ENVIRONMENTAL STUDY OF PUBLIC TRANSPORT SYSTEM USING KNOWLEDGE MANAGEMENT TECHNIQUES

A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree

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DOCTOR OF PHILOSOPHY

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MANAGEMENT STUDIES

by

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis entitled **Environmental Study of Public Transport System Using Knowledge Management Techniques** in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy and submitted in the Department of Management Studies, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out at Centre for Transportation Systems (CTRANS) during the period from August 2007 to June 2011 under the supervision of Dr. S. Rangnekar, Associate Professor, Department of Management Studies & Associated Faculty, CTRANS and Dr. M. Parida, Professor of Civil Engineering Department & Associated Faculty, CTRANS, Indian Institute of Technology Roorkee, Roorkee, India.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

(RAJEEV KUMAR MISHRA)

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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The Ph.D. Viva-Voce Examination of **Mr. Rajeev Kumar Mishra**, Research Scholar, has been held on 21st October 2011.

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SYNOPSIS

Urbanization, motorization and industrialization are taking place at an ever growing phase in most parts of the world. The deterioration of the environment in terms of noise pollution and air pollution in urbanized areas of different zones of the world has reached such levels that it requires proper and immediate concern. Urbanization is a worldwide phenomenon experienced by economically advanced countries as well as developing countries. The population of India has increased from 548 million in 1971 to 683 million in 1981, 846 million in 1991, 1028 million in 2001 and 1210 million in 2011. On the other hand, the urban population of India increased over the past three decades, rising from 109 million in 1971 to 160 million in 1981 (C47%), 217 million in 1991 (C36%), 285 million in 2001 (C31%) and 286 million in 2011 (Census of India, 2011). The primary cause behind the fast urbanization is availability of opportunities in urban cities. Proper employment, better education, better health related facilities etc. are pulling factors for urbanization. These factors attract people from rural to urban areas which results into the overcrowding of the city. Mobility is also required for urban people to move within city or intercity. To fulfil this necessity vehicle population is increasing continuously in metro cities. This rapid industrialization, urbanization and motorization bring many environmental issues i.e. noise pollution, air pollution and traffic congestion that endanger sustainability of megacities like Delhi in India. The city of Delhi is highly urbanized and supports about 14 million people living in a dense mode with mixed land uses i.e. residential, commercial and industrial. In developing countries due to mixed traffic composition, impact of transport on urban environment is further critical. Like many large metropolitan urban cities, the city of Delhi is also suffering from various environmental problems like traffic noise pollution, vehicular emission, traffic congestion and open land depletion due to the expansion of transport infrastructure. Such kind of environmental pollution shows its adverse impact on human health and causes various somatic and genetic diseases in human being. Road & rail traffic are considered as primary source of noise pollution and air pollution. Due to lack of proper city planning, practically there are no control strategies for reducing the level of noise from various sources. Road traffic noise is considered to be the most awful kind of environmental problem and documented as a serious human health dilemma in developing countries like India. On the other emission from road traffic is also a very significant source group throughout the world especially in developing countries like India. Vehicular air pollution is one of the solemn problems faced by worldwide people, particularly in urban centres of developing countries. In megacities, road traffic accounts up to 90-95% of lead and carbon monoxide emissions, 60-70% of ozone precursors and a major contributor of respirable suspended particulate matter (RSPM), harmful to human health (Faiz 1993; WHO and UNEP 1992). Such a high emission of CO due to road traffic is a serious concern from human health point of view. Air pollution in urban cities is one of the greatest menaces to the human health, which in turn causing danger to the endurance of mankind. The excessive concentration of air pollutants pulls up the number of people suffering from different kind respiratory diseases and serious health hazards. Different air pollutants i.e. carbon dioxide (CO), oxides of nitrogen (NOx), sulphur dioxide (SO_2), hydrocarbon (HC) and particulate matter (PM) are added in the atmosphere from variety of sources that change the composition of air and affect the biotic environment.

Different models have been developed to examine the source of emission from the vehicles in urban areas either in terms of noise emission or vehicular air emission. Modelling is an indispensable tool for traffic noise and air pollution management and related decision making process during traffic congestion. It can help to generate different scenario for the noise and air pollution in coming years which can be used in the formulation of different policies for the environmental sustainability of transport infrastructure.

The present study is basically focused towards the analysis of the existing transport related environmental pollution problems in Delhi. In addition to this, different appropriate models have also been generated for the prediction of traffic noise and air pollutants concentrations under heterogeneous traffic conditions existing in Delhi. A number of mitigatory measures have also been recommended to overcome the environmental issues. For this, the study has been conducted at different selected locations of major public transport corridor in Delhi i.e. Mass Rapid Transit System (MRTS) and Bus Rapid Transit System (BRTS). The study consists of six major aspects namely monitoring of road and rail traffic noise, monitoring of air pollution, model development for the prediction of road noise, rail noise and vehicular pollutant, performance evaluation of the developed model, emission inventory formulation for Delhi and some mitigatory measures like design of noise barrier and application of KM and Non-KM practices in transport related environmental pollution.

For the evaluation of noise level at selected locations due to road and rail, ambient noise level has been monitored along Public Transport Corridor (PTC). The measurement of metro rail noise has been performed at different floors of high rise buildings situated near by the metro corridor. The ambient noise level analysis has been executed by comparing observed noise level with Central Pollution Control Board (CPCB) standards at each selected location. The analysis indicates that the measured noise level at every location exceeded the prescribed limits. On the other hand, to judge the air quality status due to surface transport, major pollutants i.e. CO, NOx, SO_2, HC and PM have been measured at identified locations along public transport corridor. Along with this, the traffic characteristics, meteorological data and geometrical parameters have also been collected. The analysis reveals that the concentration of oxides of nitrogen is higher than CPCB standard at all the locations. From composite air quality analysis, all the selected locations along MRTS and BRTS corridor are found under severe pollution.

In second part of study, two noise pollution model one for road traffic noise and another for metro rail noise has been developed in MS EXCEL worksheet system. Along with this for the prediction of vehicular air pollutants, a General Finite Line Source model has been formulated in the same worksheet system. The basic reason behind the development of all the models in MS EXCEL platform is its user friendly characteristics. To avoid the long mathematical calculation and complexities, the EXCEL sheet has been elected for the formulation of model. The performance evaluation of these models has been assessed by using different statistical tool and quantitative methods to judge the applicability of the model in Delhi condition. The statistical analysis reveals that modified Federal Highway Administration (FHWA) road traffic noise model and Federal Transit Administration (FTA) based metro rail noise model are applicable for the existing condition in Delhi and can be used for modelling purpose. Likewise the performance of General Finite Line Source Model is analysed with respect to various inputs such as traffic volume, temperature, wind angle, wind speed, atmospheric stability and traffic characteristics. In addition to this, statistical test has also been applied to check the appropriateness of this model in Indian condition. The performance of General Finite Line Source Model (GFLSM) is found better for the prediction of gaseous pollutants at all identified locations of major public transport corridor.

The third part of the research work is basically emphasized towards application of the study. Keeping in mind the above discussed problems, some mitigatory measures have been suggested to control the rising environmental pollution. The first part of the mitigatory measures includes installation of noise barrier along the road as well as along the elevated metro track. For each selected location, different barrier of different height is required along road as well as at elevated track of metro line and it is calculated through the developed noise barrier designing model in MS EXCEL worksheet system. In second phase of remedial measure, emission inventory is developed for Delhi for 2025. This inventory has been developed to know the overall scenario of the capital city. A number of inputs like category wise number of vehicles, distance travelled in a year by different vehicle and pollutant emission by a vehicle type per kilometre travelled. Through this inventory, it has been concluded that by the use of Public Transport System, the vehicular emission can reduced by 27% (CO), 16% (NOx), 13% (SO_2) and 31% (HC) and 12% (PM). Thus in present scenario for the reduction of vehicular emission, it is very essential to motivate people towards the use of public transport system. The last phase of the remedial measure for the reduction of vehicular pollution is the incorporation of knowledge management in transport sector. The equilibrium between the sustainable transportation and traffic overcrowding is an immense challenge to the developers, operators and policy makers of the urban transportation network. Through the application of knowledge oriented approach or knowledge based decision support system; it will become very easy to users to find the descriptive answer of his question from the system and take appropriate action at a particular situation A number of practices have been identified from the past applied models in transport sector and on the basis of that, two KM models have been proposed. The first KM model includes various knowledge and traditional practices, which can be employed in megacity like Delhi to overcome the problem of traffic noise as well as traffic air pollution. In addition to this, the orientation of the other developed model is towards proper traffic management. The basic aim of this developed model is to reduce traffic noise pollution and vehicular emission through proper traffic management. This model also consist miscellaneous knowledge and common practices and it is possible to lessen traffic noise air pollution problem, time delay problem and fuel consumption problem by the implementation of these practices in transport division.

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RAJEEV KUMAR MISHRA

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LIST OF ACRONYMS

Terms	Description
AHP	Analytic Hierarchy Process
AID	Automatic Interaction Detection
ANN	Artificial Neural Network
APOM	Air Pollution Ontology Module
APRAC3	Air Pollution Research Advisory Committee Version 3
AQMAAP	Air Quality Model Performance Assessment Package
ARIMA	Autoregressive Integrated Moving Average
ARIMA	Auto Regressive Integrated Moving Average
BRTS	Bus Rapid Transit System
CADM	Chilean Air Pollution Dispersion Model
CALINE-4	California Line Source Model
CAQI	Composite Air Quality Index
CAR	Calculation of Air Pollution from Road Traffic
CFCs	Chloro Fluoro Carbons
CMB	Chemical Mass Balance
CMS	Changeable Message Signs
CO	Carbon Monoxide
COHb	Corboxy Heamoglobin
CPCB	Central Pollution Control Board
CST	Centre for Sustainable Transport
CTM	Chemistry Transport Module
DASETT	Department of the Arts, Sports, the Environment, Tourism and Territories
DB	Data Base
dBA	Decibel
DFLSM	Delhi Finite Line Source Model
DMs	Decision Makers
DSS	Decision Support System

DVPM	Deterministic Vehicular Pollution Modelling
EC	European Community
EPA	Environmental Protection Agency
EPARM	EPA Rollback Model
EPCU	Equivalent Passenger Car Unit
ES	Expert System
FE-ANN	Feed Forward Artificial Neural Network
FHWA	Federal Highway Administration
FHWA TNP	Federal Highway Administration Traffic noise Model
FLT	Fuzzy Logic Theory
FTA	Federal Transit Administration
GA	Geometric Algorithm
GDSS	Group Decision Support System
GFLSM	General Finite Line Source Model
GHGs	Green House Gases
GIMM	Graphical Input Microcomputer Model
GIS	Geographical Information System
GM	General Motor
GRM	Generalized Rollback Model
GUI	Graphical User Interface
GVW	Gross Vehicle Weight
GZE	Grangzhou Empirical
HC	Hydrocarbon
HT	Heavy Trucks
IEA	International Energy Agency
IITLS	Indian Institute of Technology Line Source
IRF	International Road Federation
ISCST	Industrial Source Complex Short Term
ITMS	Intelligent Traffic Management Systems
ITS	Intelligent Transport System
IUCN	International Union for the Conservation of Nature
KBDSS	Knowledge Based Decision Support System
KBS	Knowledge Based Systems

KM	Knowledge Management
LLD	Log Logistic Distribution
LNP	Research Review
LSEM	Line Source Emission Model
MEF	Ministry of Environment and Forest
MLP	Multi Layer Perception
MM5	Mesoscale Meteorological Model
MOUD	Ministry of Urban development
MRTS	Mass Rapid Transit System
MT	Medium Trucks
NBDP	Noise Barrier Design and Protection
NH-2	National Highway-2
NH-58	National Highway-58
NMT	Non Motorized Transport
NNM	Neural Network Model
NO	Nitric Oxide
NOX	Oxides of Nitrogen
OECD	Organization for Economic Cooperation and Development
OLS	Ordinary Least Square
OLS	Ordinary Least Square
OMG	Osaka Municipal Government
OPAC	Optimized Policies for Adaptive Control
PAL	Point, Area and Line
PEM	Pollution Episodic Model
PWILG	Parallel Wind and Infinite Line Source Gaussian
Qw	Traffic Flow in EPCU
RB	Rule Base
REML	Refund Energy Mean Emission Level
RIVM	National Institute for Public Health and the Environment
RSPM	Respirable Suspended Particulate Matter
SCATS	Sydney Coordinated Adaptive Traffic System
SCOOT	Split-Cycle-Offset Optimization Tool
SDSS	Spatial Decision Support System

SO_2	Sulphur Dioxide
SPL	Sound Pressure Level
SPM	Suspended Particulate Matter
TCCs	Traffic Control Centres
TCM	Traffic Congestion Manager
TERI	Tata Energy Research Institute
TEXIN	Texas Instrumentation Model
TNAP	Traffic noise Analysis Package
TNAP	Traffic Noise Analysis Package
TNI	Traffic Noise Index
TNM	Traffic Noise Model
TOCs	Traffic Operations Centres
TRB	Transportation Research Board
TRRL	Transport and Road Research Laboratory
UFP	Ultra Fine Particle
UIS	Urban Information System
UKS	Urban Knowledge System
UKS	Urban Knowledge System
UNAMAP	User's Network for Applied Modelling of Air Pollution
UNCHS	United Nations Centre for Human Settlements
UNEP	United Nations Environment Programme
UNWCED	UN World Commission on Environment and Development
USEPA	United State Environmental Protection Act
USEPA	United State Environment Protection Agency
UTOPIA	Urban Traffic Optimisation by Integrated Automation
VMS	Variable Message Signs
VMS	Variable Message Signs
VOCs	Volatile Organic Compounds
WCED	World Commission on Environment and Development
WEO	World Energy Outlook
WHO	World Health Organization
WOL	Web Ontology Language
WWF	World Wide Fund for Nature

NOTATIONS AND DEFINITIONS

Notation	Definition
L_{10}	Traffic noise level that exceed 10% of the measuring time period
L_{50}	Traffic noise level that exceed 50% of the measuring time period
L_{90}	Traffic noise level that exceed 90% of the measuring time period
Qw	Traffic volume in EPCU/hr
C_{max} (t)	Maximum concentration for t hour
C_{max} (h)	Maximum concentration for one hour
L_0	Basic sound level for a stream of vehicles under specific standard conditions
L_i	Correction to take into account the number of vehicles, type of vehicles
L_{eq}	Equivalent traffic noise level
$(Lg)_E$	Reference Energy
Δ_d	Distance adjustment
Δ_s	Shielding adjustment
N	Fractional number
λ	Wavelength
Δ_{Bi}	Barrier attenuation
f	Frequency
Δ_B	Barrier adjustment
Δ_g	Gradient adjustment
Δ_f	Traffic flow adjustment
Δ_P	Payment type adjustment
Δ_d	Distance adjustment
Δ_a	Angle of view adjustment
Δ_r	Adjustment for reflection
θ	Angle
Q	Traffic noise
L_{loc}	Reference noise level for diesel electrical locomotive
A_{DL}	Distance adjustment for diesel electrical locomotive
A_{DC}	Distance adjustment for railway cars

L_c	Reference noise level for railway cars
LRT	Reference noise level for rapid transit vehicles
T_L	Train length
A_{INT}	Time interval adjustment
C	Pollutant Concentration
Z	Vertical dispersion coefficient
Y	Horizontal dispersion coefficient
h_0	Plume center height
EF	Emission Factor
T	Temperature
R^2	Regression Coefficient

Chapter 1

INTRODUCTION

1.1 General

The explosion of urban population growth is creating an increasing number of megacities (more than 10 million population), mostly in the developing world. Now a days particularly in developing countries the process of hasty urbanization has been associated with a low proportion of urban space devoted to roads. In developing countries due to mixed traffic composition there is an acute appreciation of the impacts of transport on urban environment. In present scenario megacities are the major growth centers. Urbanization is increasing at twice the rate of total population worldwide. Figure 1.1 illustrates population, motorization, and automobile use trends and projections worldwide during the period 1960–2010 (World Bank 1996). It is obvious from this figure that the urban population is increasing at a much faster rate than the total population. Motorization goes hand in hand with urbanization. Due to rising urban incomes and ownership, use of motor vehicles is increasing in developing countries at a faster rate than urbanization rate. Motor vehicle pollution generates about one-fifth of the incremental carbon dioxide in the atmosphere arising from human activity and half of the nitrogen oxides which contribute to global warming and to acidification and ecological damage respectively. A recent study estimated that during the next 15 years the average annual urban population growth in the least developed countries will be 4.6%, compared to 0.6% estimated for cities in industrialized countries (UNCHS 2001). Rapid motorization and attendant urbanization can bring many environmental risks and problems that can seriously jeopardize the sustainability of cities. In cities of developing countries, the risks and the problems are much greater because of the overwhelming scale and speed of urbanization compared to the available resources, particularly in the emerging megacities. Rapid motorization and urbanization can bring many environmental issues that can endanger the sustainability of cities. In mega and metro cities of developing countries, the risks and the problems are much greater due to devastating scale and speed of urbanization compared to the available resources. Like many urban cities, Delhi is also suffering from various environmental problems caused by traffic emission, noise pollution, traffic congestion and open land depletion. For developing countries like India, these environmental crises are going to be a big problem. Road traffic is considered as a primary source of air and noise pollution. Road transport vehicles account more than three-quarters of the transport sector's contribution to global air pollution. As result urban environmental quality and liveability has deteriorated down in cities of most developing country. In megacities, road traffic accounts for 90-95% of lead and carbon monoxide emissions, 60-70% of ozone precursors and a major contributor of respirable suspended particulate matter (RSPM), harmful to human health (Faiz 1993; WHO and UNEP 1992). In Delhi, particulate matter cause different respiratory diseases especially to young and frail. These traffic emissions affect human health, particularly of pedestrians and persons living or working nearby road traffic.

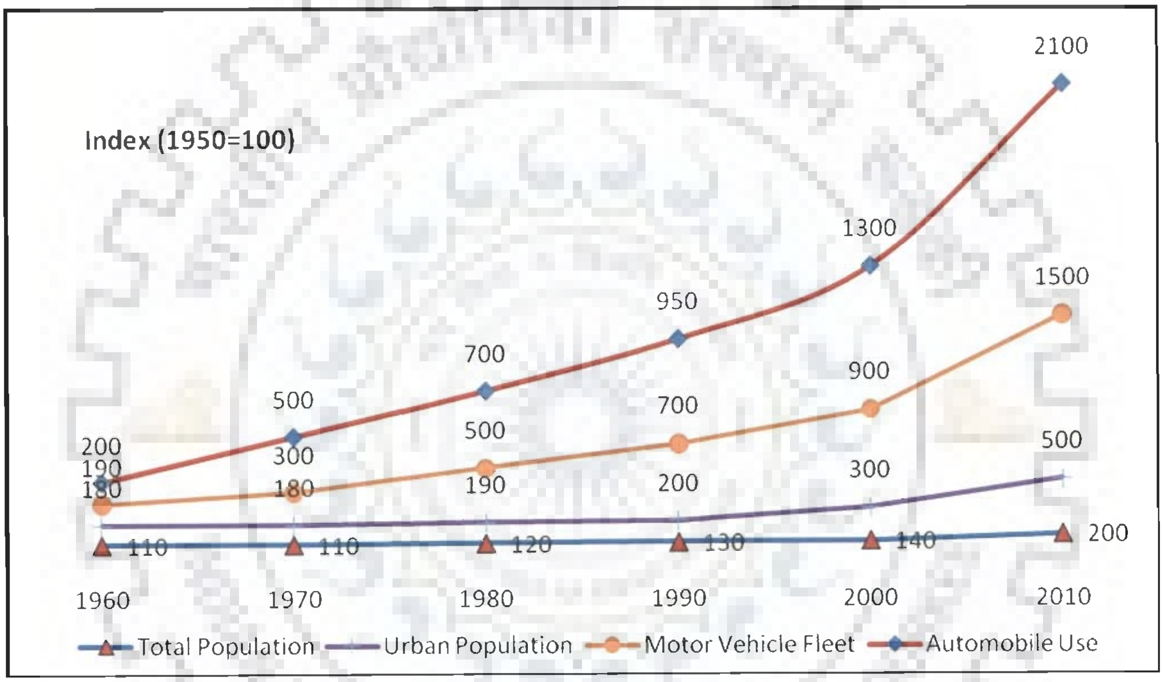


Figure 1.1: Trends in World Population and Motorization Growth

Source: World Bank, 1996

1.2 Urbanization and Transport-Environment Interaction

1.2.1 Impact of urbanization on transport: a world panorama

The world wide urban population has more than tripled to reach 2.86 billion between 1950 and 2000. Today most of the people are living in urban areas than in rural areas. It is predicted that the urban population is to be increased by 80 million every year. Currently urbanization has considerably slowed down in developed countries while developing countries are continuously urbanizing; accounting for 68% of urban population in 2000. By 2020, 77% of global urban population (3.26 billion) is expected to be in developing countries (Figure 1.2). Increasing urbanization is basically affected by two factors i.e. a natural increase in population (excess of births over deaths) and migration to urban areas.

