result of this study is that a motorway traffic noise model based on the perpendicular propagation analysis technique performs well in a statistical goodness-of-fit test against the field data, and therefore, can be used effectively in traffic noise prediction.

Golmohammadi R., Abbaspour M., Nassiri P., Mahjub H [43] described that 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. In addition, sometimes are used in the assessment of existing or envisaged changes in traffic noise conditions. In this paper a statistical modeling approach has been used for predicting road traffic noise in Iranian road conditions.

Dhananjay K. Parbat and Prashant B. Nagarnaik, [44] described that the noise generated from vehicular traffic is a major source of environmental pollution. In this paper a comprehensive study on the assessment and ANN (Artificial neural network) modeling of noise levels due to vehicular traffic flow at interrupted traffic flow conditions had been done in Maharashtra state of India. In this modeling Elite ANN software was utilized. Total traffic, traffic composition (Bus/Truck), LCV (Light commercial vehicle), TW (Two wheelers), bicycle and others in % and carriageway width, distance of sound level meter from pavement edge were considered as input data. The observed input and output data were processed using ANN at interrupted traffic flow conditions. The output was estimated as L_{10}, L_{eq}, LNP, TNI and NC. The performance of the model was tested by root mean square error (RMSE), the mean absolute error (MAE) and correlation coefficient. The model was validated using linear regression analysis where it was observed that there is no significant difference between the observed and predicted output parameters.

Sh. Givargis et al [45] described the methodology through which the UK calculation of road traffic noise (CORTN) has been converted to the algorithms that are able to calculate hourly A-weighted equivalent sound pressure level (L_{eq}, 1h) for the Tehran's roads. The methodology adopts two different approaches to model calibration and performance test through the holdout validation method on the basis of the database including 52 samples taken from 52 sampling stations located alongside 5 roads of Tehran at distances less than 4 m from the nearside carriageway edge. As to the CORTN manual the distances less than 4 m are considered to be equal to 4 m. In the first approach the model is calibrated through carrying out nonlinear regression parameter estimation using 50% of samples to replace the basic noise level parameters with the new ones that are presumably able to satisfy the objective of the study with an acceptable fitness of the model. In the second approach the model calibration is carried out on the basis of 30 measurements taken from 2 roads. In the next step the other subsets of samples are introduced into the calibrated equations to conduct the performance test.

Banerjee D.et al [46] discussed the observations, results and their interpretation based on the study. The objectives of the study were to monitor and assess the road traffic noise in its spatial-temporal aspect in an urban area. Noise recordings from site, collected from April 2006 to March 2007, were used for statistical analysis and generation of various noise indices. The study reveals that present noise level in all the locations exceeds the limit prescribed by CPCB. Based on the finding it can be said that the population in this industrial town are exposed to significantly high noise level, which is caused mostly due to road traffic.

Pamanikabud P. et al [47] reported here to build a highway traffic noise simulation model for free-flow traffic conditions in Thailand employing a technique utilizing individual vehicular noise modeling based on the equivalent sound level over 20 s (L_{eq}20 s). This L_{eq} 20 s technique provides a more accurate measurement of noise energy from each type of vehicle under real running conditions. The coefficient of propagation and ground effect for this model was then estimated using a trial-and-error method, and applied to the highway traffic noise simulation model. This newly developed highway traffic noise model was tested for its goodness-of-fit to field observations. The test shows that this new model provides good predictions for highway noise conditions in Thailand. The concepts and techniques that are modeled and tested in this study can also be applied for prediction of traffic noise for local conditions in other countries.

Based on literature review it has been found that in most of the countries L_{10} or L_{eq} noise parameters, are used for traffic noise modeling but in India the permissible standards are available for L_{eq}. Keeping this in view, the model for mathematical predicting L_{eq} and L_{10} has been tried in the present work. The various researchers have shown their interests in the following directions:

1. Establishment of various highway noise descriptors and criteria.
2. Assessment of highway noise.
3. Undertaking traffic noise survey.
4. Establishment of different parameters affecting traffic noise.
5. Formulation of mathematical models.

CHAPTER-4

EXPERIMENTAL INVESTIGATION

4.1 NATURE OF NOISE PROBLEM

Traffic noise prediction models are required as aids in the design of roads and sometimes in the assessment of existing or envisaged changes in traffic noise conditions. They are commonly needed to predict sound pressure levels, specified in terms of L_{eq}, L_{10} etc. Several models have been developed via a regression analysis of experimental data from fundamental variables such as traffic flow, speed of vehicles etc. A survey of the area revealed that the major contribution to the noise is from traffic with substantially high percentage of heavy vehicles. The average speed of the vehicles was found within range of 35-60 km/h. The noise nuisance was aggravated by the indiscriminate horn blowing, rapid accelerations and overtaking.

4.2 SITE SELECTION

To develop mathematical model for predicting the traffic noise, the first task was site selection. So, according to surveys of different areas and nature of noise problem, a two lane straight patch where continuous flow of vehicles occurs, without any obstructions like traffic signal lights etc. was selected at Patiala-Sangrur Highway (NH-64) (1.5 km from Rajindra Hospital), Patiala. Microphone is placed at a height of 1.0 meter and at distance of 10.0 meter from divider of the lane. (Fig. 4.1)

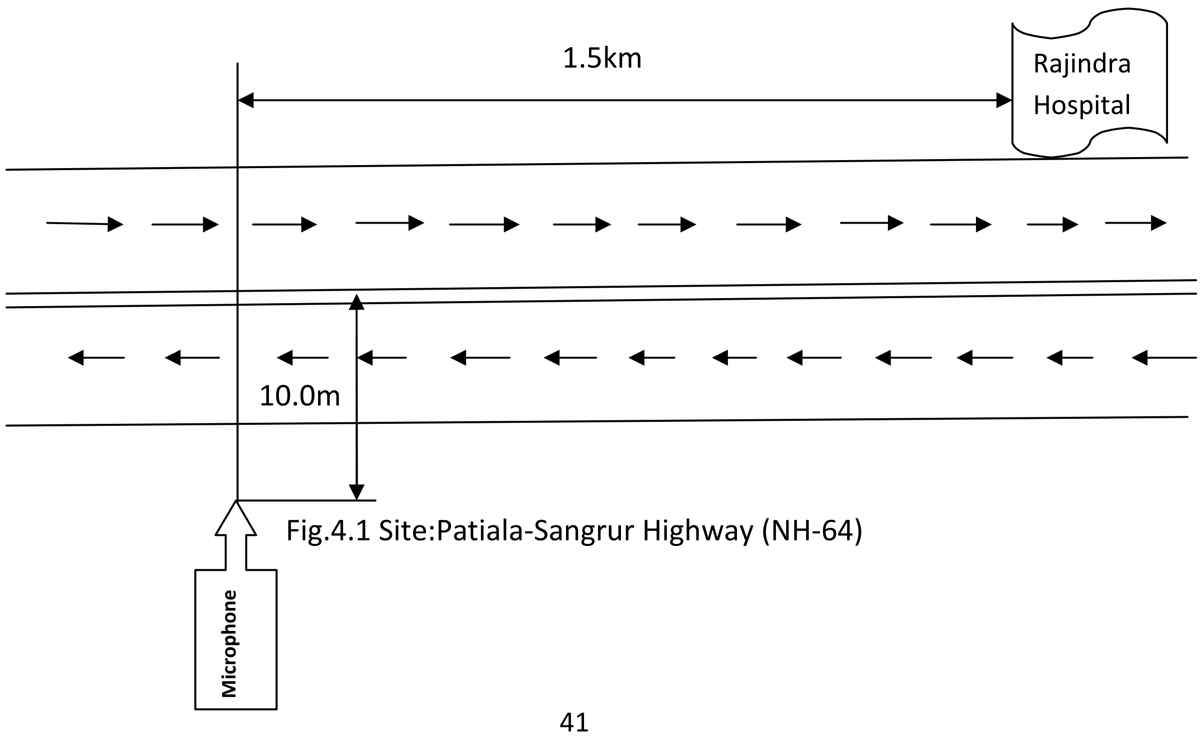

Fig.4.1 Site:Patiala-Sangrur Highway (NH-64)

4.3 METHODOLOGY

The techniques generally employed in the measurement and analysis of noise using commercial equipment, are now discussed.

Problem definition:

First step in noise measurement is to define the problem clearly, for which a series of questions are to be answered.

1. Why are the measurements to be made?

Ans. In the present study to develop road traffic noise model.

2. Where are the measurements to be made?

Ans. The measurements are to be made on Patiala-Sangrur Highway (NH-64) (1.5km from Rajindra Hospital), Patiala.

3. Are there unusual environmental problem which require protective measures?

Ans. Wind on a microphone produces a noise which may seriously affect the accuracy of a measurement. In high winds (above about 20 km/h), the noise to be measured tends to be masked by wind noise. This wind noise can be reduced significantly by the use of wind screen. These screens are commonly spherical balls or porous foamed plastic that fit over the microphone, and have negligible effect on the frequency response of the microphone.

4. What acoustic data is required?

Ans. The required acoustic data are L_{eq}, L_{10} etc.

5. Is there any allied data required?

Ans. The number of vehicles that pass through a fixed point on the highway in a given period of time.

6. What is accuracy must be required for data?

Ans. +/- 1 dB (A) is the required accuracy, which is a feasible one.

7. What are the major noise sources?

Ans. The noise due to the vehicles that pass through the nearby highway.

8. What are the operational characteristics of the noise source?

Ans. During day time the traffic intensity is very high on the highway. There is no legislation restricting the usage of horns and the type of vehicles. There will be steady noise generated due to the movement of vehicles. Horn sounds are made frequently.

4.4 MEASUREMENT PROCEDURE

For traffic noise problems it is useful to know the equivalent continuous sound level L_{eq} and the 10 percentile exceeded sound level L_{10}. Such information is obtained using a sound level meter (CESVA SC 310).

The sound level meter should be suitably calibrated. The microphone mounted on a tripod should suitably leveled with air bubble at a height of about 1.0 m from the ground. (Fig.4.2)

The noise measurements recorded are L_{eq}, L_{10}, L_{max}, L_{min}.

Values of L_{max} have measured to give the idea about maximum noise levels measured. Unusually high values of L_{max} represent the cases of vehicles honking continuously or the vehicles are without proper silencers, etc.

Values of L_{min} represent the minimum noise levels measured.

Fig. 4.2 Sound level meter on a tripod with windscreen

4.5 MEASUREMENTS

Traffic noise was measured at the selected site as per the procedure. The vehicle count was also made during the measurement period. Vehicles are divided into seven categories according to Indian conditions (Appendix A). The temperature, humidity and wind conditions were also monitored throughout.

A large number of 15 minutes measurements at the same site were repeated on different dates and timings in a random manner in order to account for statistical temporal variations in traffic flow characteristics.

Noise measurements parameters L_{10}, L_{eq}, L_{max} and L_{min} were recorded (Appendix B). Average velocity of vehicles was also measured with manual method. (Appendix C).

The following settings were kept on the sound level meter for the above measurements:

Table 4.1

Time weighting	"Slow"
Pre-set time	"15 minutes"
Frequency weighting	"A"
Displayed parameters	L_{eq},L_{10},L_{max} and L_{min}

CHAPTER-5
RESULTS AND DISCUSSIONS

5.1 MODELING OF TRAFFIC NOISE

Modeling of traffic noise has several uses, including estimating current noise exposure along roadways, assessing the effect of roadway changes, and predicting the performance of noise abatement options. The basic elements of traffic noise modeling are the traffic source levels and the propagation or attenuation of sound between traffic and receiver. Typical source related inputs to traffic noise models are the speed and volume of vehicle types, operating mode of the vehicles and the length of roadway with line of sight to the receiver location. Propagation related inputs include the acoustic characteristics of the ground, the number of lanes of travel, site geometry and topography and the type of geometry of any barriers or buildings present. Most models also consider the type of pavement at the site in regard to tyre-pavement noise generation, the prevailing wind and temperature conditions and interrupted traffic flows. There are a number of resources that can be consulted for additional, detailed information about traffic noise prediction methods [58].