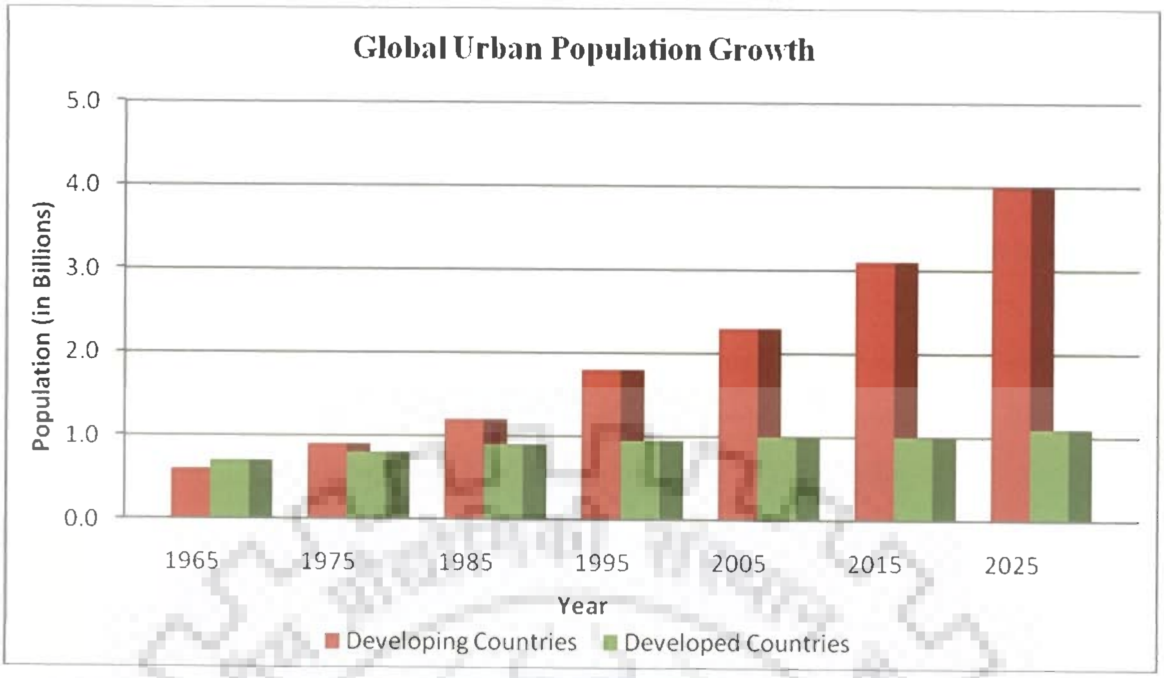


Figure 1.2: Global Urban Population Growth

Source: Ministry of Urban Development, Government of India, 2008)

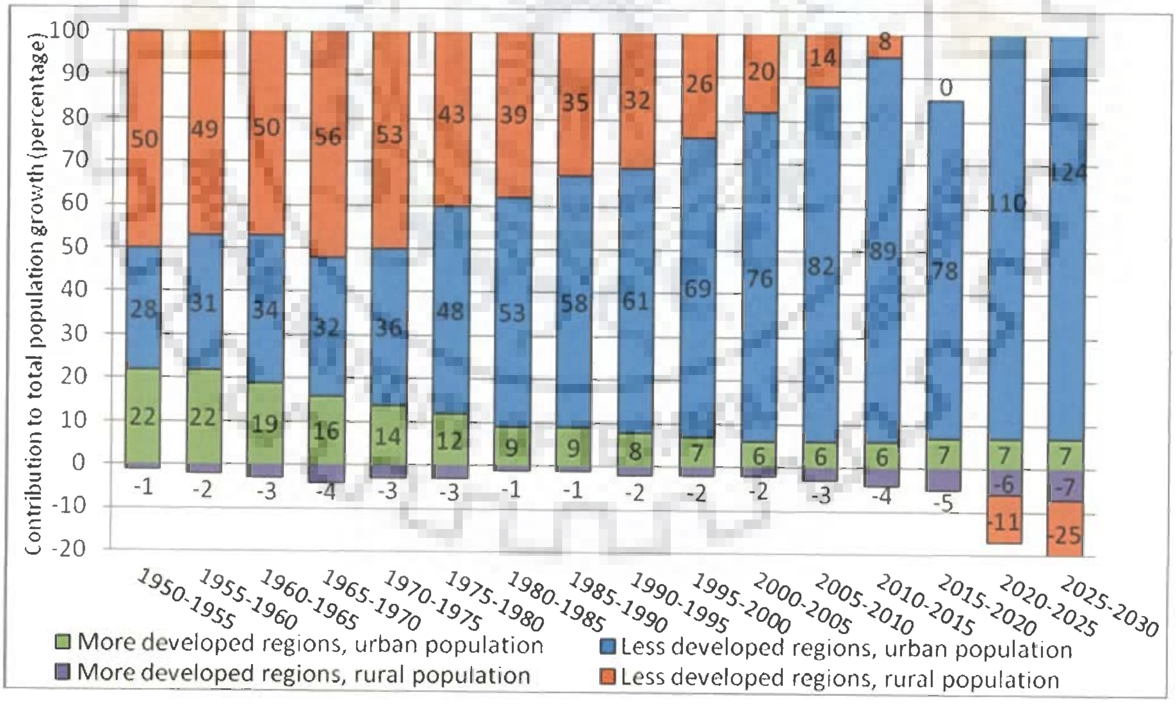


Figure 1.3: Contributions of Urban and Rural Population Growth to Total Population Growth, 1950-2030

Source: World Urbanization Prospects, 2004

At present the movement of people from rural to urban areas (internal migration) is most significant. Almost all the growth of the world's total population between 2000 and 2030 is expected to be absorbed by the urban areas of the less developed regions (Figure 1.3). Nearly 63% of the Class I city population (about 108 million) lived in the 35 million-plus cities (about 39% of total urban population). Three cities have a population of more than 10 million. Four others cities have crossed the four million mark (Table 1.1). Amongst the mega-cities, the top three – Greater Mumbai, Kolkata and Delhi – accommodated over 65% (about 42 million) of the mega-city population (about 15% of the total urban population). The process of urbanization is already advanced in the more developed regions, where 74 per cent of the population lived in 2003. The proportion of population living in urban areas is expected to increase to 82 per cent by 2030 (Table 1.2).

Table 1.1: Urban Agglomerations/Towns by Class/Category

Class	**Population Size**	**No. of UAs/Town**
Class I	1,00,000 and above	393
Class II	50,000-99,999	401
Class III	20,000-49,999	1,151
Class IV	10,000-19,999	1,344
Class V	5,000-9,999	888
Class VI	Less than 5,000	191
Unclassified		10
All classes		4378

Source: Ministry of urban development, Government of India, 2008

Table 1.2: Percentage Urban Growth by Development Group, Selected Periods, 1950-2030

	Percentage urban growth					Rate of urbanization	
	1950	**1975**	**2000**	**2003**	**2030**	**1950-2000**	**2000-2030**
World	29.1	37.3	47.1	48.3	60.8	0.96	0.85
More developed regions	52.5	67.2	73.9	74.5	81.7	0.68	0.33
Less developed region	17.9	26.9	40.5	42.1	57.1	1.63	1.15

Source: World Urbanization Prospects, 2004

1.2.2 Trends of urban transport system in India

Population growth, increasing urbanization, rising motorization, and low per-capita incomes are the most important factors common to India and other developing countries. The entire urban population of India increased over the past three decades, rising from 109 million in 1971 to 160 million in 1981 (C47%), 217 million in 1991 (C36%), and 285 million in 2001 (C31%) and 286 million in 2011 (Census of India,2011, Padam and Singh, 2001). By 2001, India had three megacities: Mumbai (Bombay) with 16.4 million inhabitants, Kolkata (Calcutta) with 13.2 million inhabitants, and Delhi with 12.8 million inhabitants and 35 metropolitan areas had populations exceeding one million, almost twice as many as in 1991 (Census of India, 2001a). The fast expansion of Indian cities has engendered a correspondingly rapid growth in travel demand, devastating the limited transport infrastructure. The piercingly increasing levels of motor vehicle ownership and use, in particular, have resulted in alarming levels of congestion, air pollution, noise, and traffic danger (Figure 1.4).

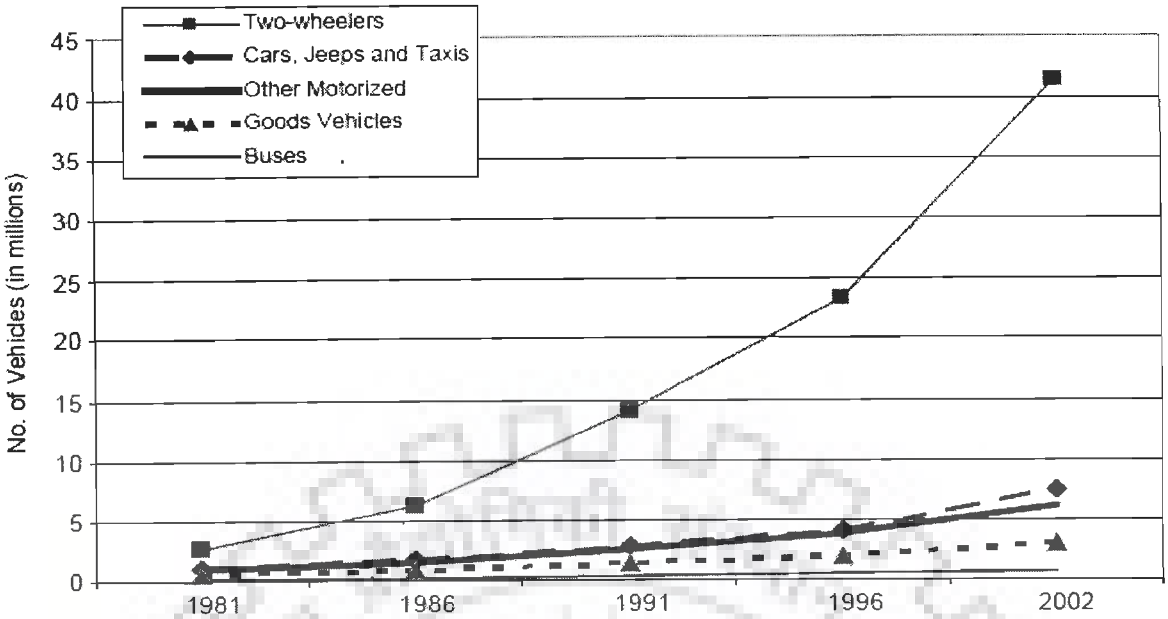


Figure 1.4 Growth of India's Motor Vehicle Fleet by Type of Vehicle, 1981–2002 (in millions)

Source: Handbook on Transport Statistics, 1999, 2000 & 2001)

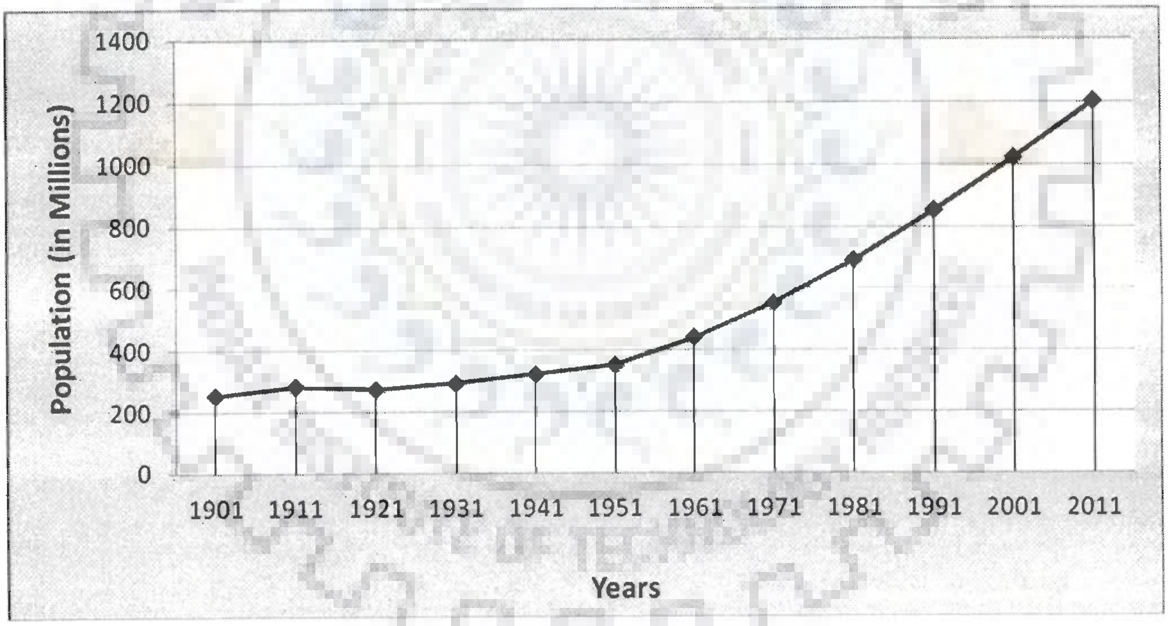


Figure 1.5: Population of India: 1901-2011

Source: Census of India, 2001b

Urban population is increasing at a very high rate in developing countries. A recent study estimated that in the next 15 years the average annual urban population growth in the least developed countries will be 4.6%, compared to 0.6% estimated for cities in industrialized countries (UNCHS 2001). India supports 16% of the world's population on 2.4% of its land. The density of population (persons per square kilometer) in India was 313. The corresponding density for arable land was as high as 559. Over the past five decades, India's population has grown nearly three-fold to one billion, from 361 million in 1951. Figure 1.5 shows the population growth curve. While the annual rate of growth of population over the fifty-year period, 1901-51 was only 0.83%, over 1951-71 it increased to 2.09, over 1971-91 to 2.17% and finally between1991-96 it fell to 1.98%. The annual growth rate for 1996-2006 is expected to be 1.57% and over 2006-2016 it is expected to be 1.44%. The 2001 census of India shows that out of the total population of 1027 million, about 742 million (72.2%) live in rural areas and 285 million (27.8%) in urban areas. The percentage decadal growth of population in rural and urban areas during the last decade is 17.9 and 31.2 percent respectively.

1.2.3 Glimpse of urban transport in Delhi

The urban population in India has increased significantly from 62 million in 1951 to 285 million in 2001 and is estimated to grow to 540 million by the year 2021. At the same time industrial growth is also moving very fast in the megacities of developing world. Population growth, urbanization, and industrial activity are the main drivers for the growth of the transport sector. In Delhi, the entire vehicle fleet — motorized and non-motorized — is growing rapidly. From 1975 to 1998, the car population increased from about 68,000 to almost 800,000, and motorized two-wheelers from about 100,000 to over 1.5 million. With continued income growth, the motor vehicle population is expected to continue expanding at a high rate (Table 1.3). The number of bicycles and cycle rickshaws is also very large and increasing, though the number is uncertain since many owners do not comply with the requirement for annual registration.

Table 1.3: Motor Vehicles in Use in Delhi (thousands)

Year	Scooters and Motorcycles	Cars/Jeeps	Auto-rickshaws	Taxis	Buses	Freight	All motor vehicles
1971	93	57	10	4	3	14	180
1980	334	117	20	6	8	36	521
1990	1077	327	45	5	11	82	1547
2000	1568	852	45	8	18	94	2584
2010	2958	1472	103	14	39	223	4809
2020	6849	2760	209	28	73	420	10339

Source: Delhi Statistical Handbook and Transport Department, Delhi and Bose and Nesamani, 2000.

Among all mega cities of India, Delhi is a fast growing and expanding mega city. The industrial development and mobility of goods have brought an enormous increase in transport sector. Due to this expansion the city faces transportation, environmental and economic challenges. Because of continuously increasing number of vehicles, this city is moving towards the dangerous level of air pollution, noise pollution and traffic congestion. Delhi is one of the 10 most polluted cities in the world. Road vehicles are continuously emitting the different types of air pollutants like carbon monoxide (CO), oxides of nitrogen (NO_x), suspended particulate matter (SPM), sulphur dioxide (SO_2), lead (Pb), hydrocarbons (HC) and volatile organic compounds (VOCs). On world level, vehicles contribute about 14-16% of CO_2, 25-30% of NO_x, 50% of HC, 60% of Pb and more than 60% of CO, of the anthropogenic total emissions (Cortese, 1990). According to the 1991 census, Delhi had a population of 9.421 million. It is predicted that it will touch to 13.2 million in 2001. In Delhi the total number of vehicles has increased from 0.235 million in 1975 to 2.63 million in 1996, and expected to touch 6 million in 2011.

1.3 Surface Transport Noise Pollution

Noise is defined as unwanted or excessive sound. It is one of the most widely experienced environmental externalities associated with transportation systems. Noise pollution has become a major concern of communities living in the vicinity of major urban arterials. The excessive noise can adversely affect real-estate value and can cause various human health problems like annoyance, frustration, impediment of learning and general stress. Migration of people from rural to urban areas, expansion of cities, infrastructure development, population growth and urbanization are important factors resulting in motorization and consequent increase in levels of noise pollution. Transport infrastructure developments, construction of flyovers in metropolitan cities are taking place in a massive way and due to this noise pollution problem has become more significant. The problem of noise pollution due to transportation system is inimitable among the all kinds of pollution. Noise generated at a particular time is not affected by previous activity, nor does it affect future activities. Unlike other pollutants, noise leaves no residual effects that are evidential of its unpleasantness. Due to this reason, there is a tendency to overlook or underrate the problem of noise pollution.

1.3.1 Sources of transportation noise

The most common transportation noise is from highway operation (autos, trucks, buses) but there can also be significant noise from other modes like planes, trains and water vessels. The different sources of transportation noise are as follows:

- **Vehicle-air interaction:** When a vehicle is in motion, fraction between the vehicle's body and the surrounding air induces a gradient in the air pressure field and thereby generate noise.
- **Tire-pavement interaction:** The pavement noise generation is a direct result of the friction and small impacts that occur as the tire rolls along the highway or runway pavement surface. Such noise is generally more pronounced for concrete pavements and less asphalt concrete pavements. In the case of rail transportation, friction between the steel wheel and the guide way often generates noise, particularly in curve areas.
- **Vehicle engines:** Vehicle engine noise levels are generally higher in areas of higher speed or with geometric designs that encourage vehicle acceleration or deceleration. With this, the larger transportation vehicles i.e. trucks, large aircraft and ocean liners generate more noise than do their smaller counterparts.
- **Vehicle exhaust system:** Exhaust systems on vehicles lead to higher noise levels, especially in case of malfunctioning noise-control devices. Exhaust noise levels are closely related to noise from vehicle engines, higher speeds, more frequent speed changes and larger vehicles are associated with higher levels of exhaust noise.
- **Vehicle horns and brakes:** Vehicle horns can constitute a significant and irritating source of urban traffic noise, particularly in traffic culture where frequent horn blowing is practiced. Brakes also constitute a significant noise source, particularly for large trucks.

Noise generated from a highway traffic stream can propagate over considerable distances and has an acoustic spectrum that can typically range from 120 to 4000 Hz. This frequency range is discernible by human ears and thus can cause great discomfort to human beings.

1.3.2 Factors affecting transportation noise propagation

Temperature variations between the lower and upper atmospheric belts affect noise propagation. The speed of sound is reduced when sound waves move into denser media.

Sound waves therefore generally bend toward cooler temperature. On a typical hot day, temperature decreases with increasing altitude, the sound waves generated at ground level tend to bend upward, creating a shadow zone. Sound levels are reduced by as much as 20 dBA at distance exceeding 152.4 meter in such type of zone. Whereas on a typical cold day, the temperature are lower at points closer to the ground than at points higher in the atmosphere. On the other hand, wind direction also influences sound propagation. When the wind blows against the direction of sound, sound waves generated at ground level tend to bend upward, creating a shadow zone. When wind blows in the direction of sound waves, sound waves tend to bend toward the site surface, bounce off the surface, and travel much farther than it does under normal conditions. There are other noise propagation factors like nature of source and distance of noise receptor from the source.

- **Point sources:** Where the noise origin is a single location, the source referred as a point source. The propagation of noises from point sources is governed by the spherical spreading phenomenon.

$$\Delta SPL\ (dB) = 10\log_{10}(r_1 \square r_2) \quad \text{.... (1.1)}$$

where ΔSPL (dB) = difference in sound pressure levels

r_1, r_2 = distance of point source from points 1 and 2 respectively

The difference in SPL from point 1 to point 2 is

$$\Delta SPL\ (dB) = 10\log_{10}(1/2)^2 = -6\ dB \quad \text{.... (1.2)}$$

For every doubling of the distance between noise source and receptor, the SPL decreases by 6 dB and for every having of the distance between the noise source and the receptor, the SPL increases by 6dB.

- **Line Sources:** Highway with a uniform traffic flow or a railway, along which a long train is moving, represents a linear extrusion of a point source in space, constituting line source. Noise propagation from line sources can be described by the cylindrical spreading phenomenon. The reduction of noise from a line source can be expressed as follows:

$$\Delta SPL\ (dB) = 10\log_{10}(r_1 \square r_2) \text{ or } 10\log_{10}(d_1/d_2) \quad \text{.... (1.3)}$$

where, r or d is the distance from the line source.

When d2 = 2d1,

$$\Delta SPL\ (dB) = 10\log_{10}(1 \square 2) = 3dB \quad \ldots. (1.4)$$

For every doubling of the distance between noise source and receptor, the SPL decreases by 3 dB, and for every halving of the distance between the noise source and the receptor, the SPL increases by 3 dB.

For the line source like highways traffic noise is expected to decrease by 3 dB for each doubling of distance from the highway. The spatial relationship between a transportation noise and the receptor not only determines the attenuation due to geometric spreading, but also determines the characteristics of the noise path, such as obstruction to the sound path.

- **Noise Barriers Effect:** Noise barrier in the path of a sound cause its diffraction or reflection (Figure 1.6), thus causing reduction of the sound levels. The area of decreased sound is called the shadow zone. Sound attenuation is maximum immediately behind the object and decreases with the distance behind the object as the sound wave reforms.

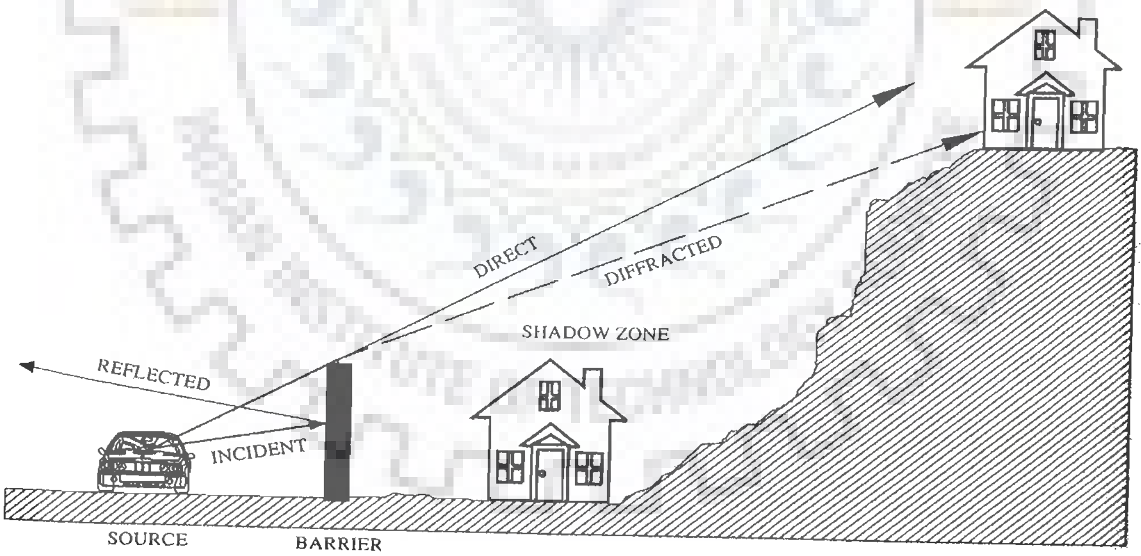


Figure 1.6: Noise Barrier Effects

1.3.3 Traffic noise pollution impact on human health

Traffic noise has a variety of adverse impacts on human health. Community noise, including traffic noise, is already recognized as a serious public health problem by the World Health Organization (WHO). Among all the adverse effects of traffic noise the most widespread is simply annoyance. There is also substantial evidence for traffic noise disturbing sleep patterns, affecting cognitive functioning (especially in children) and contributing to certain cardiovascular diseases. For raised blood pressure, the evidence is increasing. The health effects of noise are not distributed uniformly across society, with vulnerable groups like children, the elderly, the sick and the poor suffering most. In 2000, more than 44% of the European Population (about 210 million people) was regularly exposed to over 55 dB of road traffic noise, a level potentially dangerous to health. In addition, 35 million people in the EU25 (about 7%) are exposed to rail traffic noise above 55 dB. Millions of people indeed experience health effects due to traffic noise. For example, about 57 million people are annoyed by road traffic noise, 42% of them seriously. A preliminary analysis shows that each year over 245,000 people in the EU25 are affected by cardiovascular diseases that can be traced to traffic noise. About 20% of these people (almost 50,000) suffer a lethal heart attack, thereby dying prematurely. The annual health loss due to traffic noise increased between 1980 and 2000 and is expected to increase up to 2020 (Delft, 2007). Traffic is the most widespread source of environmental noise. Exposure to traffic noise is associated with a wide range of effects on human health and well-being. The different adverse health effects of traffic noise pollution include socio-psychological responses like annoyance and sleep disturbance and physiological effects such as cardiovascular diseases (heart and circulatory problems) and impacts on mental health (RIVM, 2004). Figure 1.7 summarizes the potential mechanisms of noise-induced health effects and their interactions. Potential health effects due to exposure to traffic noise are explained in following subsections.

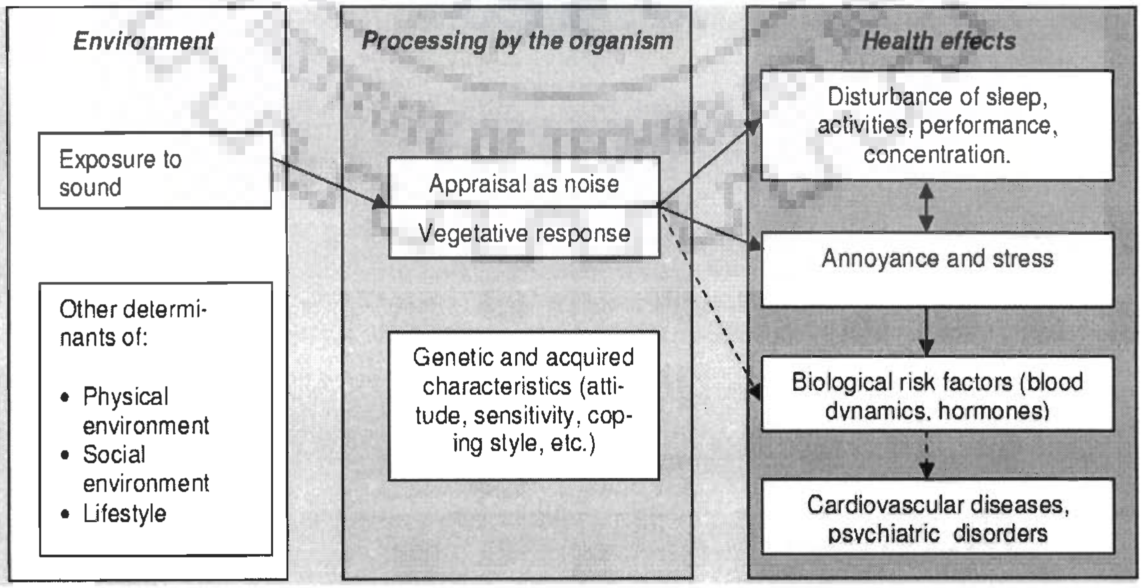


Figure 1.7: The Mechanisms of Noise-Induced Health Effects

Source: Sinha and Labi (2007)

1.3.3.1 Annoyance

The most widespread problem created by noise is quite simply annoyance. Annoyance can be defined as a general feeling of displeasure or adverse reaction triggered by the noise. In the human environment (which also includes neighbours, industry, etc.) traffic is the single most important source of noise annoyance (Niemann & Maschke, 2004; RIVM, 2004). The degree of annoyance triggered by traffic noise is determined first of all by the noise level. The higher the level, the more people are annoyed and the greater the severity of perceived annoyance (Larsen, E. et al., 2002; RIVM, 2005). The higher the pitch of the noise, the greater is the annoyance. Duration and intermittency also influence the degree of annoyance. Traffic noise-induced annoyance is governed by more than just acoustic factors, with personal and situational factors also coming into play, as well as a person's relationship to the source of the noise. Subconscious physical reactions, such as raised blood pressure, and levels of annoyance due to chronic noise will not diminish over time unless the noise itself is abated.

1.3.3.2 Sleep disturbance

Traffic noise is the main cause of sleep disturbance (Niemann & Maschke, 2004). This effect of noise on sleep has important health effects, since uninterrupted sleep is known to be a prerequisite for proper physiological and mental functioning in healthy people (WHO, 2007). Three types of effects of noise on sleep can be distinguished: effects on sleeping behaviour (primary effects), effects on performance and mood through the following day (secondary effects) and long-term effects on well-being and health. The effects of night-time traffic noise on sleep disturbance begin at fairly low volumes and become more likely as the intensity of the noise increases. Changes between sleep stages, increased body movements and heart-rate acceleration start at noise levels around 32-42 dB (A) (WHO, 2007). Sleep disturbance is influenced by other noise characteristics, too. People are far more sensitive to intermittent noise than continuous noise (Prasher, 2003).

1.3.3.3 Disturbed cognitive functioning (learning and understanding)

Exposure to traffic noise can impair an adult's cognitive functioning like information processing, understanding and learning. The influence of noise on cognitive functioning depends on a person's perceived control of the noise and its predictability. According to Bistrup et al. (2001), the adverse effects of road traffic noise exceed those of rail traffic noise. In general, the following effects have been found for children exposed to high levels of traffic noise (Bistrup et al., 2001; Clark et al., 2005; RIVM, 2005):

- Difficulty in sustaining attention.

• Difficulty in concentrating.

• Poorer discrimination between sounds and poorer perception of speech.

• Difficulty in remembering, especially complex issues.

• Poorer reading ability and school performance.

A hypothesis frequently stated to explain the impact of chronic exposure to noise on the cognitive development of children is that noise affects the intelligibility of speech communication (Bistrup et al., 2001; RIVM, 2005).

1.3.3.4 Cardiovascular disease

Exposure to traffic noise is associated with changes in blood pressure and increased risk of various types of heart disease i.e ischemic heart diseases, anginapectoris, myocardial infarction). Noise-induced cardiovascular diseases are considered to be the consequence of stress. Exposure to noise triggers the production of (stress) hormones like cortisol, noradrenalin and adrenaline. These hormones may cause changes in the values of a number of biological risk factors, such as hypertension (high blood pressure), blood lipids (e.g. cholesterol) and blood glucose. These risk factors can increase the risk of cardiovascular disease. Persistent exposure to environmental noise could therefore result in permanent changes to the vascular system, with elevated blood pressure and heart diseases as potential outcomes.

Higher risks of heart disease are found for those living in streets with average noise levels above 65-70 dB (A). For these people the risk of heart disease is approximately 20% higher than for those living in quieter areas (Babisch, 2006). This risk of heart disease is also dependent on the number of years of exposure to the traffic noise. Bluhm et al. (2006) suggests the existence of a relation between residential exposure to road traffic noise and hypertension.The longer people are exposed to a high level of traffic noise, the greater the likelihood of it having an impact and increasing the risk of a heart attack.

1.3.3.5 Adverse effects on mental health

The clear association between noise and annoyance does not necessarily translate into a more serious relationship with mental health (London Health Commission, 2003). However, noise may well accelerate and intensify the development of latent mental disorder. People already suffering mental problems are likely to be more sensitive to being annoyed or disturbed by traffic noise than the general population.

1.3.4 Noise pollution standards

Due to alarming increase in ambient noise level throughout the world, most of the countries have prescribed different noise standards. The ambient noise levels given by WHO, is presented in Table 1.4. Similarly Table 1.5 depicts the noise standards applicable in Australia, Japan and United States.

Table 1.4: Prescribed Noise Standards by WHO

Land Use	Prescribed Standards
Indoor/domestic (night time)	35 dBA
Indoor/domestic (day time)	45 dBA
Community/Urban (night time)	45 dBA
Community/Urban (day time)	55 dBA
Industrial/occupational	75 dBA

Source: http://old.kerala.gov.in/keralcaljan05/p17.pdf

Table 1.5: Prescribed Noise Standards in Different Countries

Land Use	Prescribed Standards		
	Australia	Japan	United States
Industrial	65-55	60-50	60-80/55-75
Commercial	55-45	60-50	60-80/55-65
Residential	45-35	50-40	55-65/50-60
Silence zone	45-35	45-35	NA

Source: http://old.kerala.gov.in/keralcaljan05/p17.pdf

Likewise the US Federal Highway Administration (FHWA) has also recommended noise limits based on L10 for various types of land use. Table 1.6 shows the noise standards give by FHWA. Similarly, Central Pollution Control Board (CPCB) in India has suggested the limits of ambient noise level for different zone (Table 1.7). By maintaining or achieving this noise limits, it is possible to move towards the environmental friendly sustainable transport system.

Table 1.6: Noise Standards Prescribed by FHWA

Land Use	Description of land category	Prescribed values of L10
A	For parks and open spaces where quietness is of primary importance	60 dBA
B	Residential area, churches, schools, libraries, hospitals etc.	70 dBA
C	Developed areas	75 dBA
D	Residential areas, hotels. Libraries etc.	55 dBA

Table 1.7: Ambient Noise Standards in India

Area	Leq (dBA)	
	Day Time*	Night Time**
Industrial	75	70
Commercial	65	55
Residential	55	45
Silence Zone***	50	40

*Daytime 6 A.M. to 9 P.M. i.e. 15 hours
**Night time 9 P.M. to 6 A.M. i.e. 9 hours
***Areas up to 100 meter around certain premises like hospital, educational institute and courts.
Source: CPCB, 2010

1.4 Vehicular Air Pollution

Air pollution, a visible environmental side effect of transportation, has become a public health concern for millions of urban residents worldwide (TRB, 1997). Air pollution is a major negative externality. It has become one of the worst environmental hazards in urban areas of developing countries, and transport t is usually among its main sources. The problem of air pollution is particularly relevant to urban transport, considering the high concentrations of urban population, rapid rates of urbanization, and inefficient transport systems in developing countries. Air pollutants are added in the atmosphere from variety of sources that change the composition of air and affect the biotic environment.

1.4.1 Pollutant types and their human health impact

The concentration of air pollutants depend not only on the quantities that are emitted from air pollution sources but also on the ability of the atmosphere to either absorb or disperse these emission. The pollution concentration vary spatially and temporarily causing the air pollution pattern to change with different locations and time due to changes in meteorological and topographical condition. Deterioration of air quality is a major environmental problem in many large urban centers in both industrial and developing countries. The most common urban air pollutants in the region include carbon monoxide (CO), nitrogen oxides (NOx), sulphur dioxide (SO_2), particulate matter (PM), ultra fine particles (UFP), Ozone and lead.

1.4.1.1 Carbon monoxide (CO)

Carbon monoxide (CO) is a toxic gas emitted into the atmosphere as a result of combustion processes. CO is also formed by the oxidation of hydrocarbons and other organic compounds. CO is produced almost entirely (90%) from road traffic in European cities. The largest contributors of CO are petrol-fuelled vehicles. CO binds strongly to hemoglobin in red blood corpuscles resulting in the production of carboxyhemoglobin (COHb). This impairs the transport of oxygen within the blood and can result in adverse effect on tissues with high oxygen needs such as the cardiovascular and nervous systems. High concentration (>1000 ppm) for prolonged hours (>8 hr) can give rise to hypoxia. A recent study has shown that chronic exposures to CO may cause adverse birth outcomes such as reduced birth weight and intrauterine growth retardation (Salam et al., 2005).

1.4.1.2 Oxides of nitrogen (NOx)

Nitrogen oxides are formed during combustion processes at high temperatures from the oxidation of nitrogen in air. The major types of oxides of nitrogen are nitric oxide (NO) and nitrogen dioxide (NO_2). They are collectively known as NOx. The main source of NO is road traffic, which accounts for 49% of total NO emissions in Europe and 32% in the USA. Oxides of nitrogen are immunotoxic and increase the susceptibility to respiratory tract infection such as influenza. Continued or frequent exposures to high concentrations of

NOx in breathing air may cause irritation of the lungs and consequent acute respiratory illness (Hasselblad *et al.,* 1992).

1.4.1.3 Sulphur dioxide (SO_2)

Sulphur dioxide (SO_2) is emitted in direct proportion to the amount of sulphur in fuel. Coal burning is a major source of SO_2 in air. SO_2 in ambient air can also affect human health. Routledge *et al.,* 2006), particularly in those suffering from asthma and chronic lung diseases and exacerbates respiratory symptoms and impaired breathing in sensitive individuals (Lipfert, 1994).

1.4.1.4 PM_{10}

They consist of PM with a diameter upto 10 μm. The most important particles are those having a diameter of less than 10 μm (PM_{10}) because they are respirable. PM_{10} deposit relatively quickly with a lifetime of less than 2 days, and exposure may lead to adverse responses in the lungs triggering an array of cardio-pulmonary problems (Brunekreef and Forsberg, 2005). Moreover the rise in daily mortality from increased concentrations of PM_{10} persists for several days (Zeka et al., 2005).

1.4.1.5 Fine particles ($PM_{2.5}$)

They consist of PM with a diameter up to 2.5 μm. Airborne particles smaller than 2.5 μm ($PM_{2.5}$) are usually called fine particles. fects (USEPA, 1996). Fine particles are composed mainly of carbonaceous materials (organic and elemental), inorganic compounds (sulfate, nitrate, and ammonium), and trace metal compounds (iron, aluminium, nickel, copper, zinc and lead). Exposure to the fine particles induces oxidative stress (Furuyama, 2006).

1.4.1.6 Nuclei mode or ultra fine particles (UFP)

The particles in this category are smaller than 0.1 μm. They are also known as ultrafine particle (UFP). UFP are present in great number in polluted urban air (Jaques and Kim, 2000). Exposure to high doses of UFP can cause severe pulmonary inflammation and hemorrhage, high degree of alveolar and interstitial edema, disruption of epithelial and endothelial cell layers and even death (Oberdorster et al., 1992; Peters et al., 1997, Oberdorster, 2000). UFPs cause health effects like cardiovascular problems, pulmonary disease, and development of cancer (Vinzents et al., 2005).

1.4.2 Factors affecting pollutant emission from road traffic

The major factors that affect the level of vehicle emissions are travel-related, driver related, highway related, vehicle-related, fuel type and environment (Figure 1.8).

- **Travel-related factors:** These factors include vehicle engine operating modes, speeds and accelerations and decelerations.
- **Facility-related factors:** There are certain facility designs that encourage transportation vehicles to operate at low-emitting speeds or modes.
- **Driver-related factors:** These factors play very significant role in pollutant emission. It varies by person and by traffic condition.
- **Vehicle-related and other factors:** Vehicle emissions are also influenced by vehicle age, mileage, condition, weight, size and engine power. Fuel types and fuel quality also affects emission levels significantly.
- **Environmental factors:** The low and high temperature can also affect the vehicular emission. Low temperature increases the level of cold start emission. On the other hand, at high temperature, the combustive emissions are low, but evaporative emissions are high, due to the increased fuel evaporation rate.

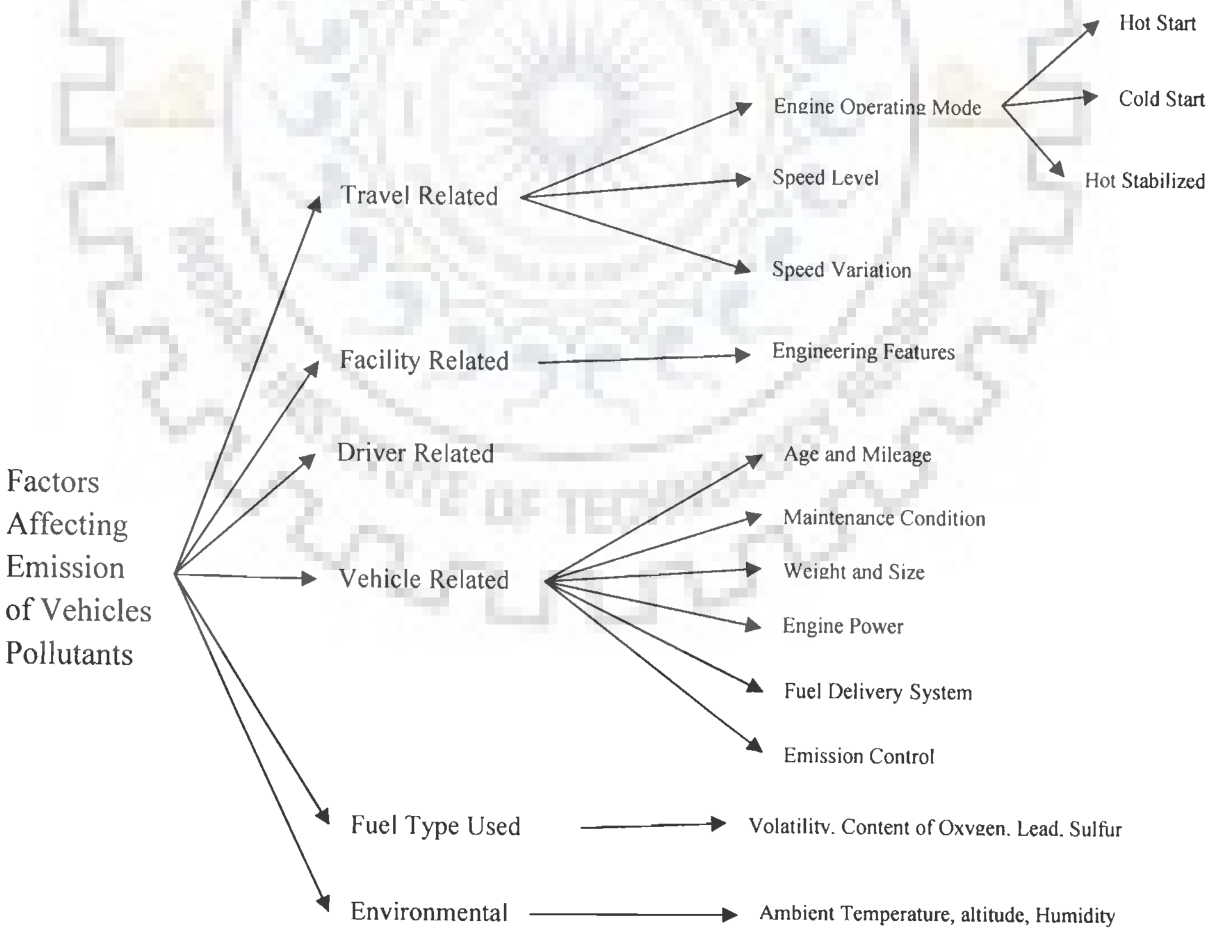


Figure 1.8: Factors Affecting Vehicle Emission

Source: Sinha and Labi (2007)

1.4.3 Air quality standards

The aim of air quality indexes is to measure the air quality with respect to its effects on human health. Ambient Air Quality Standards in India are the permissible exposures of all living and non-living things for 24 hours per day, 7 days per week. It allows the level of gaseous pollutants in the atmosphere and identifies the amount of exposure permitted to the population and to ecological system.

1.4.3.1 National ambient air quality standards

The permissible air quality standards prescribed by Central Pollution Control Board (CPCB), Ministry of Environment and Forest, Government of India vide (Prevention and Control of Pollution) Act,1981 and modified in 1994 and again modified in 2009. The National Ambient Air Quality Standard for emission of different primary pollutants is given in Table 1.8.

Table 1.8: National Ambient Air Quality Standards

Pollutants	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and Other Area	Ecologically Sensitive Area (notified by central government)
Sulphur Dioxide (SO_2), μg/m^3	Annual*	50	20
	24 hours**	80	80
Nitrogen Dioxide (NO2), μg/m^3	Annual*	40	30
	24 hours**	80	80
Particulate Matter (PM_{10}), μg/m^3	Annual*	60	60
	24 hours**	100	100
Particulate Matter ($PM_{2.5}$), μg/m^3	Annual*	40	40
	24 hours**	60	60
Lead (Pb), μg/m^3	Annual*	0.50	0.50
	24 hours**	1	1
Ammonia (NH3), μg/m^3	Annual*	100	100
	24 hours**	400	400
Carbon Monoxide (CO), mg/m^3	8 hours**	02	02
	1 hour**	04	04
Ozone (O3), μg/m^3	8 hours**	100	180
	1 hour**	180	180

*Annual arithmetic mean of maximum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals

**24 hourly or 08 hourly or 01 hourly monitored values, as applicable, shall be complied with 98% of the time in a year, 2% of the time; they may exceed the limits but not on two consecutive days of monitoring.