Embedded in traffic noise prediction routines are some assumptions about the vertical distribution of source strength on the vehicles for the operating mode under consideration. Knowledge of source height is critical for predicting propagation effects and the effectiveness of the barriers. Under cruise conditions for properly maintained cars and trucks, tyre-pavement noise typically begins to dominate power train noise at speeds above about 40 km/h. For trucks, the speed is found to be more in the range of 50 to 60 km/h. At any speed in which tyre-pavement noise dominates, the source is known to be very close to the ground, within about 100mm. At lower speeds, the distribution is skewed more to power train sources. For light vehicles, noise to the side of the vehicle comes from underbody area and wheelwell areas near the engine compartment and from the exhaust outlet. These source regions are also relatively close to the ground, typically within one meter of the ground. For trucks, the engine compartments are higher, 1 to 2 m above the ground. As a result, traffic models often rely on partial data [58].

To develop road traffic noise a relationship is found between two or more variables and these relationships are expressed in mathematical form. Followings are steps followed:

Step 1

Collect the data showing corresponding values of variables. (Table 5.1)

Step 2

Plot the graphs

L_{10} Vs Q, L_{10} Vs P, L_{10} Vs V, L_{eq} Vs Q, L_{eq} Vs P and L_{eq} Vs V.

From the scatter diagram it is possible to visualize a nature of relationship between variables. Figures (5.1-5.6)

Step 3

The curve fitting can be carried out by using multiple linear regression analysis softwares "StatPro" and "SPSS". By regression analysis [57] mathematical equation for L_{10} and L_{eq} can be developed. Computer output of regression analysis is shown in Tables (5.2-5.5).

A t-paired test is also applied to test the model for goodness of fit. Output for t-test is also shown in Tables (5.2-5.5).

Site: Patiala Sangrur Highway (NH-64) (1.5 km from Rajindra Hospital)

Measurement period: 15 minutes

Microphone at 10 meter from the centre of the inner lane and at height of 1.0 meter

Table 5.1 (Data combined for all days)

Date & Time	Traffic volume Q (Veh/h)	Heavy vehicles % (P)	Average vehicle speed V (km/h)	Sound pressure level dB (A)			
				L_{eq}	L_{10}	L_{max}	L_{min}
Date:07/04/2010 (Wednesday)							
09:00-10:00 AM	1480	36.7	46.0	77.8	79.4	96.2	55.9
10:00-11:00 AM	1395	35.9	44.3	76.8	79.6	93.4	56.6
11:00-12:00 AM	1510	38.6	50.0	79.0	80.1	102.1	57.0
12:00-01:00 PM	1475	37.2	45.0	77.8	81.5	100.3	57.5
02:00-03:00 PM	1485	38.7	43.0	77.8	80.8	99.5	56.4
03:00-04:00 PM	1435	36.5	42.9	77.1	79.2	96.9	54.2
04:00-05:00 PM	1495	37.1	45.8	78.2	80.5	99.0	55.1
05:00-06:00 PM	1400	35.7	45.3	77.0	79.8	95.5	54.7
Date:09/04/2010 (Friday)							
09:00-10:00 AM	1460	37.9	43.4	77.7	79.2	99.6	55.3
10:00-11:00 AM	1380	35.8	44.3	76.7	78.8	97.9	56.7
11:00-12:00 AM	1350	34.7	44.2	76.5	78.1	98.7	56.6
12:00-01:00 PM	1450	39.6	44.7	77.7	79.0	101.0	56.9
Date:10/04/2010 (Saturday)							
09:00-10:00 AM	1440	40.7	41.6	77.5	78.8	98.0	54.6
10:00-11:00 AM	1480	45.2	45.0	78.1	79.9	99.4	53.4
11:00-12:00 AM	1410	41.6	43.3	77.1	79.1	98.3	53.7
12:00-01:00 PM	1445	40.6	40.7	77.7	79.9	97.6	55.5
02:00-03:00 PM	1490	44.7	45.3	78.8	80.2	99.8	54.8

Date & Time	Traffic volume Q (Veh/h)	Heavy vehicles % (P)	Average vehicle speed V (km/h)	Sound pressure level dB (A)			
				L_{eq}	L_{10}	L_{max}	L_{min}
03:00-04:00 PM	1460	46.5	44.7	78.4	79.0	100.2	52.9
04:00-05:00 PM	1440	42.4	44.9	77.8	80.7	99.1	51.3
05:00-06:00 PM	1430	41.0	44.5	77.3	80.2	97.8	52.4
Date:10/04/2010 (Sunday)							
09:00-10:00 AM	1430	40.2	45.2	77.5	78.1	101.8	55.1
10:00-11:00 AM	1390	45.3	44.6	77.0	77.7	99.2	57.0
11:00-12:00 AM	1380	46.7	43.1	76.8	77.9	102.5	55.8
12:00-01:00 PM	1435	42.2	44.3	77.7	80.0	103.0	55.5
02:00-03:00 PM	1420	39.7	42.1	77.1	78.7	98.8	55.3
03:00-04:00 PM	1450	46.4	44.5	78.2	79.2	100.3	52.0
04:00-05:00 PM	1460	47.1	46.3	77.9	79.5	97.1	54.2
05:00-06:00 PM	1470	48.1	44.9	78.8	80.7	99.5	56.3
Date:14/04/2010 (Wednesday)							
09:00-10:00 AM	1515	48.7	44.1	79.3	80.5	97.9	54.4
10:00-11:00 AM	1320	36.4	43.0	75.3	78.7	93.3	54.3
11:00-12:00 AM	1295	31.3	40.6	75.0	78.5	93.7	52.5
12:00-01:00 PM	1370	36.3	42.4	76.6	79.9	91.2	55.1
02:00-03:00 PM	1425	40.4	42.4	77.1	81.0	96.7	54.2
03:00-04:00 PM	1455	43.4	45.8	78.7	82.5	97.7	53.0
04:00-05:00 PM	1435	41.7	43.6	77.2	82.1	96.1	53.3
05:00-06:00 PM	1440	43.0	44.9	78.3	82.4	99.1	53.2
Date:15/04/2010 (Thursday)							
09:00-10:00 AM	1370	35.4	42.3	76.6	78.8	92.9	55.7
10:00-11:00 AM	1335	37.4	42.5	75.9	77.7	97.8	55.5
11:00-12:00 AM	1360	36.1	41.0	76.1	78.6	97.6	54.7
12:00-01:00 PM	1365	37.2	41.3	76.3	78.5	95.4	57.7

Date & Time	Traffic volume Q (Veh/h)	Heavy vehicles % (P)	Average vehicle speed V (km/h)	Sound pressure level dB (A)			
				L_{eq}	L_{10}	L_{max}	L_{min}
02:00-03:00 PM	1340	36.2	40.5	76.0	78.6	96.8	56.2
03:00-04:00 PM	1350	36.6	41.1	76.0	78.7	94.4	55.3
04:00-05:00 PM	1310	33.1	41.1	75.4	78.3	92.7	52.9
05:00-06:00 PM	1505	44.8	45.8	78.9	80.3	101.2	50.4
Date:16/04/2010 (Friday)							
09:00-10:00 AM	1435	41.0	43.5	77.8	79.8	99.2	55.1
10:00-11:00 AM	1465	47.2	46.4	79.9	80.0	101.8	54.0
11:00-12:00 AM	1445	40.8	41.3	77.6	80.3	98.5	53.6
12:00-01:00 PM	1470	47.4	43.6	78.0	80.6	100.7	55.8
Date:17/04/2010 (Saturday)							
09:00-10:00 AM	1465	46.8	43.1	77.9	79.4	95.9	53.4
10:00-11:00 AM	1475	47.6	43.1	78.0	78.8	99.3	54.3
11:00-12:00 AM	1440	40.8	45.6	77.6	79.7	94.6	52.4
12:00-01:00 PM	1445	42.4	43.5	77.7	79.7	98.5	54.6
02:00-03:00 PM	1450	43.3	45.0	78.0	79.6	98.3	53.9
03:00-04:00 PM	1450	46.5	45.0	78.2	80.4	97.4	52.6
04:00-05:00 PM	1480	47.3	43.8	78.0	80.1	98.3	52.7
05:00-06:00 PM	1460	43.3	45.7	78.5	80.4	95.2	51.4
Date:18/04/2010 (Sunday)							
09:00-10:00 AM	1400	37.4	42.9	76.4	78.7	97.5	54.4
10:00-11:00 AM	1410	38.5	43.4	77.0	78.0	100.2	55.8
11:00-12:00 AM	1405	39.7	42.4	76.8	77.7	100.0	53.1
12:00-01:00 PM	1390	39.2	43.9	76.7	79.8	100.0	54.8
02:00-03:00 PM	1470	47.4	43.8	78.7	80.7	99.5	56.2
03:00-04:00 PM	1460	47.1	44.2	78.5	80.5	98.3	53.4
04:00-05:00 PM	1450	43.0	43.8	77.8	79.4	99.8	54.9

Date & Time	Traffic volume Q (Veh/h)	Heavy vehicles % (P)	Average vehicle speed V (km/h)	Sound pressure level dB (A)			
				L_{eq}	L_{10}	L_{max}	L_{min}
05:00-06:00 PM	1400	39.3	42.9	76.7	78.6	97.1	56.6
Date:19/04/2010 (Monday)							
09:00-10:00 AM	1445	45.3	44.2	77.8	79.9	96.0	53.6
10:00-11:00 AM	1525	47.9	44.7	79.3	82.6	96.6	52.8
11:00-12:00 AM	1535	48.3	44.8	79.5	82.2	98.3	53.6
12:00-01:00 PM	1430	40.0	42.1	77.1	79.7	96.6	53.3
Date:21/04/2010 (Wednesday)							
02:00-03:00 PM	1455	43.4	44.1	78.1	79.6	98.3	52.2
03:00-04:00 PM	1300	31.9	40.0	76.0	78.6	93.8	52.5
04:00-05:00 PM	1480	45.4	45.0	77.9	79.8	96.8	53.9
05:00-06:00 PM	1455	39.7	42.9	76.8	79.4	92.3	56.3
Date:23/04/2010 (Friday)							
09:00-10:00 AM	1450	46.6	44.1	78.1	80.1	97.5	53.2
10:00-11:00 AM	1425	40.7	42.5	77.1	80.2	95.8	54.9
11:00-12:00 AM	1430	44.4	44.9	77.4	80.1	95.1	56.3
12:00-01:00 PM	1420	39.8	42.7	77.1	80.0	93.4	55.3
02:00-03:00 PM	1460	43.4	45.3	78.7	81.4	97.1	54.3
03:00-04:00 PM	1465	44.4	45.9	79.0	80.5	99.3	53.9
04:00-05:00 PM	1530	47.7	44.8	79.3	80.3	97.9	54.5
05:00-06:00 PM	1455	43.9	46.0	78.4	80.8	100.0	55.5
Date:24/04/2010 (Saturday)							
09:00-10:00 AM	1430	41.8	44.8	77.4	79.5	98.5	52.8
10:00-11:00 AM	1435	42.3	45.7	77.5	79.9	98.0	53.4
11:00-12:00 AM	1460	44.9	45.9	78.6	80.6	96.5	53.9
12:00-01:00 PM	1305	32.2	41.8	78.0	80.2	96.6	51.4
02:00-03:00 PM	1470	44.2	45.6	78.9	80.7	97.4	53.6

Date & Time	Traffic volume Q (Veh/h)	Heavy vehicles % (P)	Average vehicle speed V (km/h)	Sound pressure level dB (A)			
				L_{eq}	L_{10}	L_{max}	L_{min}
03:00-04:00 PM	1440	41.2	44.9	77.7	80.0	98.2	53.0
04:00-05:00 PM	1420	42.3	44.4	77.3	79.2	97.3	53.4
05:00-06:00 PM	1465	47.5	44.4	78.5	80.7	94.2	54.2
Date:25/04/2010 (Sunday)							
09:00-10:00 AM	1450	46.5	44.2	78.3	80.2	96.9	54.9
10:00-11:00 AM	1455	47.8	44.9	78.1	80.0	98.7	53.2
11:00-12:00 AM	1450	45.5	44.8	77.9	79.7	97.2	51.8
12:00-01:00 PM	1445	43.1	44.2	78.4	79.7	95.0	51.7
02:00-03:00 PM	1455	46.7	44.4	78.2	80.1	97.4	53.9
03:00-04:00 PM	1510	48.8	43.7	79.1	80.3	98.1	53.6
04:00-05:00 PM	1445	45.9	44.3	78.1	80.1	98.1	56.6
05:00-06:00 PM	1440	46.3	44.7	77.9	79.4	95.0	52.8
Date:28/04/2010 (Wednesday)							
02:00-03:00 PM	1445	47.3	44.7	77.4	79.7	96.8	53.3
03:00-04:00 PM	1445	45.1	44.4	78.1	80.1	98.9	51.6
04:00-05:00 PM	1540	50.4	47.9	79.5	79.2	100.8	53.9
05:00-06:00 PM	1500	48.3	43.3	79.0	79.6	96.2	53.2
Date:03/05/2010 (Monday)							
09:00-10:00 AM	1460	47.3	44.3	78.7	80.6	97.6	52.6
10:00-11:00 AM	1450	48.9	44.3	78.6	80.3	97.7	51.9
11:00-12:00 AM	1495	49.4	45.8	79.0	80.6	99.2	53.1
12:00-01:00 PM	1470	48.4	41.1	79.8	82.0	97.6	52.3
02:00-03:00 PM	1440	49.4	45.5	77.3	79.7	96.2	51.9
03:00-04:00 PM	1390	39.9	42.5	76.2	79.5	97.5	52.8
04:00-05:00 PM	1440	42.0	44.6	77.7	80.3	96.4	53.0
05:00-06:00 PM	1440	41.0	44.7	77.5	79.5	99.0	52.7

Date & Time	Traffic volume Q (Veh/h)	Heavy vehicles % (P)	Average vehicle speed V (km/h)	Sound pressure level dB (A)			
				L_{eq}	L_{10}	L_{max}	L_{min}
Date:04/05/2010 (Tuesday)							
09:00-10:00 AM	1430	40.6	42.2	77.1	78.9	97.8	52.1
10:00-11:00 AM	1415	42.2	44.2	77.3	79.3	99.4	53.1
11:00-12:00 AM	1450	48.6	44.3	78.5	80.0	95.4	53.5
12:00-01:00 PM	1435	41.9	41.8	77.6	79.3	92.7	52.0
Date:10/05/2010 (Monday)							
09:00-10:00 AM	1440	42.4	41.2	77.5	80.0	97.0	53.4
10:00-11:00 AM	1445	43.1	42.3	77.5	79.6	96.9	52.8
11:00-12:00 AM	1450	45.4	44.2	78.0	79.5	99.6	52.3
12:00-01:00 PM	1455	40.6	42.9	76.9	79.2	97.2	52.6
02:00-03:00 PM	1445	45.2	42.2	78.2	80.1	97.0	53.1
03:00-04:00 PM	1410	41.7	43.9	77.1	79.0	96.6	53.1
04:00-05:00 PM	1450	46.9	44.2	77.9	80.5	99.8	52.6
05:00-06:00 PM	1420	40.6	43.0	76.8	79.3	95.5	52.3
Date:11/05/2010 (Tuesday)							
09:00-10:00 AM	1440	43.9	42.3	77.4	79.3	94.6	52.5
10:00-11:00 AM	1445	41.6	44.2	77.8	79.9	96.6	54.7
11:00-12:00 AM	1415	41.3	42.1	77.1	79.0	98.1	52.8
12:00-01:00 PM	1445	45.3	44.4	77.9	80.0	97.7	52.0
02:00-03:00 PM	1430	41.7	44.4	77.3	79.1	97.4	53.3
03:00-04:00 PM	1370	35.5	42.4	76.6	78.6	98.3	53.9
04:00-05:00 PM	1450	48.8	44.1	78.4	80.0	97.8	52.6
05:00-06:00 PM	1425	41.9	43.9	77.2	79.4	96.2	51.7
Date:12/05/2010 (Wednesday)							
09:00-10:00 AM	1380	38.5	43.7	77.0	79.3	96.1	53.7
10:00-11:00 AM	1415	41.3	44.3	77.1	79.1	98.1	52.2

Date & Time	Traffic volume Q (Veh/h)	Heavy vehicles % (P)	Average vehicle speed V (km/h)	Sound pressure level dB (A)			
				L_{eq}	L_{10}	L_{max}	L_{min}
11:00-12:00 AM	1505	45.6	44.1	79.1	80.5	100.3	53.6
12:00-01:00 PM	1435	41.3	43.7	77.4	79.1	97.8	52.8
Date:13/05/2010 (Thursday)							
09:00-10:00 AM	1450	41.3	42.1	76.8	79.0	95.4	53.5
10:00-11:00 AM	1455	45.4	43.2	78.2	80.5	97.8	52.9
11:00-12:00 AM	1410	40.3	44.0	76.7	79.3	96.1	56.3
12:00-01:00 PM	1460	48.4	44.9	78.6	79.7	98.3	56.5
02:00-03:00 PM	1445	46.2	44.4	77.9	79.8	96.3	52.1
03:00-04:00 PM	1395	40.8	43.2	76.8	79.2	99.1	55.5
04:00-05:00 PM	1455	46.7	43.1	78.1	79.9	95.3	52.0
05:00-06:00 PM	1375	37.0	42.4	76.8	79.4	97.1	54.1
Date:14/05/2010 (Friday)							
09:00-10:00 AM	1445	44.5	43.0	77.4	79.3	94.4	53.6
10:00-11:00 AM	1410	41.5	44.4	77.1	79.9	98.7	55.7
11:00-12:00 AM	1450	44.2	43.8	77.5	78.9	97.1	53.1
12:00-01:00 PM	1455	43.5	43.6	77.5	80.3	94.7	54.2
02:00-03:00 PM	1455	48.1	44.2	78.4	80.1	95.2	54.0
03:00-04:00 PM	1445	41.9	43.1	76.8	78.9	97.6	53.2
04:00-05:00 PM	1430	40.5	42.5	77.0	79.2	98.7	52.9
05:00-06:00 PM	1425	41.7	43.5	77.4	78.9	98.2	52.7
Date:17/05/2010 (Monday)							
02:00-03:00 PM	1380	38.1	42.5	76.9	79.5	97.1	53.5
03:00-04:00 PM	1440	46.1	43.9	78.3	80.5	97.9	53.2
04:00-05:00 PM	1450	45.1	44.3	77.9	80.0	95.6	53.5
05:00-06:00 PM	1455	45.7	44.7	77.9	79.9	97.7	51.6
Date:18/05/2010 (Tuesday)							

Date & Time	Traffic volume Q (Veh/h)	Heavy vehicles % (P)	Average vehicle speed V (km/h)	Sound pressure level dB (A)			
				L_{eq}	L_{10}	L_{max}	L_{min}
09:00-10:00 AM	1370	35.6	42.1	76.6	78.8	95.9	53.8
10:00-11:00 AM	1440	42.8	44.7	77.8	80.2	97.1	53.8
11:00-12:00 AM	1435	41.8	42.3	77.7	79.5	97.7	54.9
12:00-01:00 PM	1365	34.8	42.9	76.5	79.0	98.4	52.5
02:00-03:00 PM	1370	35.5	42.9	76.7	78.8	94.6	55.5
03:00-04:00 PM	1395	38.2	43.1	77.0	79.2	98.2	53.4
04:00-05:00 PM	1430	42.2	44.7	77.8	80.3	99.3	52.6
05:00-06:00 PM	1430	40.4	42.4	77.5	79.3	94.3	52.0
Date:20/05/2010 (Thursday)							
09:00-10:00 AM	1370	36.5	43.1	76.7	78.9	94.4	54.0
10:00-11:00 AM	1440	42.0	43.2	77.5	78.9	98.6	53.3
11:00-12:00 AM	1420	40.7	43.9	77.3	79.3	97.3	54.3
12:00-01:00 PM	1455	46.5	44.3	77.8	79.8	99.0	54.1
02:00-03:00 PM	1450	43.6	44.3	78.0	79.6	97.8	55.5
03:00-04:00 PM	1440	46.1	44.8	78.3	80.3	97.9	55.2
04:00-05:00 PM	1415	41.6	43.3	77.0	79.7	98.4	53.4
05:00-06:00 PM	1425	42.4	43.9	77.4	79.7	98.4	55.1
Date:25/05/2010 (Tuesday)							
02:00-03:00 PM	1375	38.2	44.0	76.9	79.0	97.5	53.0
03:00-04:00 PM	1450	42.7	45.0	77.5	79.2	98.2	52.1
04:00-05:00 PM	1380	38.9	44.4	76.7	78.9	97.6	53.3
05:00-06:00 PM	1435	42.7	43.4	77.6	79.8	97.3	53.7

Temperature (Range): 35-44^{o} C

Humidity (Range): 11-52%

Wind speed/direction (Range): 3-14.8 km/h (NW, SE, WNW, East)

Summary:

(A) Duration of data collection- 07/04/2010 to 25/05/2010

(B) No. of days- 26

(C) 4 hours per day (total days)- 9

(D) 8 hours per day (total days)- 17

(E) Total data collection hours- 172

(F) Critical observation: On Sundays and holidays the percentage of heavy vehicles has increased and due to that L_{10} and L_{eq} sound pressure levels got increased but on working days the percentage of heavy vehicles are not much. In some cases the L_{max} has increased upto 103 dB (A) because of blowing horn nearby sound level meter.

(G) Traffic volume is more during 9:00AM to 11:00AM and 3:00PM to 5:00PM. During other timing, traffic volume was normal.

Table 5.2 (Regression output for L_{10} with two independent parameters Q and P)

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	L_{10} Measured dB (A)	L_{10} Predicted dB (A)	% Error
1480	36.7	79.4	80.1	-0.9
1395	35.9	79.6	79.2	0.4
1510	38.6	80.1	80.5	-0.5
1475	37.2	81.5	80.1	1.7
1485	38.7	80.8	80.2	0.7
1435	36.5	79.2	79.6	-0.6
1495	37.1	80.5	80.3	0.2
1400	35.7	79.8	79.3	0.6
1460	37.9	79.2	79.9	-0.9
1380	35.8	78.8	79.0	-0.4
1350	34.7	78.1	78.7	-0.7
1450	39.6	79.0	79.8	-1.1
1440	40.7	78.8	79.7	-1.2
1480	45.2	79.9	80.2	-0.4
1410	41.6	79.1	79.4	-0.4
1445	40.6	79.9	79.8	0.1
1490	44.7	80.2	80.3	-0.1
1460	46.5	79.0	80.0	-1.4
1440	42.4	80.7	79.8	1.1
1430	41.0	80.2	79.6	0.7
1430	40.2	78.1	79.6	-1.9
1390	45.3	77.7	79.2	-2.0
1380	46.7	77.9	79.1	-1.6
1435	42.2	80.0	79.7	0.3
1420	39.7	78.7	79.5	-1.1
1450	46.4	79.2	79.9	-0.9
1460	47.1	79.5	80.0	-0.7
1470	48.1	80.7	80.1	0.6
1515	48.7	80.5	80.6	-0.2
1320	36.4	78.7	78.4	0.4
1295	31.3	78.5	78.1	0.6
1370	36.3	79.9	78.9	1.3
1425	40.4	81.0	79.6	1.8
1455	43.4	82.5	79.9	3.1
1435	41.7	82.1	79.7	2.9
1440	43.0	82.4	79.8	3.2
1370	35.4	78.8	78.9	-0.2
1335	37.4	77.7	78.6	-1.1
1360	36.1	78.6	78.8	-0.3