Source: Central Pollution Control Board (CPCB), 2010

1.4.3.2 Emission standards

Motor vehicle emission standards are the primary technical policy for controlling from vehicles. The first initiative to regulate vehicle emissions in India started in the year 1989 when Ministry of Environment & Forests constituted an expert committee to notify the emission standards for both new and in-use vehicles under the Environment (Protection) Act. The first Indian emission regulations were idle emission limits which became effective in 1989. These idle emission regulations were soon replaced by mass emission limits for both gasoline (1991) and diesel (1992) vehicles. In year 1998 the Government notified emission norms for vehicles fitted with catalytic converters, which were over 50% stricter than the 1996 norms. In 2000, following the European model, Euro-1 equivalent emission norms called India Stage-1 were notified throughout the country which were overtaken by Euro-II equivalent Bharat stage-II norms in the four metro cities of India by 2001. The emission standards for gasoline and diesel powered vehicles are given in Table 1.9 and Table 1.10.

Table 1.9: Emission Norms for Gasoline Powered Vehicles

Vehicle	Year	Emission Standards in g/km			
		CO	HC	NOx	HC+NOx
Two Wheelers	1991	12-30	8-12	-	-
	1996	4.50	-	-	3.60
	2000	2.00	-	-	2.00
	2005 BS II	1.50	-	-	1.50
	2010 BS III	1.0	-	-	1.0
Three Wheelers	1991	12-30	8-12	-	-
	1996	6.75	-	-	5.40
	2000	4.00	-	-	2.00
	2005 BS II	2.25	-	-	2.00
	2010 BS III	1.25	-	-	1.25
Car	1991	14.3-27.1	2.2-2.9	-	-
	1996	8.68-12.4	-	-	3-4.36
	1998	4.34-6.20	-	-	1.5-2.18
	2000	2.72	-	-	0.97
	BS II*	2.2	-	-	0.5
	BS II**	2.2-5.0	-	-	0.5-0.7
	BS III*	2.30	0.20	0.15	-
	BS III**	2.3-5.22	0.20-0.29	0.15-0.21	-
	2010 BS IV*	1.00	0.10	0.08	-
	2010 BS IV**	1.00-2.27	0.10-0.16	0.08-0.11	-

Note: For catalytic converter filter vehicles

*Up to 6 seaters and Gross Vehicle Weight (GVW) up to 2500 kg

**More than 6 seaters and GVW up to 3500 kg

Source: Central Pollution Control Board (CPCB), 2010

Table 1.10: Emission Norms for Diesel Powered Vehicles

Vehicle	Year	Emission Standards					
		CO	HC	NOx	HC+NOx	PM	Type
Diesel vehicles (GVM up to 3.5 tons)	**By Engine Dynamometer in g/kwh**						
	1991	14.0	3.5	18	-	-	
	1996	11.20	2.40	14.4	-	-	
	2000	4.5	1.1	8.0	-	0.36/0.61#	
	BS II	4.0	1.1	7.0	-	0.15	4 wheeler
	BS III	2.1	1.6	5.0	-	0.10	
	By Chassis Dynamometer in g/km						
	1991	17.3-32.6	2.7-3.7	-	-		Light duty
	1996	5.0-9.0	-	-	2.0-4.0		
	2000	2.72-6.90	-	-	0.97-1.7	0.14-0.25	
	BS II	1.0-1.5	-	-	0.7-1.2	0.08-0.17	4 wheeler
	BS III	0.64-0.95	-	0.50-0.78	0.56-0.86	0.05-0.10	
	BS II 2005	1.00	-	-	0.85	0.10	2 & 3 wheeler
	BS III	0.50 DF 1.1	-	-	0.50 DF 1	0.05 DF 1.2	
Diesel vehicles (GVM>3.5 tons)	**By Engine Dynamometer in g/kwh**						
	1992	17.3-32.6	2.7-3.7	-	-	-	
	1996	11.20	2.40	14.4	-	-	
	2000	4.5	1.1	8.0	-	0.36/0.36#	
	BS II	4.0	1.1	7.0	-	0.15	
	2005 BS II	2.1	0.66	5.0	-	0.10/0.13	Smoke 0.8 m^{-1}
	2010	1.5	0.46	3.5	-	0.02	Smoke

	BS IV						$0.5\ m^{-1}$
	By Chassis Dynamometer in g/km						
	BS II*	1.0	-	-	0.7	0.8	
	BS II**	1.0-1.5	-	-	0.7-1.2	0.08-0.17	
	2005 BS II*	0.64	-	0.50	0.56	0.05	DF: CO 1.1, NOx 1.0, PM 1.2
	2005 BS III**	0.64-0.95	-	0.50-0.78	0.56-0.86	0.05-0.10	
	2010 BS IV*	0.50	-	0.25	0.30	0.025	DF: CO 1.1, NOx 1.0, PM 1.2
	2010 BS IV**	0.50-0.74	-	0.25-0.39	0.30-0.46	0.025-0.06	

For engines with power exceeding 85 kw/ for engines with power up to 85 kw

*Up to 6 seaters and GVW upto 2500 kg

** More than 6 seaters and GVW upto 3500 kg

Source: Central Pollution Control Board (CPCB), 2010

1.4.4 Air quality index (AQI)

In 1976 the U.S. EPA a, b established a Pollutant Standards Index (PSI) which rated air quality from 0–500, with 100 equal to the National Ambient Air Quality Standards (NAAQS). The PSI is calculated for every pollutant with a NAAQS. The daily PSI is determined by the highest value of one of the five main air pollutants: particulate material (PM_{10}), ozone (O_3), sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2). The PSI was revised, renamed to the Air Quality Index (AQI), and subsequently implemented in 1999 by the USEPA. Air pollution indices are commonly used to indicate the level of severity of air pollution to the public. The index aims at measuring the status of air pollution with respect to its effect on human health. The main objective of air quality indexes is to measure the air quality with respect to its effects on the human health. A daily AQI has been proposed by Environmental Protection Agency (EPA) (1999). It is defined with respect to the five main common pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM_{10}) and sulphur dioxide (SO_2). Pollutants concentrations are converted into a numerical index (AQI) which assumes values in the range 0–500. The overall range is subdivided into six ranges to which six categories of air quality correspond (Table 1.11).

Table 1.11: Breakpoints for AQI of EPA in USA

AQI	Levels of health concern
0-50	Good
51-100	Moderate
101-150	Unhealthy for sensitive groups
151-200	Unhealthy
201-300	Very unhealthy
301-500	Hazardous

Source: http://en.wikipedia.org/wiki/Air_quality

In Canada, the air quality has been reported for several years with provincial Air Quality Indices. Air Quality Health Index (AQHI) is a scale designed to help understand the impact of air quality on health. It is used as a health protection tool to make decisions to reduce short-term exposure to air pollution by adjusting activity levels during increased levels of air pollution. Table 1.12 presents the different AQHI and related levels of health risk applicable in Canada. Similarly the Air Pollution Index (API) is used in Hong Kong, which is related to measured concentration of ambient respirable suspended particulate (RSP), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3) and nitrogen dioxide (NO_2) over a period of 24-hour based on potential health effects of air pollutants. The API and related air pollution level are depicted in Table 1.13. Likewise China's Ministry of Environmental Protection (MEP) has also defined different rating scale of air pollution index and related level of air pollution and its health impact (Table 1.14).

Table 1.12: Rating Scale of Air Quality Health Index in Canada

AQHI	Levels of health risk
1-3	Low
4-6	Moderate
7-10	High
>10	Very high

Source: http://en.wikipedia.org/wiki/Air_quality

Table 1.13: Rating Scale of Air Pollution Index in Hong Kong

API	Air pollution level
0-25	Low
26-50	Medium
51-100	High
101-200	Very high
201-500	Severe

Source: http://en.wikipedia.org/wiki/Air_quality

Table 1.14: Rating Scale of Air Pollution Index in China

API	Air pollution level
0-50	Excellent
51-100	Good
101-150	Slightly polluted
151-200	Lightly polluted
201-250	Moderately polluted
251-300	Heavily polluted
300+	Severely polluted

Source: http://en.wikipedia.org/wiki/Air_quality

Different countries use different terminology to express the quality of air. In Singapoor, Pollution Standards Index is used to report the status of air quality instead of AQI or API. The PSI table is mentioned below by index values and descriptors by National Environment Agency (Table 1.15). On the other hand, Comprehensive Air Quality Index (CAQI) term is generally used by Ministry of Environment of South Korea to express the ambient air quality (Table 1.16), whereas, United Kingdom describes the air quality in terms of Index or banding. These levels are based on health effect of each pollutant (Table 1.17).

Table 1.15: Rating Scale of Pollution Standards Index in Singapore

PSI	Descriptor
0-50	Good
51-100	Moderate
101-200	Unhealthy
201-300	Very unhealthy
301-400	Hazardous
Above 400	Hazardous

Source: http://en.wikipedia.org/wiki/Air_quality

Table 1.16: Rating Scale of Comprehensive Air Quality Index in South Korea

CAI	Level of health risk
0-50	Good
51-100	Moderate
101-150	Unhealthy for sensitive groups
151-250	Unhealthy
251-350	Very unhealthy
351-500	Hazardous

Source: http://en.wikipedia.org/wiki/Air_quality

Table 1.17: Rating Scale of Index in United Kingdom

Index	Banding	Health effect
1-3	Low	Effects are unlikely to be noticed even by individuals who know they are sensitive to air pollutants
4-6	Moderate	Mild effects, unlikely to require action, may be noticed amongst sensitive individuals
7-9	High	Significant effects may be noticed by sensitive individuals and action to avoid or reduce these effects may be needed.

Source: http://en.wikipedia.org/wiki/Air_quality

1.4.5 Vehicular pollution and global climate change

The world average temperature has risen by about 1 F° over the past century. It is widely accepted that the global warming is related to anthropogenic Green House Gases (GHGs). GHGs include, the common gases namely carbon dioxide, water vapor and rarer gases such as nitrous oxide, methane and chlorofluorocarbons (CFCs) whose properties relate to the transmission or reflection of different types of solar radiations. The increase in such gases in the atmosphere is a result of the burning of fossil fuels, emission of pollutants into the atmosphere by power plants and vehicle engines, etc. Of all human activities, driving motor vehicles produces the most intensive CO_2 emissions and other toxic gases per capita. A single tank of gasoline releases 140 -180 kilograms of CO_2. Over 25% of transportation-related GHG emissions originate from urban passenger travel. Unsustainable trends in urban transportation have already manifested in frequent congestions, periodic gridlock and evidence linking respiratory illnesses and deaths to poor air quality.

Transport sector contributes around 14% towards the global emissions of green house gases. Carbon dioxide represents the largest proportion of basket of greenhouse gas emissions. During, the past three decades, carbon dioxide emissions from transport have increased faster than those from all other sectors and are projected to increase more rapidly in future. The Road transport alone emits around 16% of the global CO emissions (CPCB, 2010). From 1990 to 2004, carbon dioxide emissions from the world's transport sector have been increased by 36.5%. For the same period, road transport emissions have increased by 29% in industrialized countries and 61% in the other countries (CPCB, 2010). The global emissions of GHG's from different sectors have been shown in Figure 1.9. The CO_2 emissions in the major developed and developing countries around the world during 1980 to 2030 is shown in Figure 1.10. The figure shows that the global CO_2 emissions are going to get stabilized in the developed countries in the near future, the CO are likely to increase in the developing countries owing to its due economic growth as well rising human population. The mode wise distribution of CO_2 emissions from transport sector (Figure 1.11), reveals that road transport contributes major share of around 73% towards total CO_2 emission from transport sector. The emission of CO_2 from aviation, international shipping and railway sectors are about 11%, 9% & 2% respectively.

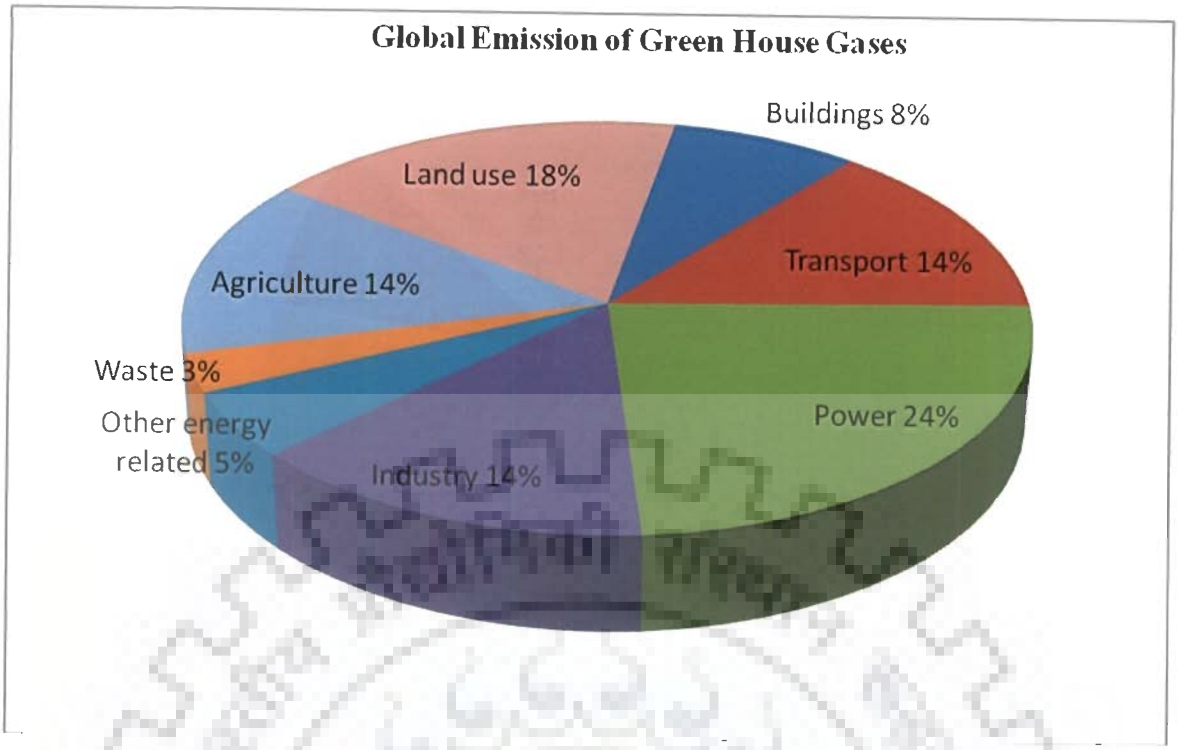


Figure 1.9: Green House Gas Emission from Different Sectors

Source: Central Pollution Control Board (CPCB), 2010

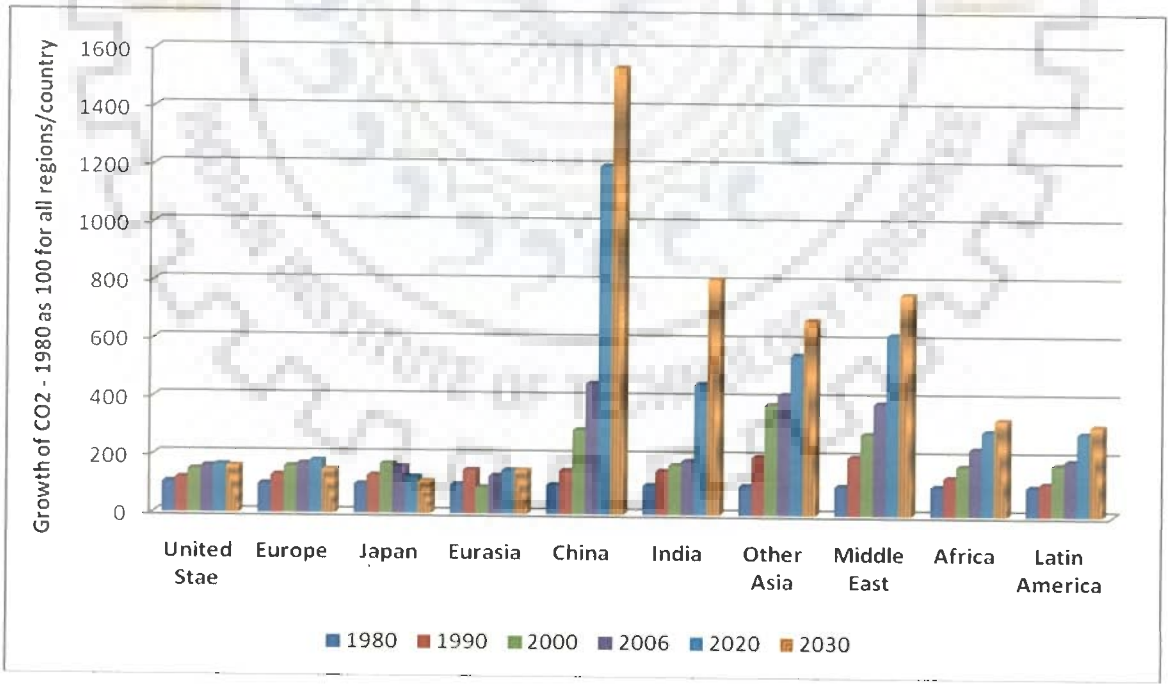


Figure 1.10: CO_2 Emissions from Transport Sector 1980 – 2030

Source: Central Pollution Control Board (CPCB), 2010

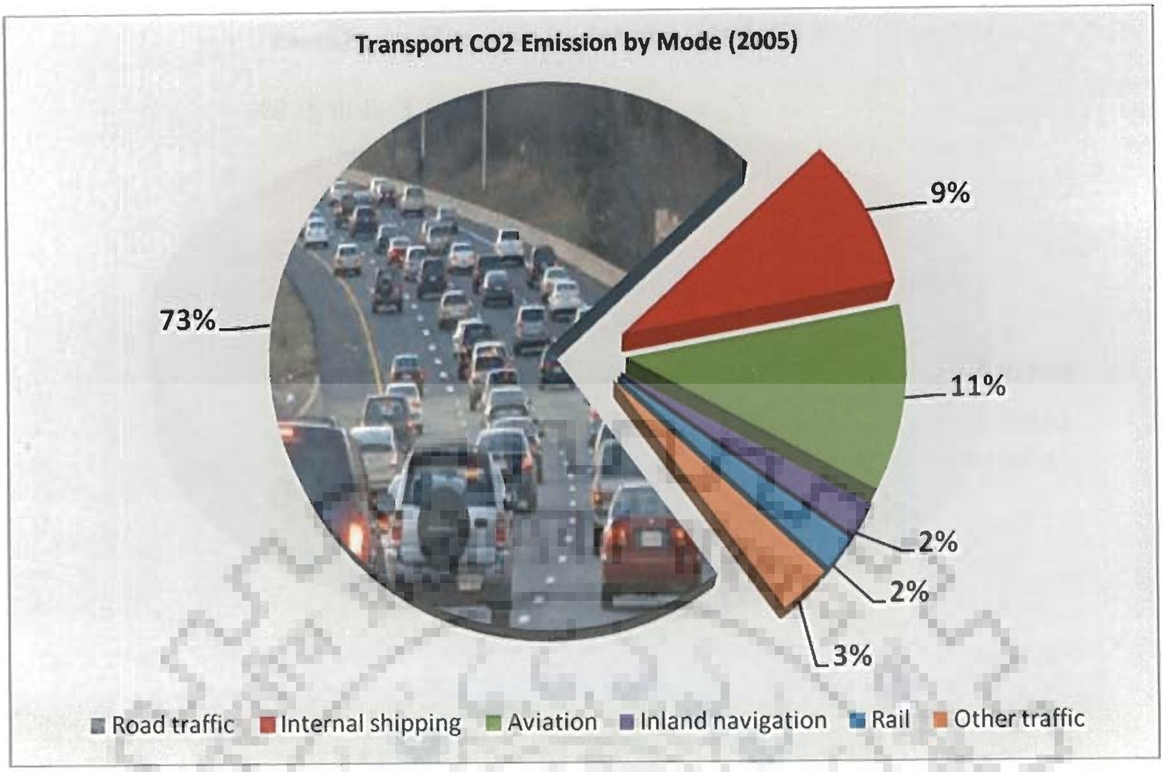


Figure 1.11: Global GHG's Emissions from Transport Sector (Mode-Wise)

Source: Central Pollution Control Board (CPCB), 2010

1.5 Sustainable Development

Sustainable development is the expression of a longstanding ethic involving people's relationship with the environment and the current generation's responsibilities to future generations. For the sustainability of society, it is required to consider environmental, economic and cultural resources. To be sustainable, development must improve economic efficiency, protect and restore biodiversity and enhance the life quality of people. Sustainable development meets the needs of the present, without compromising the ability of future generations to meet their own needs (WCED 1987). The other definition of sustainable development, which has been adopted by the International Union for the Conservation of Nature (IUCN), is the type of development which improves the quality of life within the carrying capacity of the earth's life support system (IUCN, WWF, and UNEP 1991). Hence the economic and social development objective must be defined in terms of sustainability in all developed and developing countries.

1.5.1 Concept of environmentally sustainable transport system

EST may be defined as "transportation that does not endanger public health or ecosystems and meets the needs for access consistent with (a) use of renewable resources below their rates of regeneration, and (b) use of non-renewable resources below the rates of development of renewable substitutes", (OECD, 2000).