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	L_{10} Measured dB (A)	L_{10} Predicted dB (A)	% Error
1365	37.2	78.5	78.9	-0.5
1340	36.2	78.6	78.6	0.0
1350	36.6	78.7	78.7	0.0
1310	33.1	78.3	78.2	0.1
1505	44.8	80.3	80.5	-0.2
1435	41.0	79.8	79.7	0.1
1465	47.2	80.0	80.1	-0.1
1445	40.8	80.3	79.8	0.6
1470	47.4	80.6	80.1	0.5
1465	46.8	79.4	80.1	-0.9
1475	47.6	78.8	80.2	-1.7
1440	40.8	79.7	79.7	0.0
1445	42.4	79.7	79.8	-0.2
1450	43.3	79.6	79.9	-0.3
1450	46.5	80.4	79.9	0.6
1480	47.3	80.1	80.2	-0.2
1460	43.3	80.4	80.0	0.5
1400	37.4	78.7	79.3	-0.7
1410	38.5	78.0	79.4	-1.9
1405	39.7	77.7	79.3	-2.1
1390	39.2	79.8	79.2	0.7
1470	47.4	80.7	80.1	0.7
1460	47.1	80.5	80.0	0.6
1450	43.0	79.4	79.9	-0.6
1400	39.3	78.6	79.3	-0.9
1445	45.3	79.9	79.8	0.0
1525	47.9	82.6	80.7	2.2
1535	48.3	82.2	80.9	1.6
1430	40.0	79.7	79.6	0.1
1455	43.4	79.6	79.9	-0.4
1300	31.9	78.6	78.1	0.6
1480	45.4	79.8	80.2	-0.5
1455	39.7	79.4	79.9	-0.6
1450	46.6	80.1	79.9	0.2
1425	40.7	80.2	79.6	0.8
1430	41.4	80.1	79.6	0.5
1420	39.8	80.0	79.5	0.6
1460	43.4	81.4	80.0	1.7
1465	44.4	80.5	80.1	0.5
1530	47.7	80.3	80.8	-0.6
1455	43.9	80.8	79.9	1.1
1430	41.8	79.5	79.6	-0.2

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	L_{10} Measured dB (A)	L_{10} Predicted dB (A)	% Error
1435	42.3	79.9	79.7	0.2
1460	44.9	80.6	80.0	0.8
1305	32.2	80.2	78.2	2.6
1470	44.2	80.7	80.1	0.7
1440	41.2	80.0	79.7	0.4
1420	42.3	79.2	79.5	-0.4
1465	47.5	80.7	80.1	0.7
1450	46.5	80.2	79.9	0.3
1455	47.8	80.0	80.0	0.1
1450	45.5	79.7	79.9	-0.2
1445	43.1	79.7	79.8	-0.1
1455	46.7	80.1	80.0	0.2
1510	48.8	80.3	80.6	-0.4
1445	45.9	80.1	79.8	0.4
1440	46.3	79.4	79.8	-0.4
1445	47.3	79.7	79.9	-0.2
1445	45.1	80.1	79.8	0.3
1540	50.4	79.2	80.9	-2.2
1500	48.3	79.6	80.5	-1.2
1460	47.3	80.6	80.0	0.7
1450	48.9	80.3	79.9	0.4
1495	49.4	80.6	80.4	0.2
1470	48.4	82.0	80.1	2.2
1440	49.4	79.7	79.8	-0.2
1390	39.9	79.5	79.2	0.4
1440	42.0	80.3	79.8	0.7
1440	41.0	79.5	79.7	-0.3
1430	40.6	78.9	79.6	-1.0
1415	42.2	79.3	79.5	-0.2
1450	48.6	80.0	79.9	0.1
1435	41.9	79.3	79.7	-0.5
1440	42.4	80.0	79.8	0.3
1445	43.1	79.6	79.8	-0.2
1450	45.4	79.5	79.9	-0.5
1455	40.6	79.2	79.9	-0.9
1445	45.2	80.1	79.8	0.4
1410	41.7	79.0	79.4	-0.5
1450	46.9	80.5	79.9	0.7
1420	40.6	79.3	79.5	-0.3

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	L_{10} Measured dB (A)	L_{10} Predicted dB (A)	% Error
1440	43.9	79.3	79.8	-0.6
1445	41.6	79.9	79.8	0.2
1415	41.3	79.0	79.5	-0.6
1445	45.3	80.0	79.8	0.1
1430	41.7	79.1	79.6	-0.7
1370	35.5	78.6	78.9	-0.5
1450	48.8	80.0	79.9	0.1
1425	41.9	79.4	79.6	-0.2
1380	38.5	79.3	79.1	0.2
1415	41.3	79.1	79.5	-0.4
1505	45.6	80.5	80.5	0.0
1435	41.3	79.1	79.7	-0.7
1450	41.3	79.0	79.9	-1.2
1455	45.4	80.5	80.0	0.7
1410	40.3	79.3	79.4	-0.2
1460	48.4	79.7	80.0	-0.5
1445	46.2	79.8	79.9	-0.1
1395	40.8	79.2	79.2	-0.1
1455	46.7	79.9	80.0	-0.1
1375	37.0	79.4	79.0	0.5
1445	44.5	79.3	79.8	-0.6
1410	41.5	79.9	79.4	0.6
1450	44.2	78.9	79.9	-1.3
1455	43.5	80.3	79.9	0.5
1455	48.1	80.1	80.0	0.2
1445	41.9	78.9	79.8	-1.2
1430	40.5	79.2	79.6	-0.6
1425	41.7	78.9	79.6	-0.8
1380	38.1	79.5	79.1	0.5
1440	46.1	80.5	79.8	0.9
1450	45.1	80.0	79.9	0.1
1455	45.7	79.9	80.0	-0.1
1370	35.6	78.8	78.9	-0.2
1440	42.8	80.2	79.8	0.6
1435	41.8	79.5	79.7	-0.3
1365	34.8	79.0	78.9	0.1
1370	35.5	78.8	78.9	-0.1
1395	38.2	79.2	79.2	-0.1
1430	42.2	80.3	79.6	0.8
1430	40.4	79.3	79.6	-0.4
1370	36.5	78.9	78.9	0.0
1440	42.0	78.9	79.8	-1.1

Traffic Volume Q (veh/h)	**Heavy vehicles % (P)**	**L_{10} Measured dB (A)**	**L_{10} Predicted dB (A)**	**% Error**
1420	40.7	79.3	79.5	-0.3
1455	46.5	79.8	80.0	-0.2
1450	43.6	79.6	79.9	-0.4
1440	46.1	80.3	79.8	0.6
1415	41.6	79.7	79.5	0.3
1425	42.4	79.7	79.6	0.2
1375	38.2	79.0	79.0	0.0
1450	42.7	79.2	79.9	-0.9
1380	38.9	78.9	79.1	-0.3
1435	42.7	79.8	79.7	0.2

Regression Output:

R square	0.3393
Standard error	0.7134
Constant	63.5067
Independent 1 (Q)	0.0110
Independent 2 (P)	0.0095
No. of observations	172

Equation : L_{10}=63.5067+0.0110*Q+0.0095*P

t-Test paired two sample for means		
	L_{10} (measured)	L_{10} (predicted)
Mean	79.69415	79.68990
Variance	0.76531	0.25858
Observations	172	172
Pearson Correlation	0.58566	
Hypothesized mean difference	0	
Degree of freedom	171	
t-statistics	0.07837	
Level of significance	0.05	
Probability two-tail	0.93763	
t-critical two-tail	1.97402	

Table 5.3 (Regression output for L_{eq} with two independent parameters Q and P)

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1480	36.7	77.8	77.9	-0.1
1395	35.9	76.8	76.7	0.0
1510	38.6	79.0	78.4	0.8
1475	37.2	77.8	77.8	0.0
1485	38.7	77.8	78.1	-0.3
1435	36.5	77.1	77.3	-0.3
1495	37.1	78.2	78.1	0.1
1400	35.7	77.0	76.8	0.2
1460	37.9	77.7	77.7	0.0
1380	35.8	76.7	76.5	0.1
1350	34.7	76.5	76.1	0.6
1450	39.6	77.7	77.7	0.0
1440	40.7	77.5	77.6	-0.1
1480	45.2	78.1	78.4	-0.3
1410	41.6	77.1	77.3	-0.2
1445	40.6	77.7	77.7	0.0
1490	44.7	78.8	78.5	0.4
1460	46.5	78.4	78.2	0.3
1440	42.4	77.8	77.7	0.2
1430	41.0	77.3	77.5	-0.2
1430	40.2	77.5	77.4	0.1
1390	45.3	77.0	77.2	-0.3
1380	46.7	76.8	77.2	-0.5
1435	42.2	77.7	77.6	0.1
1420	39.7	77.1	77.3	-0.3
1450	46.4	78.2	78.0	0.1
1460	47.1	77.9	78.2	-0.4
1470	48.1	78.8	78.4	0.5
1515	48.7	79.3	79.0	0.4
1320	36.4	75.3	75.8	-0.6
1295	31.3	75.0	75.2	-0.3
1370	36.3	76.6	76.4	0.2
1425	40.4	77.1	77.4	-0.4
1455	43.4	78.7	77.9	0.9
1435	41.7	77.2	77.6	-0.5
1440	43.0	78.3	77.7	0.8
1370	35.4	76.6	76.4	0.2
1335	37.4	75.9	76.1	-0.3
1360	36.1	76.1	76.3	-0.2

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1365	37.2	76.3	76.4	-0.2
1340	36.2	76.0	76.1	-0.1
1350	36.6	76.0	76.2	-0.2
1310	33.1	75.4	75.5	-0.2
1505	44.8	78.9	78.7	0.4
1435	41.0	77.8	77.5	0.3
1465	47.2	77.9	78.3	-0.4
1445	40.8	77.6	77.7	-0.1
1470	47.4	78.0	78.4	-0.5
1465	46.8	77.9	78.3	-0.5
1475	47.6	78.0	78.4	-0.6
1440	40.8	77.6	77.6	0.0
1445	42.4	77.7	77.7	-0.1
1450	43.3	78.0	77.9	0.1
1450	46.5	78.2	78.0	0.1
1480	47.3	78.0	78.5	-0.7
1460	43.3	78.5	78.0	0.7
1400	37.4	76.4	76.9	-0.7
1410	38.5	77.0	77.1	-0.2
1405	39.7	76.8	77.1	-0.3
1390	39.2	76.7	76.9	-0.2
1470	47.4	78.7	78.4	0.5
1460	47.1	78.5	78.2	0.3
1450	43.0	77.8	77.8	-0.1
1400	39.3	76.7	77.0	-0.5
1445	45.3	77.8	77.9	-0.2
1525	47.9	79.3	79.1	0.3
1535	48.3	79.5	79.2	0.3
1430	40.0	77.1	77.4	-0.5
1455	43.4	78.1	77.9	0.2
1300	31.9	76.0	75.3	0.9
1480	45.4	77.9	78.4	-0.6
1455	39.7	76.8	77.7	-1.2
1450	46.6	78.1	78.1	0.0
1425	40.7	77.1	77.4	-0.4
1430	41.4	77.4	77.5	-0.2
1420	39.8	77.1	77.3	-0.3
1460	43.4	78.7	78.0	0.9
1465	44.4	79.0	78.1	1.1

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1530	47.7	79.3	79.1	0.2
1455	43.9	78.4	78.0	0.5
1430	41.8	77.4	77.5	-0.2
1435	42.3	77.5	77.6	-0.1
1460	44.9	78.6	78.1	0.7
1305	32.2	78.0	75.4	3.3
1470	44.2	78.9	78.2	0.9
1440	41.2	77.7	77.6	0.0
1420	42.3	77.3	77.4	-0.1
1465	47.5	78.5	78.3	0.2
1450	46.5	78.3	78.0	0.3
1455	47.8	78.1	78.2	-0.1
1450	45.5	77.9	78.0	-0.1
1445	43.1	78.4	77.8	0.8
1455	46.7	78.2	78.1	0.1
1510	48.8	79.1	78.9	0.2
1445	45.9	78.1	78.0	0.2
1440	46.3	77.9	77.9	-0.1
1445	47.3	77.4	78.0	-0.9
1445	45.1	78.1	77.9	0.2
1540	50.4	79.5	79.4	0.1
1500	48.3	79.0	78.8	0.3
1460	47.3	78.7	78.2	0.6
1450	48.9	78.6	78.2	0.5
1495	49.4	79.0	78.8	0.3
1470	48.4	79.8	78.4	1.7
1440	49.4	77.3	78.1	-1.0
1390	39.9	76.2	76.9	-0.9
1440	42.0	77.7	77.7	0.1
1440	41.0	77.5	77.6	-0.2
1430	40.6	77.1	77.5	-0.5
1415	42.2	77.3	77.4	-0.1
1450	48.6	78.5	78.2	0.4
1435	41.9	77.6	77.6	0.0
1440	42.4	77.5	77.7	-0.2
1445	43.1	77.5	77.8	-0.4
1450	45.4	78.0	78.0	0.0
1455	40.6	76.9	77.8	-1.1
1445	45.2	78.2	77.9	0.4

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1410	41.7	77.1	77.3	-0.2
1450	46.9	77.9	78.1	-0.2
1420	40.6	76.8	77.3	-0.7
1440	43.9	77.4	77.8	-0.4
1445	41.6	77.8	77.7	0.1
1415	41.3	77.1	77.3	-0.2
1445	45.3	77.9	77.9	0.0
1430	41.7	77.3	77.5	-0.3
1370	35.5	76.6	76.4	0.3
1450	48.8	78.4	78.2	0.3
1425	41.9	77.2	77.5	-0.3
1380	38.5	77.0	76.7	0.4
1415	41.3	77.1	77.3	-0.2
1505	45.6	79.1	78.7	0.5
1435	41.3	77.4	77.6	-0.2
1450	41.3	76.8	77.8	-1.3
1455	45.4	78.2	78.0	0.2
1410	40.3	76.7	77.2	-0.6
1460	48.4	78.6	78.3	0.4
1445	46.2	77.9	78.0	-0.1
1395	40.8	76.8	77.0	-0.2
1455	46.7	78.1	78.1	-0.1
1375	37.0	76.8	76.5	0.3
1445	44.5	77.4	77.9	-0.6
1410	41.5	77.1	77.3	-0.3
1450	44.2	77.5	77.9	-0.6
1455	43.5	77.5	77.9	-0.6
1455	48.1	78.4	78.2	0.3
1445	41.9	76.8	77.7	-1.3
1430	40.5	77.0	77.5	-0.6
1425	41.7	77.4	77.5	-0.1
1380	38.1	76.9	76.7	0.3
1440	46.1	78.3	77.9	0.5
1450	45.1	77.9	78.0	-0.1
1455	45.7	77.9	78.1	-0.2
1370	35.6	76.6	76.4	0.2
1440	42.8	77.8	77.7	0.1
1435	41.8	77.7	77.6	0.1
1365	34.8	76.5	76.3	0.3

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1370	35.5	76.7	76.4	0.4
1395	38.2	77.0	76.9	0.1
1430	42.2	77.8	77.6	0.3
1430	40.4	77.5	77.4	0.1
1370	36.5	76.7	76.5	0.3
1440	42.0	77.5	77.7	-0.2
1420	40.7	77.3	77.3	-0.1
1455	46.5	77.8	78.1	-0.4
1450	43.6	78.0	77.9	0.2
1440	46.1	78.3	77.9	0.5
1415	41.6	77.0	77.3	-0.4
1425	42.4	77.4	77.5	-0.1
1375	38.2	76.9	76.6	0.4
1450	42.7	77.5	77.8	-0.4
1380	38.9	76.7	76.7	0.0
1435	42.7	77.6	77.6	-0.1

Regression Output:

R square	0.7796
Standard error	0.4004
Constant	56.8360
Independent 1 (Q)	0.0128
Independent 2 (P)	0.0564
No. of observations	172

Equation : L_{eq}=56.8360+0.0128*Q+0.0564*P

t-Test paired two sample for means		
	L_{eq} (measured)	L_{eq} (predicted)
Mean	77.60585	77.60556
Variance	0.72283	0.56333
Observations	172	172
Pearson Correlation	0.88292	
Hypothesized mean difference	0	
Degree of freedom	171	
t-statistics	0.00941	
Level of significance	0.05	
Probability two-tail	0.99250	
t-critical two-tail	1.97402	

Table 5.4 (Regression output for L_{10} with three independent parameters Q, P and V)

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{10} Measured dB (A)	L_{10} Predicted dB (A)	% Error
1480	36.7	46.0	79.4	80.2	-1.0
1395	35.9	44.3	79.6	79.3	0.3
1510	38.6	50.0	80.1	80.8	-0.8
1475	37.2	45.0	81.5	80.1	1.7
1485	38.7	43.0	80.8	80.1	0.8
1435	36.5	42.9	79.2	79.6	-0.6
1495	37.1	45.8	80.5	80.4	0.1
1400	35.7	45.3	79.8	79.4	0.5
1460	37.9	43.4	79.2	79.9	-0.8
1380	35.8	44.3	78.8	79.1	-0.5
1350	34.7	44.2	78.1	78.8	-0.9
1450	39.6	44.7	79.0	79.9	-1.2
1440	40.7	41.6	78.8	79.6	-1.0
1480	45.2	45.0	79.9	80.2	-0.5
1410	41.6	43.3	79.1	79.4	-0.4
1445	40.6	40.7	79.9	79.6	0.3
1490	44.7	45.3	80.2	80.4	-0.1
1460	46.5	44.7	79.0	80.0	-1.4
1440	42.4	44.9	80.7	79.8	1.0
1430	41.0	44.5	80.2	79.7	0.6
1430	40.2	45.2	78.1	79.7	-2.0
1390	45.3	44.6	77.7	79.3	-2.1
1380	46.7	43.1	77.9	79.1	-1.6
1435	42.2	44.3	80.0	79.7	0.3
1420	39.7	42.1	78.7	79.4	-1.0
1450	46.4	44.5	79.2	79.9	-0.9
1460	47.1	46.3	79.5	80.1	-0.9
1470	48.1	44.9	80.7	80.2	0.6
1515	48.7	44.1	80.5	80.6	-0.1
1320	36.4	43.0	78.7	78.5	0.3
1295	31.3	40.6	78.5	78.0	0.6
1370	36.3	42.4	79.9	78.9	1.3
1425	40.4	42.4	81.0	79.5	1.9
1455	43.4	45.8	82.5	80.0	3.0
1435	41.7	43.6	82.1	79.7	3.0
1440	43.0	44.9	82.4	79.8	3.2
1370	35.4	42.3	78.8	78.9	-0.2
1335	37.4	42.5	77.7	78.6	-1.1

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{10} Measured dB (A)	L_{10} Predicted dB (A)	% Error
1360	36.1	41.0	78.6	78.7	-0.2
1365	37.2	41.3	78.5	78.8	-0.4
1340	36.2	40.5	78.6	78.5	0.1
1350	36.6	41.1	78.7	78.6	0.1
1310	33.1	41.1	78.3	78.2	0.1
1505	44.8	45.8	80.3	80.5	-0.3
1435	41.0	43.5	79.8	79.7	0.2
1465	47.2	46.4	80.0	80.2	-0.3
1445	40.8	41.3	80.3	79.6	0.8
1470	47.4	43.6	80.6	80.1	0.6
1465	46.8	43.1	79.4	80.0	-0.8
1475	47.6	43.1	78.8	80.1	-1.6
1440	40.8	45.6	79.7	79.8	-0.2
1445	42.4	43.5	79.7	79.8	-0.1
1450	43.3	45.0	79.6	79.9	-0.4
1450	46.5	45.0	80.4	80.0	0.5
1480	47.3	43.8	80.1	80.2	-0.1
1460	43.3	45.7	80.4	80.1	0.4
1400	37.4	42.9	78.7	79.3	-0.7
1410	38.5	43.4	78.0	79.4	-1.9
1405	39.7	42.4	77.7	79.3	-2.0
1390	39.2	43.9	79.8	79.2	0.7
1470	47.4	43.8	80.7	80.1	0.8
1460	47.1	44.2	80.5	80.0	0.6
1450	43.0	43.8	79.4	79.9	-0.6
1400	39.3	42.9	78.6	79.3	-0.9
1445	45.3	44.2	79.9	79.8	0.0
1525	47.9	44.7	82.6	80.7	2.2
1535	48.3	44.8	82.2	80.8	1.7
1430	40.0	42.1	79.7	79.5	0.2
1455	43.4	44.1	79.6	79.9	-0.4
1300	31.9	40.0	78.6	78.0	0.7
1480	45.4	45.0	79.8	80.2	-0.5
1455	39.7	42.9	79.4	79.8	-0.5
1450	46.6	44.1	80.1	79.9	0.2
1425	40.7	42.5	80.2	79.5	0.8
1430	41.4	44.9	80.1	79.7	0.4
1420	39.8	42.7	80.0	79.5	0.7
1460	43.4	45.3	81.4	80.0	1.6
1465	44.4	45.9	80.5	80.1	0.4

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{10} Measured dB (A)	L_{10} Predicted dB (A)	% Error
1530	47.7	44.8	80.3	80.8	-0.6
1455	43.9	46.0	80.8	80.0	1.0
1430	41.8	44.8	79.5	79.7	-0.3
1435	42.3	45.7	79.9	79.8	0.1
1460	44.9	45.9	80.6	80.1	0.7
1305	32.2	41.8	80.2	78.2	2.5
1470	44.2	45.6	80.7	80.2	0.6
1440	41.2	44.9	80.0	79.8	0.3
1420	42.3	44.4	79.2	79.6	-0.5
1465	47.5	44.4	80.7	80.1	0.7
1450	46.5	44.2	80.2	79.9	0.3
1455	47.8	44.9	80.0	80.0	0.0
1450	45.5	44.8	79.7	79.9	-0.3
1445	43.1	44.2	79.7	79.8	-0.1
1455	46.7	44.4	80.1	80.0	0.2
1510	48.8	43.7	80.3	80.5	-0.2
1445	45.9	44.3	80.1	79.9	0.3
1440	46.3	44.7	79.4	79.8	-0.5
1445	47.3	44.7	79.7	79.9	-0.2
1445	45.1	44.4	80.1	79.9	0.3
1540	50.4	47.9	79.2	81.1	-2.4
1500	48.3	43.3	79.6	80.4	-1.0
1460	47.3	44.3	80.6	80.0	0.7
1450	48.9	44.3	80.3	79.9	0.4
1495	49.4	45.8	80.6	80.5	0.2
1470	48.4	44.1	82.0	80.1	2.3
1440	49.4	45.5	79.7	79.9	-0.3
1390	39.9	42.5	79.5	79.2	0.4
1440	42.0	44.6	80.3	79.8	0.7
1440	41.0	44.7	79.5	79.8	-0.4
1430	40.6	42.2	78.9	79.5	-0.8
1415	42.2	44.2	79.3	79.5	-0.2
1450	48.6	44.3	80.0	79.9	0.1
1435	41.9	41.8	79.3	79.6	-0.4
1440	42.4	41.2	80.0	79.6	0.5
1445	43.1	42.3	79.6	79.7	-0.1
1450	45.4	44.2	79.5	79.9	-0.5
1455	40.6	42.9	79.2	79.8	-0.8
1445	45.2	42.2	80.1	79.7	0.5
1410	41.7	43.9	79.0	79.5	-0.6