Sustainable transport does not indicate the availability of less transport than we have today, but it involves a different transport. Such type of transport system does not harm the environment or use non-renewable resources. It will focus more on public transport, non motorized transport like bicycling and walking. In present scenario megacities are the major growth centers. Urbanization is increasing at twice the rate of total population worldwide. A recent study estimated that during the next 15 years the average annual urban population growth in the least developed countries will be 4.6%, compared to 0.6% estimated for cities in industrialized countries (UNCHS 2001). The explosion of urban population growth is creating an increasing number of megacities (more than 10 million inhabitants), mostly in the developing world. At the same time industrial growth is also moving very fast in the megacities of the developing world. Now a days particularly in developing countries the process of hasty urbanization has been associated with a low proportion of urban space devoted to roads. In developing countries due to mixed traffic composition there is an acute appreciation of the impacts of transport on urban environment. Rapid motorization and attendant urbanization can bring many environmental risks and problems that can seriously jeopardize the sustainability of cities. In cities of developing countries, the risks and the problems are much greater because of the overwhelming scale and speed of urbanization compared to the available resources, particularly in the emerging megacities. Identification of specific issues on various aspects of the environment is unambiguously shown in Table 1.18 (DASETT 1991). This table shows the detailed social and environmental consequences caused by transportation in general, and highways in particular.

Table 1.18: Various Aspects of Environmentally Sustainable Transport System

Aspect of environment	Summary of Issues
Urban	• Air pollution from motor vehicles • Noise pollution from vehicles • Urban sprawl and infrastructure requirements • Maintain access to open space
Transportation Developments	• Greenhouse gas and other pollutant emissions • Road surface pollutants • Automobile dependence and lack of viability for public transport in low density urban sprawl • Noise and vibration from railways, airports, and vehicles • Spills from storage, handling, and transport of fuels • Marine oil spills and ballast discharges in ports
Atmosphere	• Motor vehicle emissions • Photochemical smog • Health aspects of deteriorating air quality
Biodiversity	• Habitat destruction for native species of wildlife
Marine	• Port development and impact of engineering works

Source: Department of the Arts, Sports, the Environment, Tourism and Territories (DASETT), 1991

1.5.2 Environmentally sustainable urban transport system: the need of society

The environmental effects of transport differ considerably by mode and it also damages the global environment. Pollution from motor vehicles produces about one - fifth of the incremental carbon dioxide in the atmosphere arising from human activity (which potentially contributes to global warming) and half of the nitrogen oxides (which contribute to continental scale acidification and ecological damage). If current trends continue unabated, by 2010 the developing countries could become the largest source of global anthropogenic emissions of carbon dioxide and methane (Faiz 1993). Presently, the key challenge for developing countries is to identify these tradeoffs and to formulate such type of policies that can avert the environmental sustainability gap from growing wider with continued economic growth.

Haq (1997) has already discussed about the requirement for a sustainable society in early seventies with the publication of several articles such as ‘‘A blueprint for survival’’. One of the often quoted definitions of sustainable development is ‘‘development which meets present needs without compromising the ability of future generations to achieve their own needs and aspirations’’. According to the definition adopted by the U.N. World Commission on Environment and Development (WCED 1987),‘‘a sustainable condition for this planet is one in which there is stability for both social and physical systems, achieved through meeting the need of the present without compromising the ability of future generations to meet their own needs.'' Five factors are there, which influence the transport development i.e. technology, government policy, land use planning, social and behavioral trends (Nijkamp et al., 1998; Masser et al., 1992, Nijkamp, 1999). These factors influence travel behavior, mobile technology, infrastructure design, motorization and policy measures. The impression of sustainability wraps a wide range of issues. The World Bank (1996) recognized the different dimensions of sustainable transportation i.e. economic and financial, environmental pollution, energy consumption, wildlife deterioration and social aspects of life. Environmental sustainability is concerned with the promotion of livable settlements and mitigation of the unavoidable environmental and ecological impacts of transport development. The goal of sustainable transportation is to ensure that environmental, social, and economic considerations are factored into decisions affecting transportation activity. During formulation of transportation-related decision, all three elements should be considered to facilitate a comprehensive impact assessment.

1.5.3 Sustainable transport systems – key issues

1.5.3.1 Traffic emission

Due to increasing urbanization, industrialization and motorization various pollutants are releasing from the vehicles. Traffic Air pollution from motor vehicles is one of the most serious and rapidly growing environmental problems in the large cities of the developing world. The increasing size of cities and the random growth of work places and residential areas lead to longer and increasing number of trips per person (Bose and Srinivasachary, 1992). These pollutants are mainly carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_x) and volatile organic compounds (VOCs). Vehicular pollution is responsible for almost 67% of the total air pollution load in the city. Vehicular population in Delhi has increased phenomenally from 235,000 in 1975 to 2,629,000 in 1996. It is estimated to touch a staggering high of 6,000,000 in 2011, (MEF, 1997). For the movement towards the sustainability there must be reduction in traffic emission.

1.5.3.2 Energy use for transport

Exhaust emissions are directly related to the fuel consumption by vehicles, which in turn, are related to the number of vehicles. In India the main resource used for transport is petroleum from which vehicle fuels such as gasoline and diesel fuels are refined. In 2005, Transport sector of India had consumed 11% of its total primary energy demand (16.9 % of commercial energy supply). Seventy eight percent of this demand was consumed by Road Transport, 11% by Aviation, 10 % by Rail Transport and 1% by Inland Water. The

Transport sector is set to grow at over 6% per annum on the back of rising economic activity and a rapid surge in the vehicle stock. By 2030, the share of transport sector is likely to double to about 20 % of the primary energy demand. Globally, the share of the Indian transport sector is likely to triple from its low of 2% in 2005 to about 6% in 2030. The growth of transport sector, primarily driven by road transport will remain heavily dependent on the availability and affordability of oil. The total demand of primary energy is likely to go up from 566 Mtoe in 2006 to 1280 Mtoe in 2030 with a CAGR of 3.5 %, higher than that of China at 3% and the World average of 1.6%. (Singh, 2009). Some key energy indicators for the year 2006 for India in relation to China, USA, OECD countries and the World are given in Table 1.19.

The economic growth of any country is vitally linked to the health of its transport sector. India is likely to become the most populous country in the world by 2031. The explosive growth of two wheelers and cars will lead to a massive demand for road infrastructure, urban planning and availability of fuel. Transport sector consumed 27% of total oil and oil products in India during 2006-07. This is likely to go up to 45% by 2030; 97% of its fuel requirement will be met by the liquid fuels (petroleum products), where India is already import dependent for crude oil (WEO-2008). The share in the primary energy increases from 10 % in 2005 to 20 % in 2030. Further, the share of global transport energy is likely to triple from 2% in 2005 to about 6 % in 2030 (WEO 2007). The likely mode-wise projection for share of energy is given in Table 1.20.

Table 1.19: Selected Energy Indicators for 2006

Country/Economy	Indicator unit	Population	GDP (PPP)	GDP per capita	Energy production	Primary energy TPES	Energy supply per capita	Energy intensity TPES/GDP (PPP)	Electricity consumed per capita
		million	billion 2000 $	PPP	Mtoe	Mtoe	Kgoe	Toe	KWh
INDIA		1110	3671	3310	436	566	510	0.15	503
CHINA		1319	8916	6760	1749	1897	1440	0.21	2060
USA		300	11265	37675	1654	2320	7740	0.21	13515
OECD		1178	31158	26450	3842	5537	4700	0.18	8381
WORLD		6536	57564	8807	11740	11740	1800	0.2	2659

Mtoe : Million tonnes of oil equivalent   Toe : Tonnes of oil equivalent

Kgoe : Kgm of oil equivalent   TPES : Total Primary Energy Supply

Source: Key World Energy Statistics 2008, International Energy Agency (IEA)

Table 1.20: Mode Wise Share of Energy in Transport Sector

Mode	**2006-07**	**2029-30**
Road	78%	86%
Aviation	11%	9%
Railways/IWT	11%	5%

Source: World Energy Outlook (WEO), 2007, International Energy Agency (IEA)

A sustainable transportation system is one that minimizes consumption of non-renewable resources. Progress towards environmental sustainability would have required a reduction in the consumption of non-renewable resources.

1.5.3.3 Greenhouse gas emissions and climate change

Now a day's greenhouse gas emission has become a challenging issue worldwide. Level of greenhouse gases (GHGs) in the atmosphere are continuously increasing, which suggests that they are being produced at a rate beyond the planet's ability to absorb them. This is known as greenhouse effect. Transport sector is also a major source of emission of greenhouse gas emissions from human activity on global level. The most important GHG emitted by transport sector is carbon dioxide gas emission. The emission of CO_2 by the transport sector from fuel combustion in 2005 was 6,337 million tons or 19.8 per cent of global emissions (31, 962 million tons). Within the transport sector 4,648 million tons or 73.3 per cent were from the road subsector. Table 1.21 provides the quantities and percentages of the remaining subsectors in 2005.

Table 1.21: Global CO_2 Emissions from Fuel Combustion in the Transport Sector

	Mt of CO_2	Percentage
Road	4647.9	73.3
Domestic aviation	314.1	5.0
Rail	124.9	2.0
Pipeline transport	159.6	2.5
Domestic navigation	111.1	1.8
Non-specified transport	12.7	0.2
Non-energy use in transport	7.6	0.1
Memo: international marine bunkers	543.4	8.6
Memo; international aviation	415.7	6.6
Transport	6337.0	100.0

Source: United Nations Economic and Social Council (2008)

Continuous rise in greenhouse gas emission indicates movement away from sustainable transportation. Consequently progress towards sustainability would have required a reduction in greenhouse gas emissions from transport.

1.5.3.4 Injuries and fatalities

The rapid and unprecedented motorization in India combined with the lack of a safety environment has been a noticeable feature. The number of registered motor vehicles in India has risen from 3.68 million in 1980-81 to 68.05 million in 2004-05, making an average annual growth rate of 12.7 % for the period (Figure 1.12). Two-wheelers (i.e. motor cycles and scooters) and cars together account for more than three-quarters of the total number of registered vehicles with an average annual growth rate of 14.36% between 1980 and 2004. In comparison, the number of registered buses has increased at an average annual growth rate of only 7.42% (TERI, 2008). The 23 metropolitan cities account for 33% of total vehicles in India. Two-wheelers, cars, jeeps and taxis, buses, goods vehicles and others account for 71%, 13%, 1%, 5% and 10% respectively of the total vehicle population (Figure 1.13), while the total number of buses increased from 331,000 in 1991 to 669,000 in 2002 (an increase of 102%), two wheelers increased from 14,200,000 to 41,478,000 (an increase of 300%).

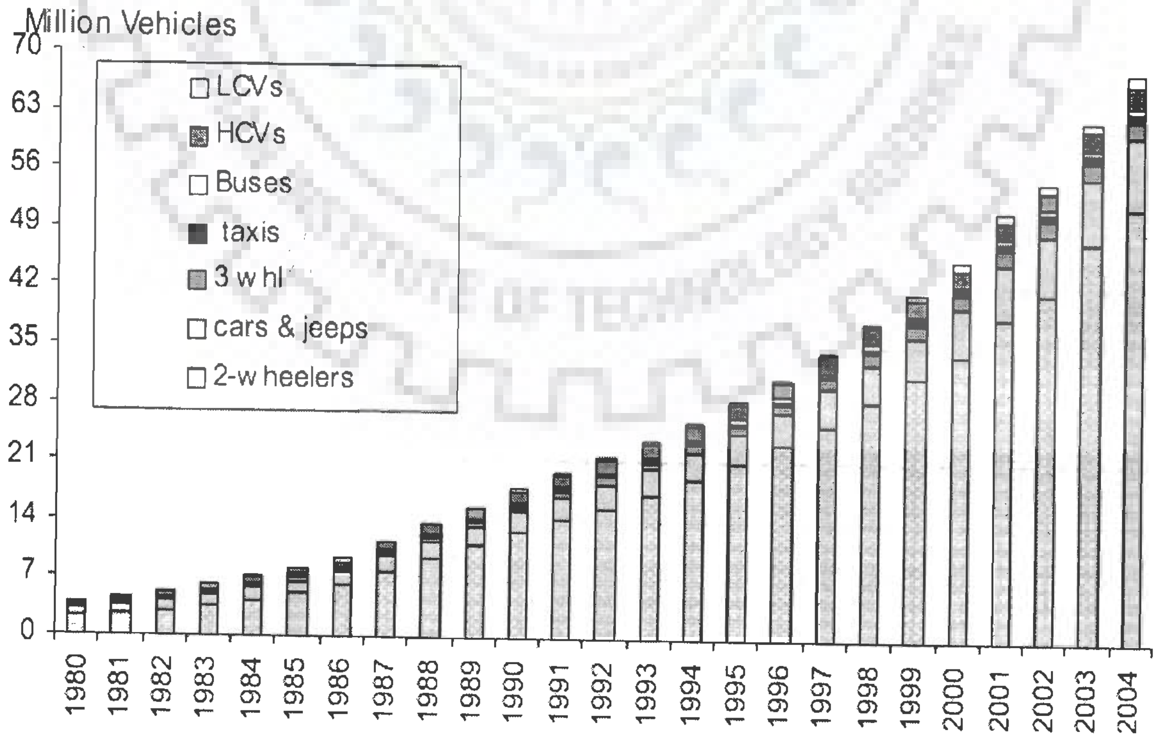


Figure 1.12: Trends in Total Number of Registered Motor Vehicles in India

Source: Tata Energy Research Institute (TERI), 2008

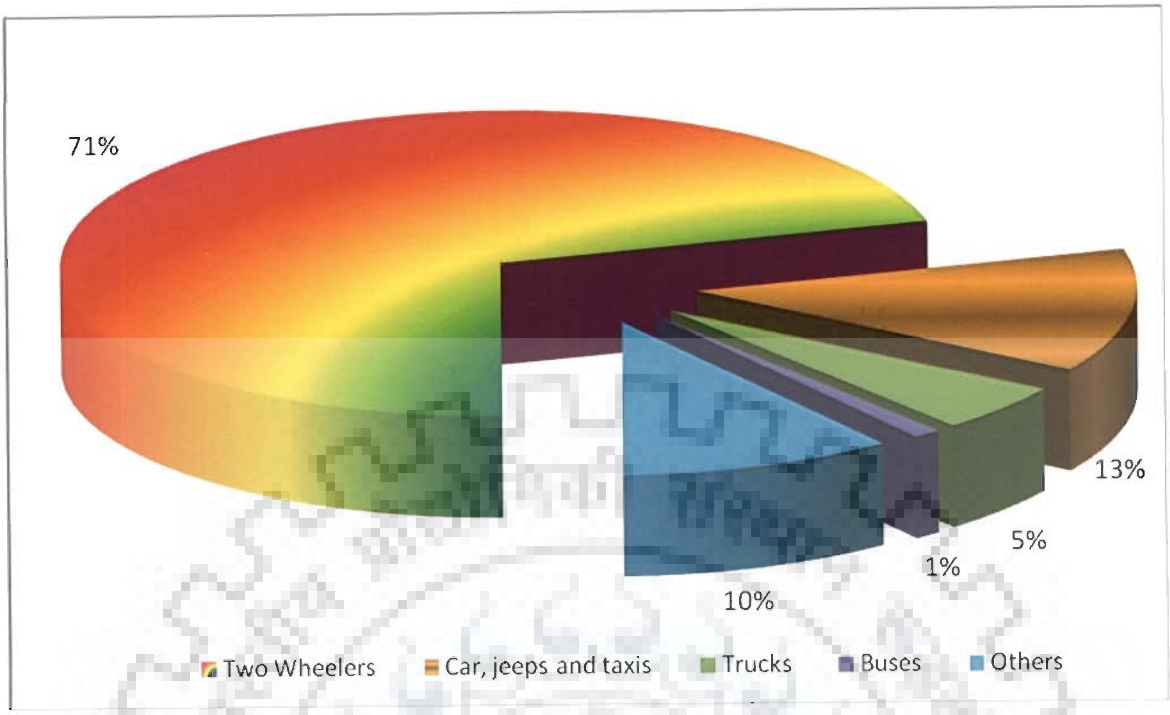


Figure 1.13 Percentage Distributions of Vehicles in India 2002

On an average, 3242 persons die each day around the world in road crashes (Road Peace 2003). As per WHO estimates, nearly 1.2 million people died in road crashes in 2002 (WHO 2004). The overall global mortality rate was 19/100,000 with nearly 90% of these occurring in low- and middle-income countries. Table 1.22 depicts the total number of injury accidents in different country. The motorization of India, especially during the past two decades, has resulted in greater number of deaths and injuries due to absence of safety policies, programmes and environmental norms. Road accident information collected for various cities for the year 2005 is presented in Table 1.23. Maximum numbers of road accidents are recorded in Mumbai followed by Delhi.

Table 1.22: Total Number of Injury Accidents, per Country (n)-2002/2007

Country	2002	2003	2004	2005	2006	2007
Armenia	1,002		1,64	1,312	1,574	1,943
Costa Rica	56,699	53,668	52,362	57,129	68,607	69,761
Croatia	17,071	18,592	17,140	15,679	16,706	18,029
India	**407,497**	**406,726**	**429,910**	**439,200**	**460,920**	**479,219**
Israel	18,490	17,745	17,762	16,987	17,193	16,016
Japan	936,721	947,993	952,191	933,828	886,864	832,454
Kazakhstan		19,705	21,930	14,517	16,038	15,942
Lithuania	6,091	5,965	6,357	6,777	6,589	6,448
Mauritius	18,022	19,178	19,495	2,144	1,947	2,190
Morocco	52,137	53,814	51,687	51,559	54,492	58,924
Russian Federation			208,558	223,300	229,100	233,800
Ukraine	34,488	42,409	45,593	46,485	49,491	63,554

Source: International Road Federation (IRF), World road statistics (2009) (www.irfnet.org)

Table 1.23: Road Accident Statistics (2005) for the Selected Cities

Sl. No.	City	No of Fatalities	Total Road Accidents	% of fatal accidents
1	Gangtok	24	180	13
2	Panji	68	892	8
3	Shimla	33	171	19
4	Pondichery	136	780	17
5	Bikaner	159	367	43
6	Rajpur	364	2059	18
7	Bhubaneswar	200	2000	10
8	Chandigarh	131	529	25
9	Hubli-Dharwad	250	1000	25
10	Guwahati	436	784	56
11	Amritsar	192	255	75
12	Trivandrum	202	3258	6
13	Madurai	116	836	14
14	Agra	109	349	31
15	Bhopal	205	2690	8
16	Kochi	234	3053	8
17	Patna	108	241	45
18	Varanasi	130	169	77
19	Nagpur	246	1628	15
20	Jaipur	495	2681	18
21	Kanpur	598	884	68
22	Surat	230	1129	20
23	Pune	216	1477	15
24	Ahmedabad	467	2460	19
25	Hyderabad	1196	6149	19
26	Chennai	1055	4499	23
27	Bangalore	833	7575	11
28	Kolkata	484	3751	13
29	Delhi	2023	9351	22
30	Mumbai	787	21678	4

Source: Ministry of Urban Development, Government of India, 2008

The above figure shows the movement far from sustainable transportation. A sustainable transportation system is one that allows the basic needs of individuals to be met safely. Thus when injuries and fatalities will decline, there will be progress towards sustainability.

1.5.3.5 Personalised vehicle ridership

This is related with the movement of personalized vehicles. Due to increasing urbanization, populations of motor vehicles are also increasing which results in the mounting of personal vehicles. With the increment in the number of personalized vehicles, the energy consumption will also increase. The future mode share including non-motorized transport (NMT) is presented in the Table 1.24 given below. A significant decrease in public transport and a very high increase in private mode share for all city categories are predicted.

Table 1.24: Estimated Mode Share for Selected Cities for Future (%)

City Category	Population	2007			2011			2021			2031		
		PT	PV + IPT	NMT	PT	PV + IPT	NMT	PT	PV + IPT	NMT	PT	PV + IPT	NMT
Category-1a	<0.000005 million with plain terrain	5	57	38	4	59	36	3	66	31	2	72	26
Category-1b	<0.000005 million with hilly terrain	8	34	58	7	37	56	5	47	48	3	57	40
Category-2	0.000005-0.00001 million	9	39	53	8	42	50	6	51	43	5	58	36
Category-3	0.00001-0.00002 million	13	43	44	12	46	43	10	52	38	9	57	34
Category-4	0.00002-0.00004 million	10	47	43	9	49	42	8	51	41	8	52	40
Category-	0.00004-	22	42	36	21	45	35	15	51	34	12	54	34

5	0.00008 million												
Category-6	>0.00008 million	46	24	30	42	28	30	31	40	29	26	46	28

Note: PT- Public Transport, PV- Personal vehicles, IPT- Auto rickshaw, NMT- Non motorised transport including walk and cycles

Source: Ministry of Urban Development, Government of India, 2008

Thus the progress towards sustainability would have required a reduction in the number of personalized vehicles. For this public transport system operation need to be strengthened in urban areas which include commuter trains, subways, light rail, buses and paratransit services.

1.5.4 Sustainable transport indicators

Sustainable transport indicators are designed to provide information for understanding and enhancing the relationships between economic, energy use, environmental and social elements inherent in long-term sustainability. Sustainable transport indicators can serve as valuable tools for profiling regional air quality, climate change, noise quality and land use criterion. Table 1.25 lists various sustainable transportation indicators. It indicates the desired direction of change, possible disaggregation and its priority rating:

A = should be collected in virtually all situations.

B = should generally be collected if feasible.