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{10} Measured dB (A)	L_{10} Predicted dB (A)	% Error
1450	46.9	44.2	80.5	79.9	0.7
1420	40.6	43.0	79.3	79.5	-0.3
1440	43.9	42.3	79.3	79.7	-0.5
1445	41.6	44.2	79.9	79.8	0.2
1415	41.3	42.1	79.0	79.4	-0.5
1445	45.3	44.4	80.0	79.9	0.1
1430	41.7	44.4	79.1	79.7	-0.8
1370	35.5	42.4	78.6	78.9	-0.4
1450	48.8	44.1	80.0	79.9	0.1
1425	41.9	43.9	79.4	79.6	-0.2
1380	38.5	43.7	79.3	79.1	0.2
1415	41.3	44.3	79.1	79.5	-0.5
1505	45.6	44.1	80.5	80.5	0.1
1435	41.3	43.7	79.1	79.7	-0.7
1450	41.3	42.1	79.0	79.7	-1.0
1455	45.4	43.2	80.5	79.9	0.7
1410	40.3	44.0	79.3	79.4	-0.2
1460	48.4	44.9	79.7	80.1	-0.5
1445	46.2	44.4	79.8	79.9	-0.1
1395	40.8	43.2	79.2	79.3	-0.1
1455	46.7	43.1	79.9	79.9	-0.1
1375	37.0	42.4	79.4	79.0	0.5
1445	44.5	43.0	79.3	79.8	-0.6
1410	41.5	44.4	79.9	79.5	0.5
1450	44.2	43.8	78.9	79.9	-1.3
1455	43.5	43.6	80.3	79.9	0.5
1455	48.1	44.2	80.1	80.0	0.2
1445	41.9	43.1	78.9	79.8	-1.1
1430	40.5	42.5	79.2	79.6	-0.5
1425	41.7	43.5	78.9	79.6	-0.8
1380	38.1	42.5	79.5	79.0	0.5
1440	46.1	43.9	80.5	79.8	0.9
1450	45.1	44.3	80.0	79.9	0.1
1455	45.7	44.7	79.9	80.0	-0.1
1370	35.6	42.1	78.8	78.9	-0.2
1440	42.8	44.7	80.2	79.8	0.5
1435	41.8	42.3	79.5	79.6	-0.2
1365	34.8	42.9	79.0	78.9	0.1
1370	35.5	42.9	78.8	78.9	-0.2

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{10} Measured dB (A)	L_{10} Predicted dB (A)	% Error
1395	38.2	43.1	79.2	79.2	-0.1
1430	42.2	44.7	80.3	79.7	0.8
1430	40.4	42.4	79.3	79.6	-0.3
1370	36.5	43.1	78.9	79.0	0.0
1440	42.0	43.2	78.9	79.7	-1.1
1420	40.7	43.9	79.3	79.5	-0.4
1455	46.5	44.3	79.8	80.0	-0.2
1450	43.6	44.3	79.6	79.9	-0.4
1440	46.1	44.8	80.3	79.8	0.5
1415	41.6	44.3	79.7	79.5	0.2
1425	42.4	43.9	79.7	79.6	0.2
1375	38.2	44.0	79.0	79.1	0.0
1450	42.7	45.0	79.2	79.9	-0.9
1380	38.9	44.4	78.9	79.2	-0.4
1435	42.7	43.4	79.8	79.7	0.2

Regression Output:

R square	0.3447
Standard error	0.7126
Constant	62.4622
Independent 1 (Q)	0.0100
Independent 2 (P)	0.0082
Independent 3 (V)	0.0572
No. of observations	172

Equation : L_{10}=62.4622+0.0100*Q+0.0082*P+0.0572*V

t-Test paired two sample for means		
	L_{10} (measured)	L_{10} (predicted)
Mean	79.69415	79.68941
Variance	0.76531	0.26226
Observations	172	172
Pearson Correlation	0.59114	
Hypothesized mean difference	0	
Degree of freedom	171	
t-statistics	0.08780	
Level of significance	0.05	
Probability two-tail	0.93014	
t-critical two-tail	1.97402	

Table 5.5 (Regression output for L_{eq} with three independent parameters Q, P and V)

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1480	36.7	46.0	77.8	78.0	-0.2
1395	35.9	44.3	76.8	76.9	-0.1
1510	38.6	50.0	79.0	78.8	0.3
1475	37.2	45.0	77.8	77.9	-0.1
1485	38.7	43.0	77.8	77.9	-0.1
1435	36.5	42.9	77.1	77.2	-0.2
1495	37.1	45.8	78.2	78.2	0.0
1400	35.7	45.3	77.0	77.0	0.0
1460	37.9	43.4	77.7	77.6	0.1
1380	35.8	44.3	76.7	76.7	0.0
1350	34.7	44.2	76.5	76.3	0.3
1450	39.6	44.7	77.7	77.7	0.0
1440	40.7	41.6	77.5	77.4	0.2
1480	45.2	45.0	78.1	78.4	-0.4
1410	41.6	43.3	77.1	77.2	-0.2
1445	40.6	40.7	77.7	77.4	0.4
1490	44.7	45.3	78.8	78.5	0.3
1460	46.5	44.7	78.4	78.2	0.3
1440	42.4	44.9	77.8	77.8	0.1
1430	41.0	44.5	77.3	77.6	-0.3
1430	40.2	45.2	77.5	77.6	-0.1
1390	45.3	44.6	77.0	77.3	-0.5
1380	46.7	43.1	76.8	77.2	-0.5
1435	42.2	44.3	77.7	77.6	0.0
1420	39.7	42.1	77.1	77.2	-0.1
1450	46.4	44.5	78.2	78.1	0.1
1460	47.1	46.3	77.9	78.4	-0.6
1470	48.1	44.9	78.8	78.4	0.4
1515	48.7	44.1	79.3	78.9	0.5
1320	36.4	43.0	75.3	75.9	-0.8
1295	31.3	40.6	75.0	75.1	-0.2
1370	36.3	42.4	76.6	76.4	0.2
1425	40.4	42.4	77.1	77.3	-0.2
1455	43.4	45.8	78.7	78.1	0.7
1435	41.7	43.6	77.2	77.6	-0.5
1440	43.0	44.9	78.3	77.8	0.7
1370	35.4	42.3	76.6	76.4	0.3
1335	37.4	42.5	75.9	76.1	-0.3

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1360	36.1	41.0	76.1	76.2	0.0
1365	37.2	41.3	76.3	76.3	0.0
1340	36.2	40.5	76.0	75.9	0.1
1350	36.6	41.1	76.0	76.1	-0.1
1310	33.1	41.1	75.4	75.5	-0.1
1505	44.8	45.8	78.9	78.7	0.3
1435	41.0	43.5	77.8	77.5	0.4
1465	47.2	46.4	77.9	78.5	-0.7
1445	40.8	41.3	77.6	77.4	0.2
1470	47.4	43.6	78.0	78.3	-0.4
1465	46.8	43.1	77.9	78.1	-0.3
1475	47.6	43.1	78.0	78.3	-0.4
1440	40.8	45.6	77.6	77.8	-0.2
1445	42.4	43.5	77.7	77.7	0.0
1450	43.3	45.0	78.0	77.9	0.1
1450	46.5	45.0	78.2	78.1	0.1
1480	47.3	43.8	78.0	78.4	-0.5
1460	43.3	45.7	78.5	78.1	0.5
1400	37.4	42.9	76.4	76.9	-0.6
1410	38.5	43.4	77.0	77.1	-0.2
1405	39.7	42.4	76.8	77.0	-0.2
1390	39.2	43.9	76.7	76.9	-0.3
1470	47.4	43.8	78.7	78.3	0.6
1460	47.1	44.2	78.5	78.2	0.4
1450	43.0	43.8	77.8	77.8	0.0
1400	39.3	42.9	76.7	77.0	-0.4
1445	45.3	44.2	77.8	77.9	-0.2
1525	47.9	44.7	79.3	79.0	0.4
1535	48.3	44.8	79.5	79.2	0.4
1430	40.0	42.1	77.1	77.3	-0.3
1455	43.4	44.1	78.1	77.9	0.2
1300	31.9	40.0	76.0	75.2	1.0
1480	45.4	45.0	77.9	78.4	-0.6
1455	39.7	42.9	76.8	77.6	-1.0
1450	46.6	44.1	78.1	78.0	0.0
1425	40.7	42.5	77.1	77.3	-0.3
1430	41.4	44.9	77.4	77.6	-0.3
1420	39.8	42.7	77.1	77.2	-0.2
1460	43.4	45.3	78.7	78.1	0.8
1465	44.4	45.9	79.0	78.3	0.9

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1530	47.7	44.8	79.3	79.1	0.3
1455	43.9	46.0	78.4	78.1	0.3
1430	41.8	44.8	77.4	77.6	-0.3
1435	42.3	45.7	77.5	77.8	-0.4
1460	44.9	45.9	78.6	78.2	0.5
1305	32.2	41.8	78.0	75.4	3.3
1470	44.2	45.6	78.9	78.3	0.8
1440	41.2	44.9	77.7	77.7	-0.1
1420	42.3	44.4	77.3	77.5	-0.2
1465	47.5	44.4	78.5	78.3	0.3
1450	46.5	44.2	78.3	78.0	0.3
1455	47.8	44.9	78.1	78.2	-0.2
1450	45.5	44.8	77.9	78.0	-0.2
1445	43.1	44.2	78.4	77.8	0.7
1455	46.7	44.4	78.2	78.1	0.1
1510	48.8	43.7	79.1	78.8	0.4
1445	45.9	44.3	78.1	78.0	0.2
1440	46.3	44.7	77.9	78.0	-0.2
1445	47.3	44.7	77.4	78.1	-0.9
1445	45.1	44.4	78.1	77.9	0.2
1540	50.4	47.9	79.5	79.6	-0.1
1500	48.3	43.3	79.0	78.6	0.5
1460	47.3	44.3	78.7	78.2	0.6
1450	48.9	44.3	78.6	78.2	0.5
1495	49.4	45.8	79.0	78.9	0.2
1470	48.4	44.1	79.8	78.4	1.8
1440	49.4	45.5	77.3	78.2	-1.1
1390	39.9	42.5	76.2	76.9	-0.9
1440	42.0	44.6	77.7	77.7	0.0
1440	41.0	44.7	77.5	77.7	-0.3
1430	40.6	42.2	77.1	77.3	-0.3
1415	42.2	44.2	77.3	77.4	-0.2
1450	48.6	44.3	78.5	78.2	0.4
1435	41.9	41.8	77.6	77.4	0.2
1440	42.4	41.2	77.5	77.4	0.1
1445	43.1	42.3	77.5	77.6	-0.1
1450	45.4	44.2	78.0	78.0	0.0
1455	40.6	42.9	76.9	77.7	-0.9
1445	45.2	42.2	78.2	77.7	0.6

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1410	41.7	43.9	77.1	77.3	-0.3
1450	46.9	44.2	77.9	78.1	-0.2
1420	40.6	43.0	76.8	77.3	-0.6
1440	43.9	42.3	77.4	77.6	-0.2
1445	41.6	44.2	77.8	77.7	0.1
1415	41.3	42.1	77.1	77.2	0.0
1445	45.3	44.4	77.9	77.9	-0.1
1430	41.7	44.4	77.3	77.6	-0.4
1370	35.5	42.4	76.6	76.4	0.3
1450	48.8	44.1	78.4	78.2	0.3
1425	41.9	43.9	77.2	77.5	-0.3
1380	38.5	43.7	77.0	76.8	0.3
1415	41.3	44.3	77.1	77.4	-0.3
1505	45.6	44.1	79.1	78.6	0.6
1435	41.3	43.7	77.4	77.5	-0.2
1450	41.3	42.1	76.8	77.6	-1.1
1455	45.4	43.2	78.2	77.9	0.3
1410	40.3	44.0	76.7	77.2	-0.7
1460	48.4	44.9	78.6	78.3	0.4
1445	46.2	44.4	77.9	78.0	-0.1
1395	40.8	43.2	76.8	77.0	-0.2
1455	46.7	43.1	78.1	78.0	0.1
1375	37.0	42.4	76.8	76.5	0.3
1445	44.5	43.0	77.4	77.8	-0.4
1410	41.5	44.4	77.1	77.3	-0.4
1450	44.2	43.8	77.5	77.9	-0.5
1455	43.5	43.6	77.5	77.9	-0.5
1455	48.1	44.2	78.4	78.2	0.3
1445	41.9	43.1	76.8	77.6	-1.1
1430	40.5	42.5	77.0	77.3	-0.4
1425	41.7	43.5	77.4	77.4	-0.1
1380	38.1	42.5	76.9	76.6	0.3
1440	46.1	43.9	78.3	77.9	0.5
1450	45.1	44.3	77.9	78.0	-0.2
1455	45.7	44.7	77.9	78.1	-0.3
1370	35.6	42.1	76.6	76.4	0.3
1440	42.8	44.7	77.8	77.8	0.0
1435	41.8	42.3	77.7	77.4	0.3
1365	34.8	42.9	76.5	76.3	0.3
1370	35.5	42.9	76.7	76.4	0.4

Traffic Volume Q (veh/h)	Heavy vehicles % (P)	Average speed V (km/h)	L_{eq} Measured dB (A)	L_{eq} Predicted dB (A)	% Error
1395	38.2	43.1	77.0	76.9	0.1
1430	42.2	44.7	77.8	77.6	0.2
1430	40.4	42.4	77.5	77.3	0.2
1370	36.5	43.1	76.7	76.5	0.3
1440	42.0	43.2	77.5	77.6	-0.2
1420	40.7	43.9	77.3	77.4	-0.1
1455	46.5	44.3	77.8	78.1	-0.4
1450	43.6	44.3	78.0	77.9	0.1
1440	46.1	44.8	78.3	78.0	0.4
1415	41.6	44.3	77.0	77.4	-0.5
1425	42.4	43.9	77.4	77.5	-0.2
1375	38.2	44.0	76.9	76.7	0.3
1450	42.7	45.0	77.5	77.9	-0.5
1380	38.9	44.4	76.7	76.9	-0.2
1435	42.7	43.4	77.6	77.6	-0.1

Regression Output:

R square	0.7942
Standard error	0.3881
Constant	55.1781
Independent 1 (Q)	0.0113
Independent 2 (P)	0.0544
Independent 3 (V)	0.0907
No. of observations	172

Equation : L_{eq}=55.1781+0.0113*Q+0.0544*P+0.0907*V

t-Test paired two sample for means		
	L_{eq} (measured)	L_{eq} (predicted)
Mean	77.60585	77.60479
Variance	0.72283	0.57330
Observations	172	172
Pearson Correlation	0.89126	
Hypothesized mean difference	0	
Degree of freedom	171	
t-statistics	0.03601	
Level of significance	0.05	
Probability two-tail	0.97132	
t-critical two-tail	1.97402	