C = should be collected when needed to address specific community needs

Table 1.25: Potential Sustainability Indicators

Category	Subcategory	Indicator	Desired Direction	Disaggregation	Rating
Travel Activity	Vehicles	Motor vehicle ownership	Up for low-income, down for high-income	By type of vehicle, owner demographics, location	A
	Mobility	Motor vehicle travel	Up for low-income, down for high-income	Trip type, traveler type, travel conditions	A

	Mode split	Portion of trips by auto, public transit, and non-motorized modes	Reduced automobile share	Trip type, traveler type, travel conditions	A
Air Pollution Emissions	Emissions	Total vehicle emissions	Down	Type of emission, mode, location	B
	Air pollution exposure	Ambient air quality	Down	Demographic groups affected	A
	Climate change	Climate change emissions (CO_2, CH_4)	Down	Mode	A
	Embodied emissions	Emissions from vehicle and facility construction	Down	Type of emission and mode	B
Noise Pollution	Traffic noise	People exposed to traffic noise above 55 LAeq,T	Down	Demographic group, location, transport mode	B
	Aircraft noise	People exposed to aircraft noise above 57 LAeq,T	Down	Demographic group, location, transport mode	B
Traffic	Crash Casualties	Crash deaths and injuries	Down	Mode, road, type and cause of collision.	A
	Crashes	Police-reported	Down	Mode, road, type and cause	A

risk		crashes		of collission	
	Crash costs	Traffic crash economic costs	Down	Mode, road, type and cause of collission	B
Economic Productivity	Transport costs	Consumer expenditures on transport	Down	Mode, user type, location	A
	Commute costs (time and money)	Access to employment	Down	Mode, user type, location	A
	Transport reliability	Per capita congestion costs		Mode, locat	B
	Infrastructure costs	Expenditures on roads, public transit, parking, ports, etc.	Down per unit of travel (cost efficiency)	Mode, location	A
	Shipping costs	Freight transport efficiency	Down	Mode, geographic	B
Overall Accessibility	Mobility options	Quality of walking, cycling, public transit, driving, taxi, etc.	UP	Trip purpose, location, user	A
	Land use accessibility	Quality of land use accessibility	Up	Trip purpose, location, user	B
	Mobility substitutes	Internet access and delivery service	Up	Trip purpose, location, user	B

		quality			
Land Use Impacts	Sprawl	Per capita impervious surface area	Down	By location and type of development	B
	Transport land consumption	Land devoted to transport facilities	Down	By mode	B
	Ecological and cultural degradation	Habitat and cultural sites degraded by transportation facilities	Down	Type of habitat and resource, location	B
Transport Policy and Planning	Pricing efficiency	Cost-based pricing	Up	By mode, type of cost (road, parking, etc.)	B
	Strategic planning	Degree to which individual planning decisions support strategic goals	Up	By mode, agency	B
	Planning efficiency	Comprehensive and neutral planning	Up	By mode, agency	C
	User satisfaction	User survey results	Up	By group (disabled, children, low income...)	B
	Affordability – Transport	Portion of household budgets needed to provide	Down	Demographics, especially disadvantaged groups	A

Equity		adequate transport.			
	Affordability – Housing	Affordable housing accessibility	Up	By demographic group, especially low income and disabled groups	C
	Accessibility	Quality of accessibility for people with disabilities	Up	By geographic area, mode, type of disability	B

Source: Transportation Research Board, USA (2010)

1.5.5 Role of technology towards the sustainability of transport system

Sustainability reflects the fundamental human desire to improve the future world. It demands the need of limiting resource consumption to ecological constraints (such as limiting land use to protect habitat and fossil fuel use to minimize climate change), Thus sustainable development requires maximizing the efficiency with which wealth provides social welfare as indicated in Figure 1.14.

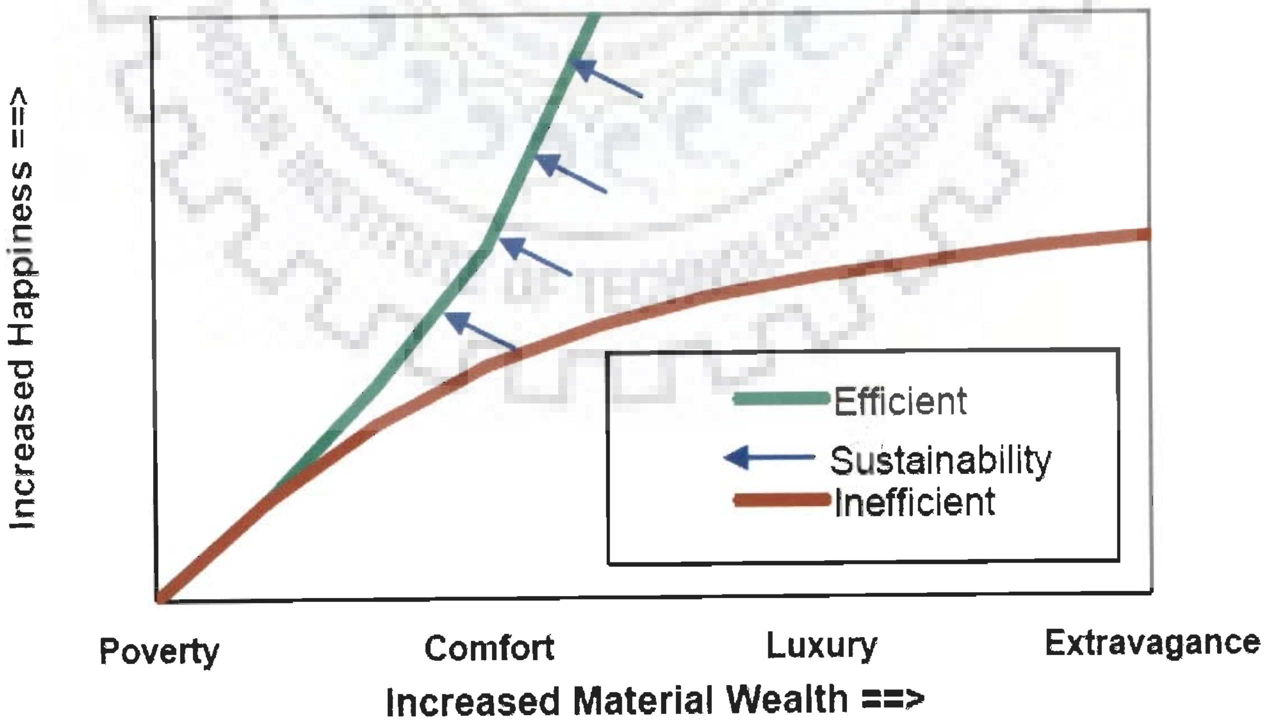


Figure 1.14: Sustainable Development

Source: Litman, 2006

Considering the present scenario by improving the following technology the transport system can move towards the environmentally sustainable transport system.

1.5.5.1 Vehicle technology

By improving the technology of vehicles, the mobility with protection of the environment can be reconciled. For this fuel efficiency must be improved. Improved fuel quality will suppress the emission of noxious and other harmful pollutants. This can improve environmental quality in terms of air quality means improve the environmentally sustainability of transport system.

In developing countries like India the average usage of vehicle fleet is almost double that in developed countries. Older vehicles pollute more. The use of catalytic converters in older vehicles is not cost effective in developing countries, because the gases suppressed are not usually the most health problematic and because in the absence of the capability to enforce maintenance of the equipment, it becomes ineffective. In such type of situation it is required to introduce policies and efficient fiscal incentives to accelerate the scrapping of high polluting and high uses vehicles such as older taxis, buses and trucks. At the same time it is also essential to focus towards the maintenance and proper inspection of the vehicles.

1.5.5.2 Fuel quality improvement

Fuel quality plays very important role towards the sustainability of transport system. Better fuel quality will improve the air quality of environment means pollution free environment. The substitution of liquefied petroleum gases (LPG) and compressed natural gas (CNG) for gasoline may be justified both environmentally and economically, in a larger number of countries that have local gas resources. In current scenario the introduction of cleaner fuels would also need to be supported by other policies. Relative fuel prices must also be adjusted to give efficient incentives to use clean technology and clean fuels.

1.5.5.3 Traffic management

According to present scenario in developing countries, proper traffic management is very important towards the sustainable movement. There must be usage of on-line computerized traffic control. This technology is now applied in most of the industrialized countries for the management of traffic. On-line computerized traffic control gives priority to public transport vehicles at traffic signals. It has also increased effective capacity of road system as well as allowing traffic to flow at speeds at which emission per vehicle mile are much lower. Thus most of this technology must be applied in developing countries. As consequence simple management schemes such as segregated bus lanes or computer controlled traffic signals have often been considered to be more appropriate for developing countries. Traffic management can also protect environmentally sensitive areas or road user categories from vehicular traffic.

1.5.5.4 Intelligent transport system

Due to speedy urbanization and motorization, it has become indispensable to devise elegant method to fulfill the growing traffic demands. The ITS is found an advanced technology which facilitates increasing operating speeds, closing vehicles headway and eliminating as much as human involvement. It is a concept which combines the recent technology to make travel safer and smoother. The kernel of ITS exists in its improved ability to manage transportation services on the basis of accessibility of accurate, real-time information. It can enhance productivity, safety and reduce the undesirable impacts on urban transportation systems. Its development may also be significant in shaping the role of transport in the sustainable way. The modern information technology within transport supply has helped the performance of both vehicles and systems, making them cheaper, more efficient and hence relatively more attractive.

1.5.5.5 Role of non-motorized transport system

A sustainable transport system must provide mobility and accessibility to all urban residences with safe and environmental friendly modes of transport. NMT (Non Motorized Transport) modes can play efficient role in this direction. In particular as urban road congestion increase and public transport receives increased attention, the non-motorized transport like bicycle can act as an efficient and environmentally friendly local distributor to reconcile the need for high local accessibility with inherently courser structure of public transport networks. The cyclists and pedestrians are to be provided with a safe infrastructure either road space for them must be physically segregated from motorized traffic or the speed of the motorized traffic must be reduced. Thus the bicycle can also act as the main mode for a wide range of journey purposes like journey to work, school and shopping in particular.

1.6 Concept of Knowledge, Knowledge Management and Sustainable Transport System

1.6.1 Knowledge

In current scenario's rapid changing environment, knowledge is the highest source of power. (Toffler, 1990). Knowledge is the main source of sustainable competitive advantage and profitability (Prahalad and Hamel, 1990; Nonaka, 1991; Hansen *et al.*, 1999; Desouza and Evaristo, 2003). Knowledge is a complex concept and it is more than just mere data and information. Data can be considered as the basis for creating information and knowledge (Willke, 1998). ''Data is a set of discrete, objective facts about events'' (Davenport and Prusak, 1998). They are represented by characters and can be produced, codified and distributed without a reference to the context or person (Rehaeuser and Krcmar, 1996). In contrast to data, information refers to a context (Rehaeuser and Krcmar, 1996). Information can be considered as messages or news created by the interpretation of data. This information can be understood by the recipient and has meaning to the recipient (Augustin, 1990; Nonaka and Takeuchi, 1995). Knowledge emerges from the processing of the perceived information and contextualization of a person. Knowledge can only exist in the context of person and his beliefs and experience (Nonaka and Takeuchi, 1995). ''Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information'' (Davenport and Prusak, 1998). Knowledge is the ability of persons to evaluate information and act efficiently (Sveiby, 1998). It can provide added value if it results in actions and decisions (O'Dell and Grayson, 1998). Thus knowledge is a very significant and powerful resource for organization like transport sector to use it in the preservation of heritage, accumulation of experience, creation of new thoughts and sharing of new knowledge. Knowledge can be distinguished in two different types – tacit and explicit knowledge (Polanyi, 1966).

1.6.1.1 Tacit knowledge

Tacit knowledge is the personal and context-specific knowledge of a person. It is bound to the person and is thus difficult to formalize and communicate (Nonaka and Takeuchi, 1995). Consequently, it is not possible to separate, store, and distribute the whole knowledge of somebody (Davenport and Donald, 1999).

1.6.1.2 Explicit knowledge

Explicit knowledge in contrast can be codified, collected, stored, and disseminated. It is not bound to a person and has primarily the character of data. Explicit knowledge is ''grounded'' in tacit knowledge and is created by externalization (visualization, articulation or codification) of tacit knowledge (Nonaka and Takeuchi, 1995). It is the part of tacit knowledge that can be expressed verbally and does not represent the entire body of knowledge (Nonaka and Takeuchi, 1995).

1.6.2 Knowledge identification

This can take place at personal, group and organisational levels. At the personal level the focus is on speedy access to knowledge, focussed conversations and fast comprehension. This requires tools such as portals, productivity tools, and personal virtual work spaces. Tools such as search engines, internet, and E-mail support community interactions.

1.6.3 Capture and codification of knowledge

Explicit knowledge can be captured as it is created and implicit knowledge can be elicited from the sources using questionnaires, interviews or leveraging a collaborative environment. Knowledge thus gathered can be represented using schemes such as semantic networks, scripts, expert systems etc. Tacit knowledge, on the other hand, cannot be captured at this stage of the knowledge life cycle but can only be identified as existing in a particular expert's mind. The discovery and availability of such an expert can be codified as a knowledge source (Satyadas and Harigopal, 2001). Artificial intelligence can be used for capturing and codifying the knowledge of the community and so are expert systems, neural networks, fuzzy logic, genetic algorithms, cased-based reasoning, agents and knowledge discovery databases. Automating routine organisational procedures and assisting experts by suggesting and evaluating options can improve knowledge codification. Recording valuable experience in electronic form (documents, databases, web pages, knowledge-based systems) can help prevent repetition of mistakes and the re-use of best practices while reducing costs and improving consistency. Telephones, mobile phones, pagers, faxes, storytelling, quality circles, mentoring and shadowing, coaching and job rotation are considered to be effective in sharing tacit knowledge (Egbu and Botterill, 2002).

1.6.4 Knowledge sharing and transfer

Alavi and Leidner, (2001) discussed that knowledge sharing is a processes in overall knowledge management framework apart from knowledge creation, knowledge storage/retrieval, and knowledge application. They also declared that Knowledge sharing is an important process of knowledge management to transfer knowledge to locations where it is required and can be applied (Cho et al., 2008). Knowledge created, captured, and organized is ready for distribution via multiple delivery channels. Dissemination includes "pushing" knowledge to its users and users "pulling" the knowledge they need. The range of push mechanisms includes information and knowledge portals, intelligent agents and recommendation systems. Search engines, knowledge map browsers and adaptive information retrieval mechanisms aid users in knowledge pull activities. Proven knowledge that has been used and leveraged upon regularly could be transformed into courses that can be distributed via learning initiatives within the organization. Organization's news would be an option for knowledge transfer that includes upcoming community events, recent successes and failures and newly published best practices and lessons learned. Tanlamai and Tangsiri, (2010) conferred that diagrammatic presentation is a best way to transfer knowledge in the information system. Taneerananon (2010) described that the information technology with the participation of public can improve the transport planning, traffic safety, traffic engineering and control. Information Technology tools can help to achieve some of the objectives of KM, but many other non-IT issues need to be in place in order to implement a KM strategy.

1.6.5 Knowledge management and sustainable transport system

The ideas of the sustainable development as introduced in the Brundapt report (WCED, 1987) have being become increasingly important. Achieving sustainable development to combine environmental management and knowledge management is an indispensable ingredient. Sustainable development is defined as "current generations should meet their needs without compromising the ability of future generations to meet theirs" (Bruntland, 1987). In order to meet the Bruntland report requirements, future sustainable development of the urban environment must involve radically reduced usage of natural resources and energy compared to that seen today. KM is the process required to effectively manage knowledge. According to Davenport and Prusak (1998), "knowledge derives from minds at work." Knowledge management is a dazzling, multi-faceted and controversially discussed concept. Knowledge management is a necessity due to changes in the environment such as increasing globalization of competition, speed of information and knowledge aging, dynamics of both product and process innovations and competition through buyer markets (Picot, 1998). Knowledge Management seeks a synergistic combination of data and the information –processing capacity of information technologies and the creative and innovative capacity of human being (Malhotra, 1998). Knowledge management promises to help companies to be faster, more efficient, or more innovative than the competition. The term ''management'' implies that knowledge management deals with the interactions between the organization and the environment and the ability of the organization to react and act (Macharzina, 1999). Quinn et al. (1996) defined KM generally including any processes and practices that are concerned with the creation, acquisition, capture, sharing and use of knowledge, skills and expertise. Shankar et al. (2003) described that knowledge management is a process of identification and leverage of organizational knowledge assets to deliver business advantages to the organizations and its customers. To address the knowledge conversion dilemma, there is a need for a better, broader taxonomy of both tacit and explicit knowledge (Chaudhary, 2005). Basically knowledge management includes all the activities that utilize knowledge to accomplish the organizational objectives in order to face the environmental challenges and stay competitive in the market place. The purpose of KM is to make information and knowledge accessible, reusable and sharable.

1.6.6 Knowledge management tools

Knowledge management tools can be defined as tools which support the performance of applications, activities or actions such as knowledge generation, knowledge codification or knowledge transfer (Ruggles, 1997). They also promoted and enabled the process in order to improve decision-making areas such as data access, on-line analytical processing and the use of the internet and groupware systems for decision support and thus KM are becoming the cornerstones of modern management. Technology is a powerful enabler of KM objectives. The goal of a KM tool is not to manage knowledge by itself but to facilitate the implementation process. The knowledge management tools can also be used to speed up communications elicit tacit knowledge and construct insights and catalogues (Grantham and Nichols, 1993). The selection of the most appropriate KM technologies requires a clear identification and understanding of the particular organization's KM needs. It also requires an awareness of the technologies available and their functional capabilities.

1.6.7 Knowledge management applications

The four key applications of knowledge management are based on a model practices that regards knowledge management's primary role as the sharing of knowledge throughout the organization in a way that each individual or group understands the knowledge with sufficient depth and in sufficient context as to apply it effectively in decision making and innovation. These four applications of knowledge management are:

1.6.7.1 Intermediation

Intermediation is the connection between knowledge and people. Intermediation refers to the brokerage function of bringing together those who seek a certain piece of knowledge with those who are able to provide that piece of knowledge. It is a fundamental step in internal and external responsiveness. Its role is to ''match'' a knowledge seeker with the optimal personal source(s) of knowledge for that seeker. Two types of intermediation are common, asynchronous and synchronous. Asynchronous intermediation occurs when externalization and internalization do not occur simultaneously. In this case, an external knowledge repository stores the knowledge while it is in transit. Knowledge is captured in the knowledge base, often before a specific need for that knowledge elsewhere in the organization has arisen. When a knowledge seeker requires that knowledge, the knowledge base can be searched and the relevant knowledge extracted. This approach is typically best suited to explicit knowledge. Synchronous intermediation occurs when externalization and internalization occur simultaneously. Knowledge is not stored while being transferred. Knowledge provider and knowledge seeker engage in direct communication. The challenge is to match knowledge providers with knowledge seekers intuitively and in a timely manner. This approach is far more common in tacit knowledge transfer.

1.6.7.2 Externalization

Externalization is the connection of knowledge to knowledge. It refers to the process of capturing knowledge in an external repository and organizing the knowledge according to some classification framework or ontology. A map or structure of the knowledge collection is provided as a facilitator to knowledge discovery. It is focused on bringing order to internal and external awareness. A knowledge management system, like an ecosystem, cannot be constantly depleted of its resource without constant replenishment. There are two fundamental components to externalization: the capture and storage of the knowledge in a suitable repository and the classification or organization of the knowledge. Capture and storage can take the form of a database, a document or a videotape. Classification or organization of the knowledge is the more difficult of the two functions. It relies on the knowledge possessed by the knowledge provider to shape the classification of the information into the most usable form.

1.6.7.3 Internalization

Internalization is the connection of knowledge to query. It is the extraction of knowledge from an externalized repository and filtering it to provide personal relevance to the knowledge seeker. Closely tied to an externalized knowledge base, internalization reshapes the knowledge base specifically to address the focal point of the query issuer.

1.6.7.4 Cognition

Cognition is the linking of knowledge to process. It is the process of making or mapping decisions based on available knowledge. Cognition is the application of knowledge that has been exchanged through the preceding three functions. It is a highly proactive form of internal and external responsiveness. It is achieved by applying experience to determine the most suitable outcome to an unprecedented event, opportunity or challenge.

1.7 Need of the Study

Previously, a number of studies have been conducted in Delhi to know overall scenario of noise and air quality generated by traffic. At present, due to hasty urbanization, motorization a various environmental problems i.e. traffic noise, metro noise, air quality and traffic congestion are rising in Delhi. To minimize such kind of pollution problem, major public transport corridor has been designed in Delhi like MRTS and BRTS. Environmental Impact Assessment study has been undertaken before the implementation of MRTS and BRTS. After operationalization of these MRTS and BRTS corridors, no study has been conducted to check the status of noise quality and air quality due to plying vehicles along various locations of developed corridors. Along with this, no study has also been conducted in capital city, in which KM practices has been focused to mitigate the traffic noise and air pollution with proper traffic management. Nowadays, people are much concern about adverse effects of noise and air generated by traffic. Keeping in view these concerns, there is a need of study of traffic noise, metro rail noise and air pollution scenario along public transport corridor and study of KM practices as mitigatory measures to diminish the above mentioned problems in Delhi, India.

1.8 Objectives of the Study

On the basis of above research gap, the study has identified following objectives:

1. To study ambient noise levels along major public transport corridors in Delhi.
2. To observe concentration of gaseous pollutants at different locations along major public transport corridors in Delhi.
3. To estimate the current scenario of aggregate emission for Delhi and forecast vehicular emission for 2025.
4. To analyze suitability and performance of air quality dispersion model and traffic noise prediction model.

5. To use different knowledge management practices to achieve an environmentally sustainable transport system.
6. To design noise abatement barrier along the road and at elevated corridor of identified metro line.
7. To develop knowledge based model to control traffic and environmental parameters.

1.9 Research Methodology

It includes identification of transport-related environmental issues like traffic noise, metro rail noise and traffic air emission along the public transport corridor i.e. Mass Rapid Transit System (MRTS) Corridor and Bus Rapid Transit System (BRTS) Corridor of Delhi. The locations which are selected for the study are Rithala, Pitampura, Kashmiri Gate, Jhilmil, Dilshad garden along MRTS and Panchsheel enclave at BRTS corridor. These locations are used for the study of traffic noise, metro noise as well as for traffic air pollution. Barrier designing has also been carried out at all the locations. In second stage of the study traffic related data i.e. classified traffic volume, spot speed, geometric parameters, ambient noise level due to road traffic, noise generation due to metro, air pollutant concentrations and meteorological parameters have been collected at all the identified locations. A number of secondary data i.e. registered number of vehicles in Delhi have also been collected from different sources. After analyzing primary & secondary data, different knowledge based traffic noise model, noise barrier designing model, metro rail noise model and air pollution model have been developed. These models are free from conventional mathematical complexities and developed within MS EXCEL worksheet system. They are mini knowledge management tools to enhance transparency and easy application for transport environment interaction studies. Through the application of different KM based models; the equivalent noise level has been calculated at different locations of corridor, which has been used to compute the required height of barrier along the public transport corridor or at metro elevated corridor. On the other hand, measured pollutant concentration has been used to validate the developed air pollution model, while secondary data has been applied to estimate the aggregate emission for the mega city Delhi. Last step of study includes application of different knowledge practices to reduce environmental pollution in terms of traffic noise and air. Figure 1.15 depicts the methodology adopted during the research work.

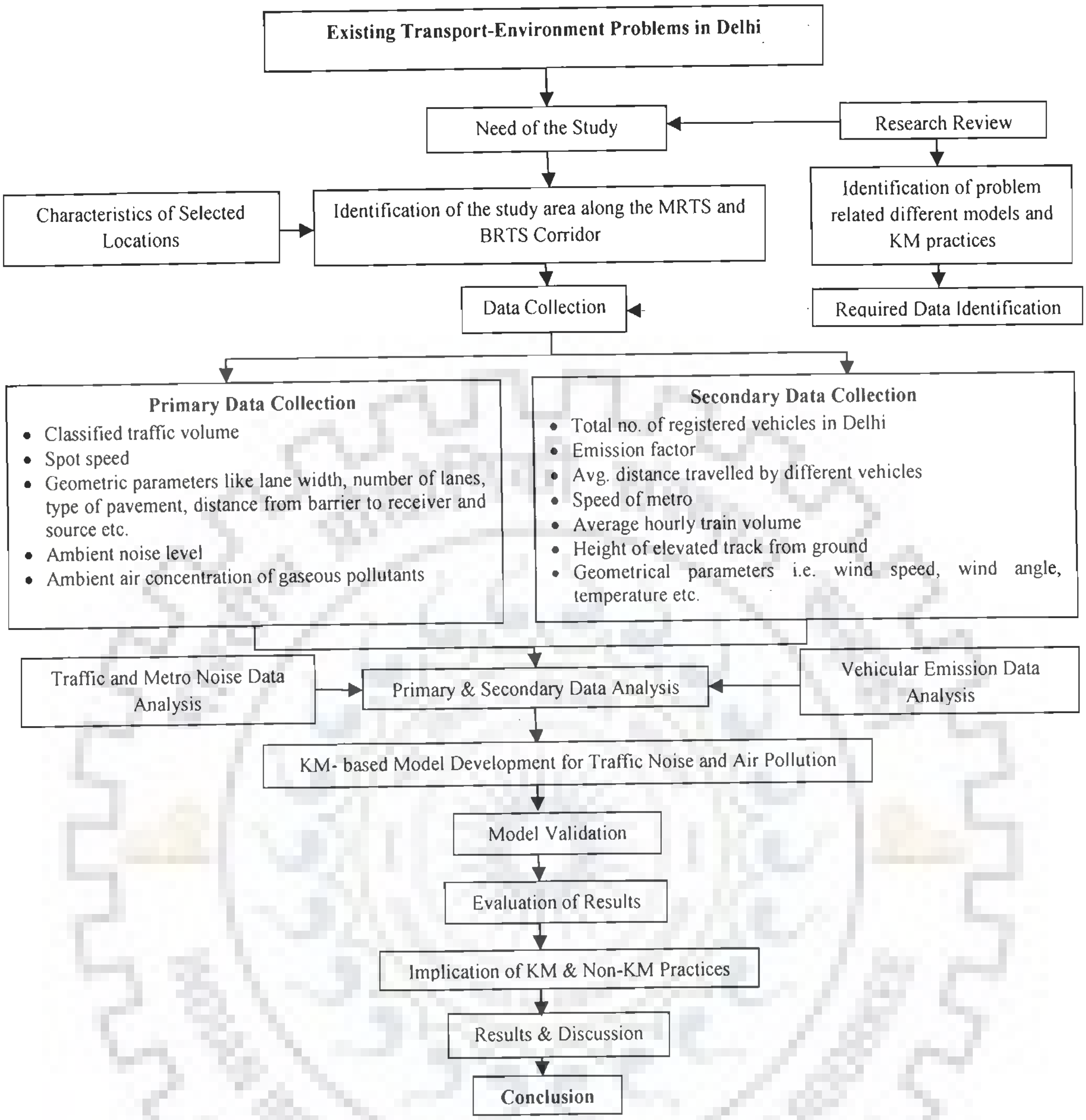


Figure 1.15: Methodology of Study

1.10 Organization of Thesis

The thesis has been divided into eight chapters. Each chapter has discussed different identified aspects of the research and objectives.

Chapter 1 is focused on introduction that consists of basics about urbanization, motorization, sustainable transport, traffic noise pollution, health impact of traffic noise pollution, vehicular emission and causative factors, global climate change and role of technology in sustainable transport system. In addition to this, the chapter has also covered the concept of knowledge, knowledge management, knowledge management tool and application of knowledge management in sustainable transport. Along with this, the objectives of study and research methodology have also been covered by this chapter.

Chapter 2 presents a research review of extensive literature on traffic noise pollution, rail noise, barrier designing, vehicular air emission and knowledge management practices in transport sector to reduce environmental pollution in terms of noise pollution, air pollution and proper traffic management system.

Chapter 3 consists of various model discussion employed in this study. This chapter includes detailed description about available models for traffic noise prediction, barrier designing for road and rail, traffic air emission. Different knowledge based models and their applications have also been discussed in this chapter.

Chapter 4 illustrates various primary & secondary data collection related to road traffic noise (traffic volume, spot speed, and geometrical parameters), metro rail noise and ambient air concentration of CO, NOx, SO_2, HC and PM.

Chapter 5 covers modeling aspect of surface transport noise i.e. road traffic noise as well as metro rail noise. This chapter has discussed about formulation of KM based traffic noise model and metro rail noise model in MS EXCEL platform. Primary & secondary data analysis and prediction of noise has been covered by this section.

Chapter 6 discusses another modeling aspect of transport-environment interaction i.e. modeling of air pollutants. In this chapter, KM based developed model has been covered with detailed analysis of primary and secondary data. For the validation of developed models, some statistical tests have also been exposed in this chapter.

Chapter 7 is oriented towards the application of this study. Model development for barrier designing has been covered by this chapter. Air quality analysis and development of emission inventory for Delhi city is also presented in this chapter. In addition to this, development and application of KM practices based model for the reduction of traffic noise pollution, vehicular emission and traffic congestion has also been incorporated in this chapter.

Chapter 8 presents conclusions, findings and limitations of this research study. It includes different outcomes extracted from the entire study and implications of the results in field condition. Directions for future research has also recommended in this chapter.

1.11 Summary

This chapter focuses basically the introductory part of research. It includes trend of population growth, urbanization, motorization in all over the world as well as in India. Along with this, surface transport noise and its impact on human health, vehicular pollution and its impact on people have also been covered. The burning environmental issues like global warming and climate change have been discussed thoroughly in this chapter. Since environmental sustainability, which is an important asset of the nature and society has also been covered by this chapter. In this chapter, a very significant module has been discussed which can play a very important role to overcome the transport related environmental issues i.e. knowledge management. In addition to this, objectives of the research study, methodology and organization of thesis have also been enveloped.

Chapter 2

RESEARCH REVIEW

2.1 General

The increasing vehicular traffic is the prime source of noise pollution and air pollution in World as well as in India. Traffic noise and air is an increasing problem in the modern society and it is dominating in urban environment. Traffic noise represents an environmental problem that is perceived by humans more directly than the usual chemical emissions or resource uses. In the cities of developing countries, the air pollution problem is a solemn environmental dilemma. The path of air pollution in urban atmosphere consists of emission and transmission of air pollutants, resulting in ambient air pollution. All over the world, the motor traffic emission is a very important source. Urban population growth may be a major probable reason for the air quality problems (**Helmut, 1999**). A lot of studies related to traffic noise pollution and air pollution have been done at global and national level.

2.2 Traffic Noise Pollution: World Scenario

Johnson and Saunders (1968) built up a model based on the conjecture that all motor vehicles are uniformly spaced and are generating the same maximum noise. They proposed a technique to predict the statistical mean sound level L_{50} due to free flowing traffic. They explained that in case of higher traffic the noise level decreases by 3 dB per doubling of distance.

Langdon and Scholes (1968) explained a technique relating the noise levels produced by traffic to the nuisance caused to people living the neighborhood. They used traffic noise index to predict the nuisance likely to be produced by a given intensity of traffic and conferred the methods for reducing this nuisance to an acceptable low figure.

Thiessen and Olson (1968) viewed the various abhorrent sources including automobiles, buses, trucks, trains, motor cycles and power driven equipments like lawn movers and advised that noise control actions could be applied to the source, the transmission path, residential zoning or through legislation.

Scholes and Vulkan (1969) summarized different aspects of noise measuring techniques in order to provide a useful framework to be used for further developments in technique.

Thomas (1969) recommended an economic technique to reduce the traffic noise by the use of noise reducing materials.

Scholes *et al.* (1971) suggested design rules for estimating the effect of long noise barriers on the propagation of motorway noise peaks in terms of L_{10}. **Scholes and Sargent (1972)** discussed about some factors to be considered in setting standards for traffic noise and have extended discussion of possible units for depicting traffic noise levels to include the noise pollution level. **Kugler and Piersol (1973)** assessed the key procedures in the Design Guide, using field data for selected highway configurations under different normal and environmental conditions.

Nelson and Godfrey (1974) studied the road traffic noise in rural environment. During their study they measured the traffic noise alongside 26 miles of the A66 within the Lake District National Park and in the towns of Keswick and Coker mouth and they built a 50 dB (A) L_{10} contour for road traffic noise.

Roberts and Borthwick (1975) developed a comprehensive vehicle noise prevention and control program. By the data collection, analysis and computer modeling, they assessed the efficiency of alternate vehicle noise control strategies. **Joyce and Williams (1975)** studied the environmental impact, traffic behavior and street characteristics in locations throughout the London Borough of Hammersmith and the Royal Borough of Kensington and Chelsea.

Bolt *et al.* (1976) proposed a noise model for free flowing traffic. They illustrated that propagation loss varies from 3-4.5 dB per doubling of distance depending on the ground cover. **Delany *et al.* (1976)** calculated noise levels L10 from road traffic noise and developed an improved procedure. The overall performance of this procedure assessed with reference to a comprehensive data bank specifically assembled for that purpose.

Kugler *et al.* (1976) recommended an overview of the suggested noise prediction methodology as a four step process including noise impacts, refining the prophecy using computer programs, introducing suitable noise-control options and finally calculating the selected options using the computer program.

Nelson and Piner (1977) categorized road vehicles to measure the road traffic noise. Measurements of speed, noise level and vehicles had made in road conditions ranging from fairly congested urban situations with speeds around 20 kmph to free flow on motorways with speeds over 100 kmph. They used these measurements to construct approximate vehicle noise levels and speed characteristics over the speed range 20 – 100 kmph for up to 6 vehicle categories, and used as input in the Transport and Road Research Laboratory (TRRL) computer model of traffic noise.

Plotkin (1977) develop a model for the measurement of strategies of highway noise control through vehicle noise control. **Samuels and Thomas (1978)** learned the measurement and analysis of road noise. During their study they measured the roadside noise levels as a vehicle passes by test track under various conditions of speed, load and engine operation and so on. **Jones *et al.* (1979)** developed predictive equations for various noise indexes using digital computer simulation techniques for unrestricted traffic in urban situations. **Silvani (1979)** had made correction for the effect of highway gradient. **Gilbert (1980)** developed a noise model for estimating noise in terms of L10 for interrupted traffic flow and found suitable for typical urban streets.

Jacobs *et al.* (1980) developed a computer model to envisage traffic noise in built-up situations for free flow traffic conditions and for a flow interrupted by a traffic light. **Pearson and Sabir (1988)** carried out noise level study for community noise and peak noise emission in eastern Saudi Arbia and New Delhi.

Jung and Blaney (1988) suggested a streamlined but somewhat limited version of 'STAMINA MODEL' computer program developed in Basis for the use of personal and pocket computers. The basic version is very helpful to predict noise from hourly traffic for many simple situations. This model is designed to estimate highway noise level from computer traffic, geographic and geometric data. This is also helpful in the development of noise barrier system for a specified series of objectives.

Klæboe et al. (2000) adopted an integrated alternative approach in Oslo traffic study to allow people's environmental annoyances to be studied relative to indicators of air pollution, road traffic noise and residential traffic. Exposure indicators for air pollution as well as road traffic noise and residential traffic levels were produced for each respondent by comprehensive environmental modelling. It is found that higher the road traffic noise levels are exposed to, the more likely they are to be highly annoyed by exhaust smell at a specified air pollution level. The higher air pollution levels people are exposed to the more likely they are to be annoyed by road traffic noise at a specified noise level.

Allen et al. (2009) evaluated roadway roadway proximity exposure surrogates in relation to the measured levels, estimated noise–air pollution correlation coefficients, and evaluated the impact of regional-scale pollution gradients, wind direction, and roadway proximity on the correlations. For this, study had been conducted at 105 locations, selected primarily to characterize gradients near major roads, in each of 9 U. S. Communities. Moderate correlations between traffic generated air pollution and noise suggest the possibility of confounding, which might be minimized by considering regional pollution gradients and/or prevailing wind directions in epidemiologic studies.

Asensio *et al.* (2009) applied global positioning systems-based techniques for acquiring vehicle speed data and adapted to fulfil the requirements of noise prediction models. The results obtained by this method are considered to be sufficiently accurate.

Murphy *et al.* (2009) conducted to determine estimates of the extent of environmental noise exposure from road transport on residents and workers in central Dublin, Ireland. They used Harmonoise calculation method to calculate noise values for the study area while a Geographical Information System (GIS) is utilised as a platform upon which levels of noise exposure are estimated. Residential exposure is determined for L_{den} and L_{night} while worker exposure is determined for L_{den}. From the study, it is concluded that the extent of noise exposure in Dublin is considerable, and in relative terms, it is worse for the night time period. From the analysis, it has also been concluded that traffic management have the potential to lead to significant reductions in the level of noise exposure.

Givargis and Karimi (2010) presented a basic and preliminary neural network model using a restricted database to predict LAeq, 1h for Tehran's roads. UK Calculation of Road Traffic Noise (CORTN) approach applied in the model. For this, data were collected from 50 sampling locations near five roads in Tehran at nearside carriageway edge distances of less than 4 m. The overall model efficiency had been examined by using non-parametric tests, such as the Wilcoxon matched-pairs signed-rank test for the training step and the Kolmogorove – Smirnov test for two independent samples for the validation step. It study indicated that a neural network approach can be applied for traffic noise prediction in Tehran in a statistically sound manner. The Wilcoxon matched-pairs signed-ranks test detects no significant difference between the absolute testing set errors of the developed neural network and a calibrated version of the CORTN model.

Phan *et al.* (2010) conducted noise study in Hanoi and Ho Chi Minh City. A comprehensive dataset of noise had been collected that included 24-hour noise measurements as well as short-term noise recordings. Noise datasets from both cities were compared with a dataset of Japanese traffic noise obtained in Kumamoto. The findings showed that the traffic noise in Hanoi and Ho Chi Minh City was characterized by relatively high noise exposure levels due to the large number of motorbikes and frequent horn sounds.

Pirrera *et al.* (2010) reviewed noise processing in general and in relation to sleep, as well as methodological aspects in the study of noise and sleep. It was found that mediating factors such as noise sensitivity play very important role.

Pamanikabud and Tansatcha (2010) investigated the impact of traffic noise on the high-rise building and surrounding area by the side of a new motorway that links Bangkok to the new Suwannaphum International Airport and Pattaya. For this, they applied a traffic noise simulation model in 3D form on a GIS system. The investigation indicated the high traffic noise impact on foreground and front façade of the building, rendering this area unsuitable for residential purposes.

Sobotova et al. (2010) investigated and evaluate the relationship between road traffic noise and cardiovascular risk. During this study, they collected 659 samples of university students. The results highlighted the association between road traffic noise annoyance, interference with various activities and cardiovascular risk among young healthy individuals.

Mehdi *et al.* (2011) studied spatial and temporal patterns of noise exposure due to road traffic in Karachi City, Pakistan and found that levels of noise were generally higher during mornings and evenings because of the commuting pattern of Karachi residents. The average value of noise levels was obtained over 66 dB, which could cause serious annoyance according to the World Health Organization (WHO) outdoor noise guidelines. Maximum peak noise was over 101 dB, which is close to 110 dB, the level that can cause possible hearing impairment according to the WHO guidelines. It is concluded from the study that noise pollution is not an environmental problem reserved for developed countries, but also occurs in developing countries as well.

Fung and Lee (2011) measured traffic-induced noise levels and PM10 concentrations by the roadside of two busy roads in Hong Kong and at selected case study residential units at Royal Ascot and City One Shatin. The measurement conducted from 2:00 pm to 5:00 pm in weekdays during early summer time. During the study, linear correlation had been observed (r2 ¼ 0.76 and 0.92) between the measured levels at six case study units and the logarithm of the distance to confirm that the six case study units were directly affected by road traffic-induced noise and were selected for subsequent PM10 concentrations monitoring. The regression analysis suggests that the 10-min averaged PM10 concentrations correlates with the logarithm of the distance from road (log R). From the findings of this study it is clear that under high roadside PM10 level, at moderate weather conditions, within the investigated road distance, and in the absence of external screening, "log R" can be used as a common parameter to evaluate the impact of traffic induced noise and air pollutions on a residential unit.

Rahmani *et al.* (2011) studied noise pollution level in the city of Mashhad and developed traffic noise level prediction model i.e. TID (time-independent) and TD (time-dependent), for the purpose of traffic noise level reduction by redesigning its flow or other means. First model i.e. TID does not consider the direct effect of time in its calculation. The second, which is called TD, is the modified form of the first model with consideration of the direct time effect. These models estimate the measured data very well, with some improvements for the TD model.

2.3 Traffic Noise Pollution in India

Gangil *et al.* (1979) tried to develop relationship between the vehicular noise and stream flow parameters. They built up a relationship between the vehicular noise and stream flow parameters.

$$L_{10} = 18.092433 + 19.90357 \times \log_{10} (Qw) \quad \text{dB (A)} \qquad \text{.... (2.1)}$$

Where, Qw = traffic volume in EPCU / hr

Gupta *et al.* (1984) developed a monogram for noise prediction. **Gupta *et al.* (1986)** carried out their study about road traffic noise for different land uses for mixed traffic flow in Roorkee at different selected locations. In their study they computed L_{10}, L_{50}, L_{90}, L_{eq} and noise pollution levels. **Sarin *et al.* (1990)** assessed the road traffic noise problems of residential scientist apartments near a busy highway intersection in Delhi. On the basis of his calculation he found higher equivalent noise levels at all the floors (up to 7th floors) than the permissible noise level by Indian Standards i.e. 65 dB (A).

Rao (1991) studied the first comprehensive traffic noise in Visakhaptnam city. During his study, he measured the noise for different types of land use areas and developed prediction equations. **Srivastava *et al.* (1993)** estimated the environmental noise pollution on the SH-

45 between Ghaziabad and Roorkee in continuation of their earlier study. **Mehndiratta *et al.* (1993)** studied the variation in noise pollution for buses running in different gears. On the basis of measured data they developed various correlation between the engine gear, vehicle speed and noise parameter. **Srivastava (1994)** assessed the environmental noise pollution on NH-58 and developed a model to predict the noise levels.

Gupta *et al.* (1994) developed a computer software package named "Traffic Noise Analysis Package" in 1993. This software has four different options. By the use of first option the various noise parameters like L_{10}, L_{50}, L_{90} and L_{eq} can be calculated. The second option is for the prediction of noise level (L_{eq}). The L_{eq} can be estimated for a given classified traffic volume per hour and at a desired distance (in meter) from the centre of traffic flow. The third option offers facility to attain the combined noise level of a mixed traffic flow stream by giving their individual noise levels as input data. At last the fourth option provide exit to the program.

Yognarayana and Ramalingeswara (1994) monitored noise level at different selected junctions to measure the overall environmental noise problem in Ramagundam. During their study they recorded L_{10}, L_{50}, L_{90} and L_{eq}. On the basis of these values they calculated and analyzed the TNI and LNP.

Nigam (1996) suggested methodology to design an acoustic barrier on highway with particular reference to situation around the Red Fort, Agra. **Kumar (1997)** learned the urban noise scenario in Delhi and developed different traffic parameters like traffic volume, traffic speed and distance from pavement edge and the equivalent sound level L_{eq}. From the developed correlations, it is possible to envisage the impact of traffic developments in terms of noise pollution in future and timely measures for control can be implemented (**Gupta *et al.* 1986**). For silence zone, the developed equation is:

$$L_{eq}\,(1h) = 47.45 + 8.58 \times \log (Qw) - 0.14\, d \quad dB\,(A) \qquad \text{.... (2.2)}$$

where: Qw = traffic volume in EPCU / hr

Siddiramulu (1998) developed a software package TNP-MM for traffic noise prediction. **Kumar (2000)** recommended a model for Indian conditions by calibrating FHWA model. **Kalita (2000)** estimated noise levels at different selected localities of the Roorkee township for various landuses. In his study he compared the existing noise levels of different landuses of the township with the existing permissible standards. He identified possible landuse compatibility of different noise zones within the township and suggested abatement strategies. **Bhattacharya *et al.* (2001)** proposed a highway noise model for Indian conditions. Noise study was carried out at 169 km on NH-58 and 42 km on NH-2. Individual vehicle noise differs with speed, so individual vehicle noise levels over a wide range of speeds are taken. On the basis of their study they developed individual noise level equations for bituminous and cement concrete surface. **Neeraj (2001)** developed NBDP (Noise Barrier Design and Prediction) software for designing noise barrier in C^{++}. This software is very useful to design barrier for two lane and four lane national highways with the both bituminous and cement concrete surfaces.

Sheikh (2002) performed his study on NH-58 and developed a noise prediction model for Indian traffic conditions by collecting various data like traffic flow rate, traffic speed, gradient, percentage of heavy vehicles and road surface.