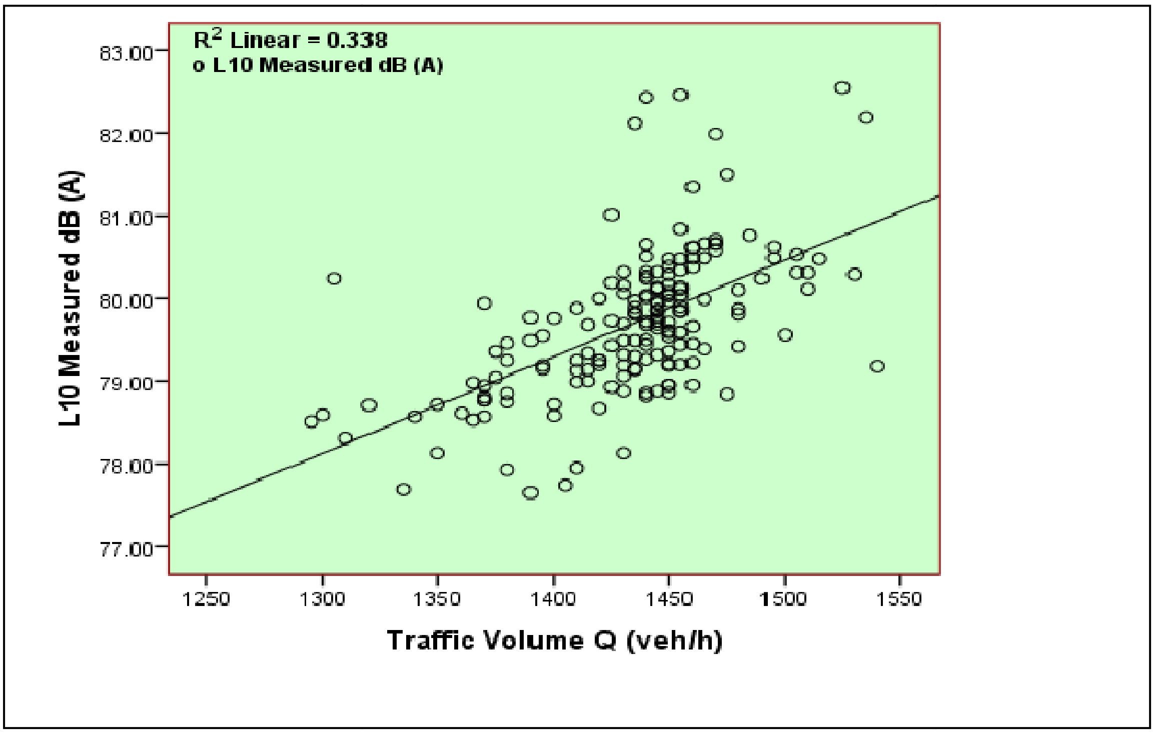

Fig. 5.1 Graph of L_{10} vs. Q

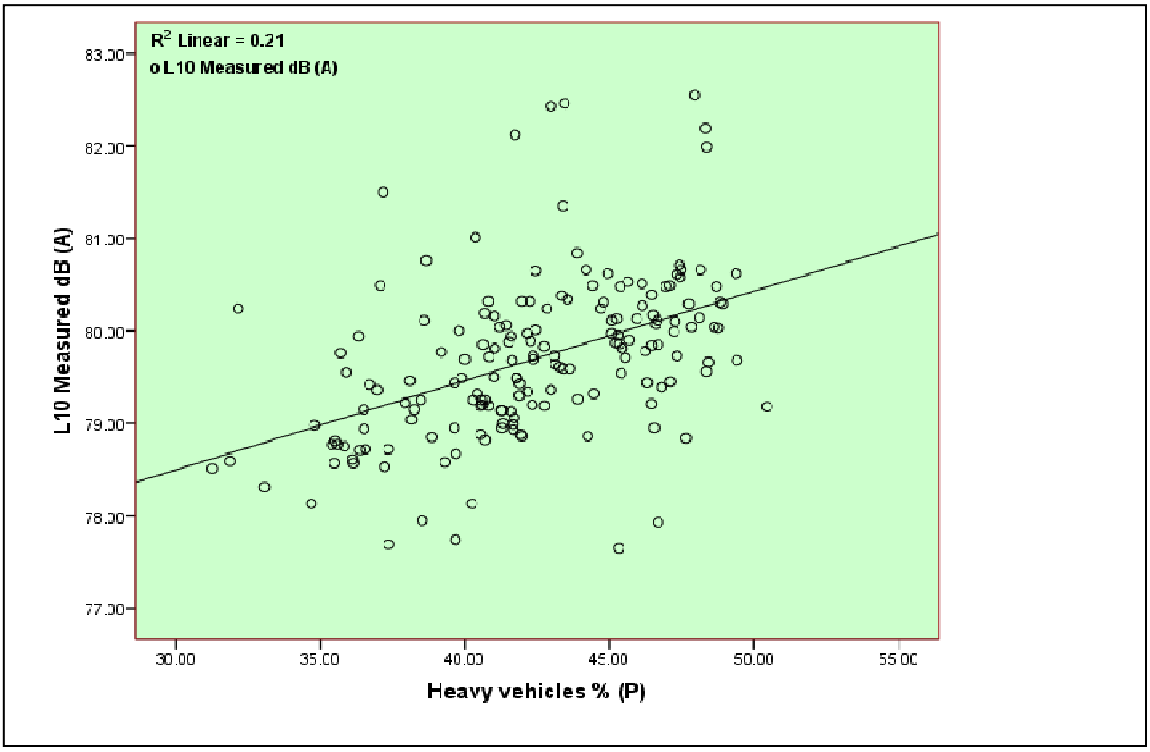

Fig. 5.2 Graph of L_{10} vs. P

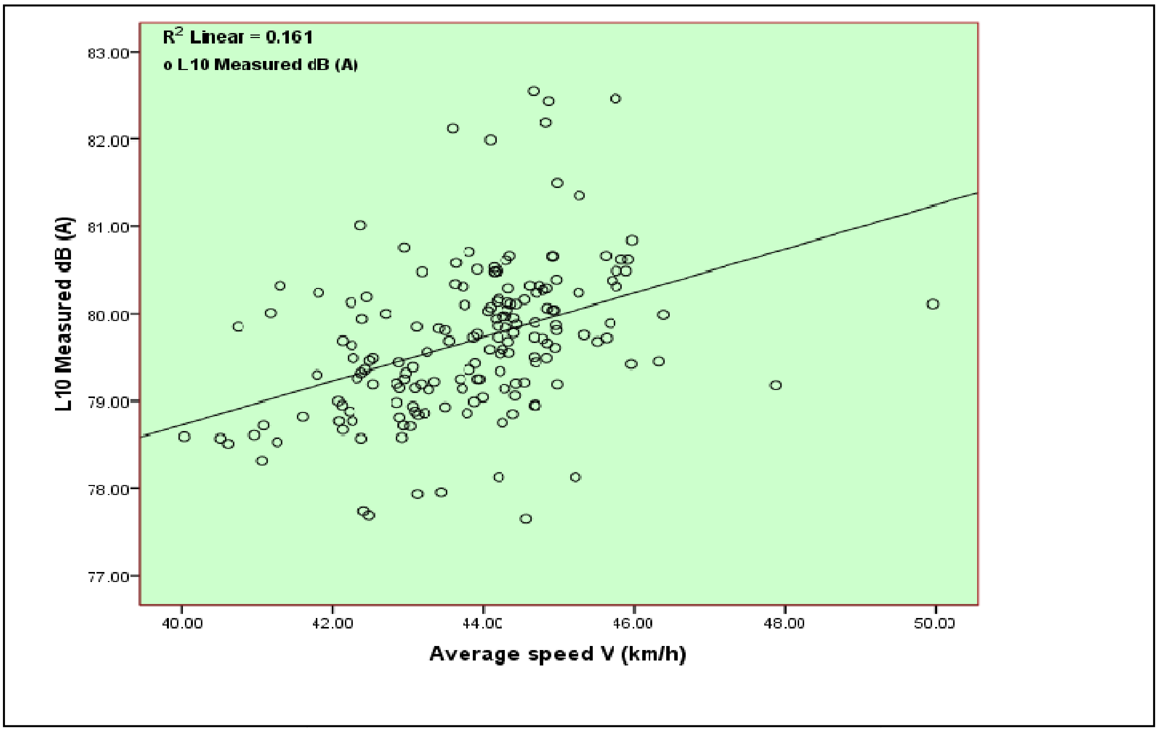

Fig. 5.3 Graph of L_{10} vs. V

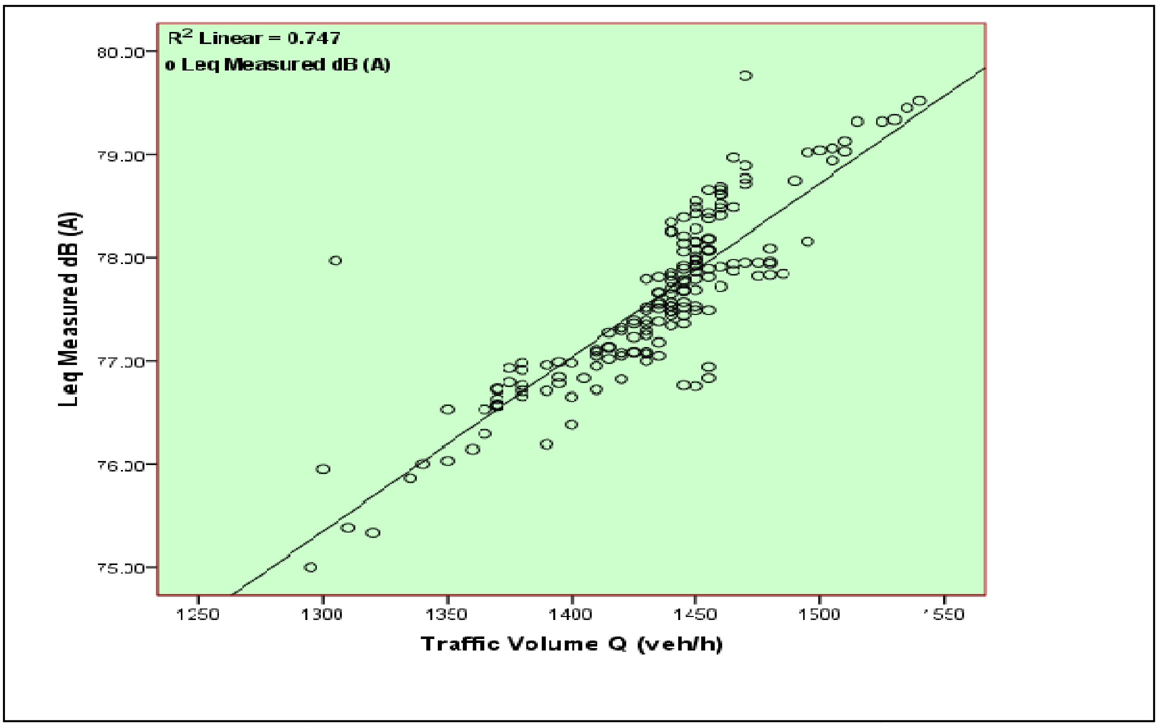

Fig. 5.4 Graph of L_{eq} vs. Q

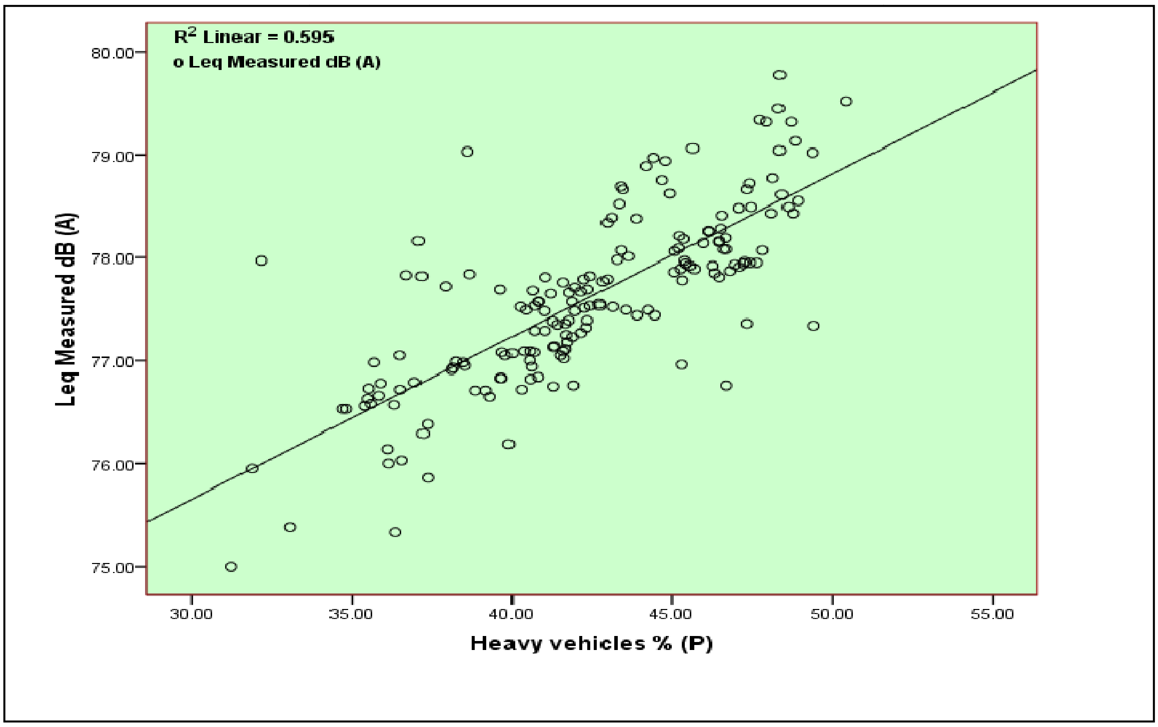

Fig. 5.5 Graph of L_{eq} vs. P

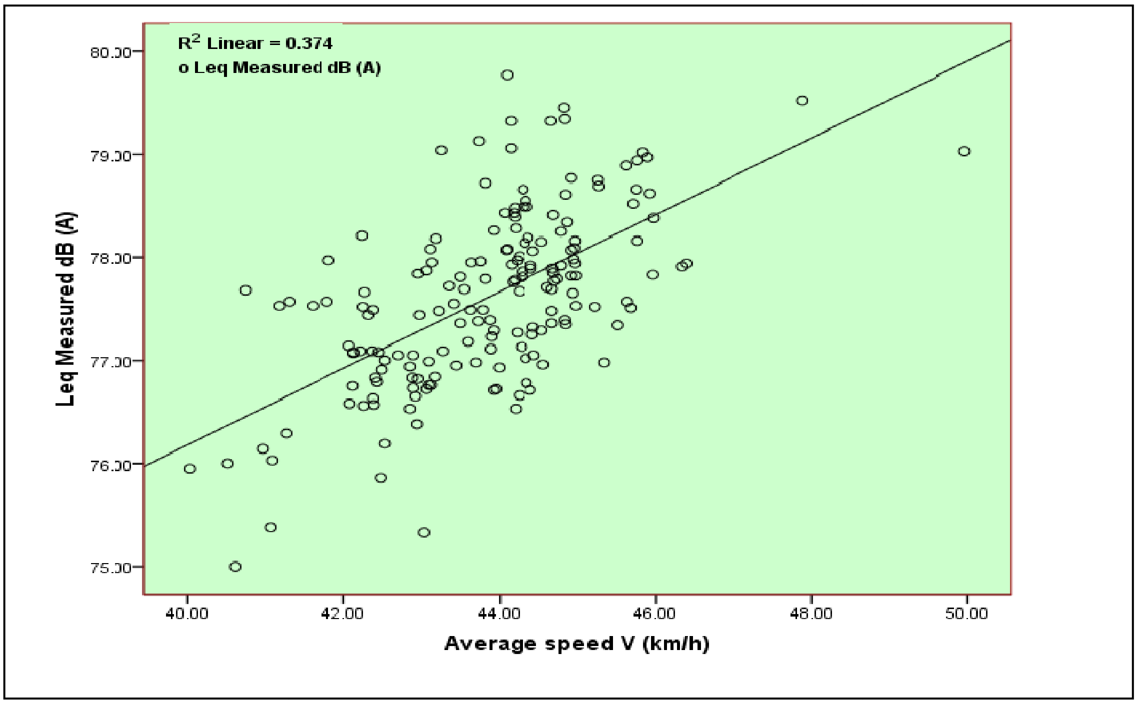

Fig. 5.6 Graph of L_{eq} vs. V

5.2 FINDINGS

Following are the findings collected from the above results:

1. Equation for L_{10} with two independent variables Q and P:

   L_{10}=63.5067+0.0110*Q+0.0095*P

2. Equation for L_{eq} with two independent variables Q and P:

   L_{eq}=56.8360+0.0128*Q+0.0564*P

3. Equation for L_{10} with three independent variables Q, P and V:

   L_{10}=62.4622+0.0100*Q+0.0082*P+0.0572*V

4. Equation for L_{eq} with three independent variables Q, P and V:

   L_{eq}=55.1781+0.0113*Q+0.0544*P+0.0907*V

5. At Patiala-Sangrur Highway (NH-64), traffic volume varied from 1295 to 1540 veh/h.
6. The percentage of heavy vehicles varied from 31.3 to 50.4.
7. Average vehicle speed varied from 40.0 km/h to 50.0 km/h.
8. L_{10} noise pressure level varied from 77.7 dB (A) to 82.6 dB (A).
9. L_{eq} noise pressure level varied from 75.0 dB (A) to 79.8 dB (A).
10. L_{max} noise pressure level varied from 91.2 dB (A) to 103.0 dB (A).
11. L_{min} noise pressure level varied from 50.4 dB (A) to 57.7 dB (A).
12. Excessive horn noise of the vehicles caused some odd noise levels which are different from the normal noise levels. For example in some cases maximum noise level reached at 103 dB (A).
13. In the regression analysis, value of R^2 varied from 0.1 to 0.7 along with different independent variables. This value may increase when data should be collected from different locations. For good results, R^2 should be above 0.5 or should vary from 0.7 to 1.0.
14. Percentage error varied from:

    (a) -2.2 to 3.2 for L_{10} with two independent variable Q and P (Table 5.2).

(b) -1.3 to 3.3 for L_{eq} with two independent variables Q and P (Table 5.3).

(c) -2.4 to 3.2 for L_{10} with three independent variables Q, P and V (Table 5.4).

(d) -1.1 to 3.3 for L_{eq} with three independent variables Q, P and V (Table 5.5).

15. A t-paired test for means was also applied to the models for goodness of fit. Value of t-critical was found to be greater than t-statistics, which was found to be successful for the null hypothesis assumed.

16. Most of the scatter plots of L_{10} and L_{eq} vs Q, P and V were not found to be normal as expected but depend on the amount of data. If there were more data sets in different dates and different locations then better correlation are expected.

CHAPTER-6

CONCLUSION AND SCOPE FOR FUTURE WORK

6.1 CONCLUSION

Collected data on noise generating parameters was applied to calculate the predicted noise level with the help of regression analysis. The comparison tests were made in order to examine the goodness of fit, between the predicted and measured noise level from the collected field data and to suggest a suitable model for Indian conditions. From the present study following conclusions are drawn:

1. Correlation equations have been obtained between L_{10} and L_{eq} with vehicle volume, % of heavy vehicles and vehicle speed. Percentage errors between the measured and predicted volumes are quite low in general.
2. R^2 value ranges from 0.1 to 0.7 for different equations of L_{10} and L_{eq} for the data of 172 hrs collected on different dates and timings. As the R^2 value of range 0.7 to 1.0 indicate a very good correlation between the observed and predicted data sets, the value of R^2 can be improved by incorporating variations by taking number of different locations and taking more data sets.
3. The paired t-test was also carried out to provide the statistical test for the differences between the predicted results from the model and the measured result from the field. The null hypothesis was $\mu=0$, that is the mean value of the differences between pairs of measured noise and predicted noise is equal to zero. The results from paired t-test at a significance level of 5% show that the critical value is greater than t-statistics, so the null hypothesis is accepted, that is the mean value of difference between measured and predicted noise level is zero.
4. The scatter plots of L_{10} and L_{eq} vs. Q, P and V were plotted which conclude that if there are more data sets of different locations and timings then it may have

better correlation.

6.2 SCOPE FOR FUTURE WORK

1. In this work, vehicle speed was measured manually, but more accurate data can be achieved by using radar gun.

2. All the measurements were taken at single location. If different location and timing can be taken then better results can be obtained.

3. In the present work only three parameters were included heavy vehicle percentage (P), vehicle volume (Q) and vehicle speed. So, one more parameter observer distance (D) can be included in the prediction and it may give better results.

4. All kinds of vehicles (like motor cycles, mopeds, scooters, 3-wheelers, cars, mini trucks, buses, heavy trucks, construction equipments, tractors, etc.) should be included to calculate average speed of vehicles and their flow volume to give a more realistic analysis.

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APPENDIX-A

CALCULATION FOR TRAFFIC VOLUME

Date........................

Vehicle Category	Talley Chart
2-wheelers (Motor Cycles, Scooters, Mopeds etc)	
3-wheelers	
Cars	
Buses	
Trucks (light wt upto 12 Ton)	
Trucks (heavy wt more than 12 Ton)	
Tractors	

APPENDIX-B

Site: ……………………………………………..

Measurement period: 15 min.

Sound level meter (Microphone):

Distance from centre of the road (meter)……………………

Height from level of the road (meter) ……………………….

Temperature: ……………….^{0} C

Humidity: ……………………%

Wind speed/direction:…………………………………..

	Date & Time	Traffic Vol. Q (veh/h)	Heavy vehicles P (%)	Avg. vehicle speed V (km/h)	Sound pressure level dB (A)			
					L_{eq}	L_{10}	L_{max}	L_{min}
1								
2								
3								
4								
5								

APPENDIX-C

OBSERVATION/CALCULATION FOR AVERAGE SPEED

Distance travelled (meters).........time in seconds

Date/Time	2-Wheelers	3-wheelers	Cars	Buses	Trucks (light wt. < 12T)	Trucks (heavy wt. >12T)	Tractors