Singh (2002) developed a regression model for Indian conditions to correlate the traffic parameters and geometric parameters with traffic noise. The statistical analysis of this model shows that the model is reliable for prediction of noise in urban areas at 95% confidence level.

Jetti (2003) studied the performance assessment of noise prediction model. During his study, he collected data related to ambient noise level, classified traffic volume, classified traffic speed and highway geometrics from different selected location in Delhi. By putting these values in Federal Highway Administration Traffic Noise Model (FHWA TNM), he determined the relative prediction efficiency of this model.

Pathak et al. (2008) evaluated the noise pollution problem and its effect on exposed people in Varanasi. During the study, 85% of the people were disturbed by traffic noise, 90% of the people reported that traffic noise is the main cause of headache, high BP problem, dizziness and fatigue.

Agarwal and Swami, (2011) developed an empirical noise prediction model for the evaluation of equivalent noise level (Leq) in terms of equivalent traffic density number under heterogeneous traffic flow conditions.

2.4 Traffic Air Pollution: World Scenario

McGuire and Noll (1971) find out the relationship between air pollutants concentration and averaging time. For this he studied five different air pollutants in 17 cities of California in U.S.A. they developed and equation to show this relationship-

$$C_{\max(t)} = C_{\max(h)} t^{b} \quad \text{.... (2.3)}$$

where,

$C_{\max(t)}$ is maximum concentration for t hours.

$C_{\max(h)}$ is maximum concentration for one hour

t is averaging time in hours corresponding to $C_{\max(t)}$

b is exponent which varies with the pollutant and sampling location.

This equation gives maximum concentration for different averaging times. This relationship is sufficiently accurate in the prediction of maximum concentration for averaging time up to one year. This technique's accuracy is determined by the line of the maximum fits the logarithmic relationship shown in equation and the temporal and spatial constancy of b in the area going to be studied.

APRAC – 1A, model is basically a modified form of the receptor – oriented Gussian plum formulation, which was developed by **Clarke (1964)**. This model is mainly used for predicting the concentration of inert, vehicle related pollutants. As input it requires meteorological and traffic data and gives areal concentration isopleths, sequential hourly point and frequency distribution. This model is very useful to predict the current and future impacts of motor vehicles on the air quality in urban communities. It can be used by traffic engineers to supplement their other tools and interpret the changes in traffic parameters in terms of the consequent changes in pollutant concentration.

Mccollister and Wilson (1975) developed Linear Stochastic Models by using the method of time – series analysis (**Box and Jenkins, 1970**). There are two related time series models and developed to forecast the concentration of various air pollutants. These models had been tested on CO and oxidant for the Los Angeles basin. In this model, one model was for forecasting daily maximum concentrations of a particular pollutant by using the past daily maximum values as input of that pollutant. The other used model was for forecasting one hour (1-h) average concentration by using the past hourly average values.

Chock (1977) set up an experiment of General Motors Sulphate dispersion of different pollutants near the roadway. On the basis of his experiment he concluded that when the crossroad wind component was low then there was upwind dispersion within a few meters of the road. Further he found the enhancement in the dispersion in the presence of a wind component opposing the traffic in the upwind lanes.

General Motor (GM) model was developed by **Chock (1978)** to describe the downwind dispersion of pollutant near the roadway. There are so many other models, which describe the dispersion of pollutants from roadways (**Darling *et al.*, 1975, Noll, 1975**). According to this experiment mechanical mixing plays an important role in the dispersion of pollutants near the roadway.

Bencala and Seinfeld (1979) developed a package consist the collection of subroutines, which is known as AQMAAP. It has been prepared and coded in FORTRAN for the evaluation of air model performance. AQMAAP is useful for the study ranging from small single model evaluation with a few days' data to large multiple model evaluations with the order of a few months of data. The AQMAAP package requires both observed and predicted concentration values. Whatever the statistical comparisons are to required, one can specify with the help of AQMAAP.

Finzi *et al.* (1979) enlightened about stochastic predictors of daily and hourly SO_2 concentration in the Venetian Lagoon area. On the basis of his study he conclude that the wind speed and direction related information gives adequate enhancement of one day ahead forecast with respect to ARIMA models.

Peterson (1980) proposed that HIWAY-2 model is a steady-state Gaussian model. This model can be applied to determine air pollution concentrations at receptor locations downwind of 'at-grade' and 'cut-section' highways located in relatively uncomplicated terrain.

Finzi and Tebaldi (1982) depicted ARMAX model for the forecasting of SO_2 in urban area during domestic season. By originating the real-time predictor from this model they developed a technique to forecast the pollution for different areas.

Benson (1989) developed CALINE 4 model. This model was based on Gaussian diffusion equation. In addition to this, the model uses a mixing zone to characterize the dispersion of pollutants over roadway. It can predict the pollutant concentrations for receptors sited within 500 meter of the roadway.

Juda (1986) estimated the SO_2 concentration of Cracow, Poland by using three-level Eulerian dispersion model. On the basis of this model Juda concluded that instead of a single parameter, a group of parameter (wind speed, direction and temperature) will be required for the evaluation of the performance of air quality model.

Kono and Ito (1990) expressed a micro-scale model 'Osaka Municipal Government (OMG) Volume – Source Model' for estimating the pollutant concentration of motor vehicle exhaust. This model is useful in an urban area within the range of 200 meter from the side of the road.

Bardeschi *et al.* (1991) examined the concentration of CO and NOx pollutant emitted from motor vehicles in Milano (Itlay) urban area by using APRAC3 (Air pollution Research Advisory Committee Version 3) model of the EPA UNAMAP (User's Network for Applied Modelling of Air Pollution) system. During their study, they compared between calculated and measured pollutant concentration and finally wrapped up that the APRAC3 is to be a helpful instrument in making strategies intended at reducing pollution from motor vehicles.

Huang (1992) employed cluster analysis method for air quality prediction in the urban district of Xiamen, China. On the basis of graphical and statistical tests, the cluster method has been verified a viable approach for short-term air quality prediction. This used method also enhanced the previous AID (Automatic Interaction Detection) and can be applied to environmental quality prediction.

Benson (1992) reviewed the development and application of CALINE 3 and CALINE 4 models. On the basis of the assessment of both models he concludes that the CALINE 4 has ability to handle a greater variety of problems in a more flexible manner and it has more accuracy in comparison to CALINE 3 model.

Alexopoulos *et al.* (1993) developed an emission model for the spatial and temporal estimation of traffic emission in metropolitan cities. This model is based on a special probability law. Alexopoulos use this model in Greater Athens Area in Greece to forecast the CO emission. The spatial and temporal distribution of traffic load is an essential factor in this emission model. The raw data had been used to refer traffic conditions during the period of 1986-1988. During his study he utilized all the available traffic data and determined the pollutant emission with the highest exactitude possible. They regarded the main roads as line sources of constant traffic parameters and the method permitted for the estimation of distributed area sources. In this emission model traffic data related roads are taken into report. Line sources are segregated into proper linear segments. On the basis of their study, they concluded that the private automobiles are the main source of pollution. Private automobiles are responsible for about 85% of CO emission. By implementing the model with more traffic data one can attain more precise prediction about the pollutant emission.

Qin and Chan (1993) applied the receptor method to estimate the contribution of traffic emission to street level air pollution in Guangzhou city of South China. During their study they measured various types of motor vehicle emission in idle condition and derive the composite emission factors of vehicles. They inspect the variation of traffic volume and vehicle speed in different streets. On the whole they concluded that only NOx is the most significant pollutant of traffic emission which influences the ambient air quality

Eerens *et al.* (1993) developed CAR model to calculate the average concentration and concentration percentiles in streets for inner pollutant as well as nitrogen dioxide (NO_2) by using accessible input data. From their research, they concluded that CAR model is a satisfactorily consistent and viable technique for the calculation of traffic exhaust air pollution in urban streets.

Torp and Larssen (1996) estimate the exposure value of NO_2 and PM_{10} along the main road network of Narway by using Road Air Model. By using this model he calculated the concentration of different pollutants and the result showed the maximum concentration of NO_2 and PM_{10} outside the homes of people living next to main roads.

Fomunung *et al.* (1999) developed a statistical model for the prediction of NOx emission from light duty gasoline motor vehicles. The primary end application of this model is forecasting rather than elucidation of factors that affect NOx emission. They used the combination of tree and OLS (ordinary least square) regression method to estimate a NOx emission model from the US Environmental Protection Agency (USEPA) light duty vehicles emission testing database. The obtained findings from the research suggest that gram/s NOx emission increase with average speed, which is consistent with theory and present models. The research showed that emission control technologies, mainly catalytic converter and fuel injection type, play important roles in the control of NOx emission. The model can be applied to regional or corridor-level traffic where operating conditions of the fleet can be enumerated.

Bradley *et al.* (1999) developed a device measures the CO/CO_2 ratio in the exhaust of motor vehicles passing through a single lane measured over 1000 vehicles per hour. It was observed that in 1991 global CO emissions from motor vehicles was 213 Mt, out of that 188 Mt were produced in the northern hemisphere and 25 Mt produced in the Southern hemisphere. USA was responsible for about 17% of the global CO emissions from motor vehicles in 1991 which intermediate between the JARI and EPA 1990 estimates. Between the years 1991 to 1995, there had been 46% decreasing in global CO emissions, with the USA responsible for about 12% (22 Mt) of the global emissions (177 Mt) world-wide in 1995.

Johnson and Ferreira (2001) developed a technique to predict ambient submicrometer particle concentration from traffic flows at freeway site with up to 75% accuracy.

Qi *et al.* (2004) developed simple-structured microscale emission model (POLY model) to take into account the effect of acceleration or deceleration. To entirely detain the dynamics of acceleration and deceleration, they included the value of acceleration and deceleration of the current period and previous periods. They also considered the durations of acceleration or deceleration. During their study they assessed the model from microscopic and macroscopic perspective and stated that the developed model performs better than the CMEM models and the other microscopic traffic simulation model.

Schmitz (2005) developed a three dimensional Eulerian Chemical Model, i.e. Chilean Air Pollution Dispersion Model (CADM). With the help of this model he studied the CO dispersion in order to estimate advection and diffusion as simulated by CADM and to characterize dispersion patterns in the Santiago basin. On the basis of comparing the from model simulations with observations, he concluded that CADM is appropriate for the application of air pollution dispersion in the Santiago basin and complex terrain.

Grivas and Chaloulakou (2006) focused to estimate the potential of different neural network models to offer reliable evaluations of PM_{10} hourly concentrations. For their study they selected four locations within the Greater Athens Area and covered the period of 2001-2002 for used data. Through their study of evaluation of models they conclude that the performances of examined neural network models are superior in comparison with multiple linear regression models.

Smit *et al.* (2007) presented VERSIT + LD model to estimate hot running traffic emission from light duty vehicles. They focused to predict specific traffic emissions for any particular traffic situation at different spatial levels as a function of parameters that characterize the dynamics of vehicle driving in that traffic situation.

Costabile and Allegrini (2008) analysed functional relationship linking air quality and air pollution from transport and developed a more flexible framework to allow communication between transport emissions and air quality concentrations. The paper describes the development of this framework, suggests methodological tools to mitigate its problems and showed its application to the mega-city of Beijing, in P.R. China. On the basis of the case study of Beijing, it is found that the integrated system can link traffic air pollution measurements through various modelling modules in order to automate transport-related air pollution assessment.

Parrish *et al.* (2009) measured the concentration of hydrocarbons, carbon monoxide and nitrogen oxides from three mega-cities i.e. Beijing, Mexico City, Tokyo. These values were compared with similar measurements from US cities in the mid-1980s and the early 2000s. Emissions from gasoline-fuelled vehicles dominate in all of these cities helps to develop appropriate air quality control strategies through emissions inventory development and ambient air monitoring. The ambient hydrocarbon and CO concentrations reported for the three non-US mega-cities are higher than present US ambient concentrations, but lower than those observed in the 1980s in the US. In Beijing city, the concentration of CO observed have a large contribution to a regional level.

Singh *et al.* (2009) reported sustainability indicators and composite index as a useful tool for policy making and public communication in conveying information on countries and corporate performance in environment, economy, society or technological improvement. It also compiled the information related to sustainability indices formulation strategy, scaling, normalisation, weighting and aggregation methodology.

Athanassiadou *et al.* (2010) studied the effects of climate change on air quality on two urban sites in the UK i.e. London and Glasgow. Result showed the falls in NO_2 and increases in ozone for London, while a fall in NOx was the largest percentage change for Glasgow while other changes were small. These values were compared with annual - average concentrations of NO_2, NOx, ozone and PM. For London averaged over a number of sites showed a fall in NO_X and a rise in ozone, but only small changes in NO_2 and PM10. For Glasgow, the changes in all four were small.

Ho and Clappier (2011) used the new EMISENS model for generating the Emission Inventory (EI) for road traffic sources and emission factors by using inverse air quality model method for Ho Chi Minh City, Vietnam. Results indicated that motorcycles contributing 94% of carbon monoxide, 68% of NMVOC, 61% of SO_2 and 99% of CH_4 responsible for major traffic emissions. It is also predicted from the above study that the emission of CO and CH_4 in 2015 will increase more than 30% and in 2020, it will increase more than 60%. If government planned the emission control strategies then emission of both gases in 2015 will reduce to more than 10% and it will be reduce to some percentages.

2.5 Vehicular Pollution in India: A Research Review

General Finite Line Source Model (GFLSM) was developed by **Luhar and Patil (1989)**. This model was based on Gaussian diffusion equation. This model overcomes the infinite line source constraint of the GM model. The utility of this model is to handle the all orientations of wind direction with road. The usefulness of this model is to predict the long term concentration of pollutants and the modified GFLSM can predict the concentration of particulate matter near the near roadway.

Srivastava *et al.* (1995) have developed predictive models for NH-58 to correlate various traffic flow parameters with various air pollutants using regression analysis. Emission factors were also suggested for various pollutants in terms of graph showing variations of pollutant concentration with speed and volume.

Jain and Gupta (1996) studied the environmental impact of highway projects and its control in Delhi city. Goyal and Ramakrishna (1998) studied the four different methods of source estimation of vehicular traffic and tried to determine the most appropriate method to estimate the emission rate of air pollutants from vehicular traffic. They evaluated these different methods by means of an air quality model, IIT Line Source Model (developed by Goyal *et al.*, 1995). They acquired the ground level NO_2 concentration by using IITLS model and calculate the emission rate with the help of different methods. In addition to this they also compared the IITLS model's prediction with the observed concentration of NO_2 in Delhi. On the basis of the above study they conclude that first three methods of emission estimation are in harmony with observed levels and also well corrected.

Sivacoumar and Thansekaran (1999) have attempted to identify the mathematical model that could be most useful to predict the pollution concentrations near roadways. It is observed that the performance of GFLSM was good and can be conveniently applied when the road is finite in length.

Dewan *et al.* (2001) have presented a critical analysis of transport related air pollution for the city of Delhi. The various effects of traffic air emission on life and various suggestions for control have also been given. **Nagendra and Khare (2002)** focused the use of Line Source Emission Models in the study of vehicular exhaust emissions and favored the Line source Emission Modeling (LSEM) as a useful tool for the prediction of urban air quality.

Singh *et al.* (1990) proposed an IITCO analytical dispersion model for computing CO concentration for heterogeneous traffic. **Sharma and Khare (2001a)** performed a detailed review on analytical modeling techniques, including deterministic and statistical modeling approach in the area of vehicular exhaust emissions. **Sharma and Khare (2001b)** proposed a stochastic model to estimate the CO concentration for Delhi heterogeneous traffic conditions.

Nagendra and Khare (2004) proposed one-hour average artificial neural network based CO models for two air quality control regions in Delhi city namely a traffic intersection and an arterial road. The study illustrates that the neural network models are proficient to elucidate the consequences of traffic wake on the CO dispersion in the near field regions of the roadway.

Ahmad *et al.* (2004) studied air quality at seven locations in the Haridwar district in terms of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), suspended particuale matter (SPM) and the respirable suspended particuale matter (RSPM). Prediction of these pollutants has been done by using GFLSM and CALINE-4 model. The performance of GFLSM is found better than CALINE-4 model. **Jain and Parida (2004)** have studied and analyse the different air pollutant concentrations and ambient noise levels in different cities like Delhi, Jaipur, Chandigarh, Allahabad and Lucknow.

Gokhale and Khare (2005) presented a hybrid model to forecast the CO concentration distribution at one of the intersections. The used model include two components, one GFLSM (General Finite Line Source Model) as deterministic component and other one is LLD (Log Logistic Distribution) model as statistical component. They employed this model at ITO intersection in Delhi. On the basis of their study and validation of model they concluded that the performance of the developed model is fairly well in 10-95 percentile range and thus the hybrid model exhibits intrinsic suppleness in the modeling implementation and its consistent prophecy precision.

Singh *et al.* (2007) also applied General Finite Line Source Model for the prediction of sulphur dioxide of vehicular exhaust and found its better performance in comparison to General Motor Model.

Sharma *et al.* (2008) reviewed different research papers related to road transport and their impact on the environment in Indian perspective. From their study, it is concluded that there is a requirement of comprehensive environmental management policy to minimize the adverse environmental impacts arising out of road transport activities and to achieve the objective of sustainable mobility.

Gokhale and Raokhande (2008) evaluated the air quality at one of the busiest traffic intersections in the city of Guwahati by using modified General Finite Line Source Model of particulates, the California Line Source model and the California Line Source for Queuing & Hot Spot Calculations. These models have been evaluated statistically with the vehicle-derived airborne particulate mass emissions in two sizes, i.e. PM10 and PM2.5. The study revealed that the CAL3QHC model would make better predictions compared to other models for varied meteorology and traffic conditions. Other two models have also outperformed for a class of wind speed velocities except for low winds (b1ms−1), for which, the modified General Finite Line Source Model has shown the tendency of better performance for PM10.

Sharma *et al.* (2010) analyzed the vehicular traffic emissions i.e. black carbon aerosol mass concentration, trace gases and ground reaching solar radiation during nationwide truck strike of 5–12 January, 2009 over urban environment of Hyderabad, India. A significant reduction of about 57%, 60%, 40% and 50% was found in black carbon, particulate matter, carbon monoxide and ozone respectively during that period. The study indicated considerable influence of emissions from trucks operating on diesel fuel. Effective management of these vehicles with fuel-efficient engines holds key for improving air quality in this urban region.

2.6 Research Review on Application of KM in Transport Related Problems

Due to globalization, the local environmental problems have changed into international environmental pollution issue. Environmental problems have now become some of the most important issues worldwide. The idea of knowledge-based systems was developed at the end of the 1970. Today, it is important to develop knowledge management tools to support the analysis of transport infrastructure. Therefore, it is necessary to develop a knowledge based system which can ease the traffic congestions problem in urban cities and ultimately helpful in the reduction of environmental problems and travel time. In present time the balance between the sustainable transportation and traffic congestion is a big challenge to the developers and operators of the urban transportation network. Therefore, in the solution of this problem, the cost-benefit analysis has also flourished and is becoming an important tool in the process of decision-making (**El-Diraby *et al.*, 2005**). Centre for Sustainable Transport (**CST, 2004**) defines the sustainable transportation –

(i) allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health and with equity within and between generations

(ii) is affordable, operates efficiently, offers choice of transport mode and supports a vibrant economy

(iii) limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources and minimizes the use of land and the generation of noise.

After the emergence of knowledge based system concept, many other applications came in picture like DENDRAL (**Lindsay *et al.*, 1981**), MYCIN (**Buchanan and Shortliffe, 1984**), and PROSPECTOR (**Duda *et al.*, 1979**). With the help of the application of knowledge oriented approach, the users can get the explanatory answer of his question from the system. Thus the user can understood the role played by different pieces of domain knowledge existing in the particular model, which will be helpful for him to implement any action regarding that particular traffic problem.

Oprea (2005) described the way in which knowledge from the air pollution domain was modeled in a decision support system that uses an expert system, DIAGNOZA_MEDIU, a prototype expert system for air pollution risk analysis. He developed ontology for air pollution control as well as the knowledge base for the application domain. A knowledge-based approach can reduce the high complexity of making decisions in air pollution control by structuring and integrating the various sources of knowledge in a knowledge base. A knowledge-based approach offers an alternative to the mathematical models, integrating multiple sources of knowledge in a knowledge base used by an inference engine that can deal with uncertainty. The air pollution control activity of an environmental protection institution could be assisted by a decision support system (DSS) that analyses the state of air pollution in a given area and provides solutions for emissions reduction. Figure 2.1 presents the air pollution control as a feedback from the decision factors to the atmospheric environment. The main pollution sources in urban regions are industry, motor vehicles, and domestic sources. The state of air pollution is measured and observed by the local environmental institutions that collect data in their databases (DB) and use them for analysis and control, informing the decision factors to take specific countermeasures for emissions reduction.

The main purpose of DIAGNOZA_MEDIU is to provide the state of air pollution, given the sites with possible air pollution risk and to give solutions for preventing such situations. Figure 2.2 presents the general architecture of the Air Pollution Ontology Module (APOM) that is included in the prototype expert system, DIAGNOZA_MEDIU. A preliminary version of the AIR POLLUTION ontology was implemented in Protégé, and integrated in the knowledge base of the prototype expert system DIAGNOZA_MEDIU. The decision support system uses an expert system that has the knowledge structured in a knowledge base (KB) which is composed by a rule base (RB) and a fact base (FB). The databases with emissions measurements are time series data and they were used to derive forecasting knowledge with a Feed Forward Artificial Neural Network (FF-ANN). The databases with the national and international air quality standards were used to derive rules that check the concentration level of each air pollutant according to its standard level. Figure 2.3 presents the structure of the knowledge base and the main sources for knowledge acquisition. APOM, the AIR POLLUTION Ontology Module was included in the KB structure.

The rule base contains behavior rules, control rules, decision rules and heuristic rules. The facts base was divided in two parts: the permanent facts base which contains the thresholds values for each air pollutant and other permanent facts like regarding the meteorological thresholds for different parameters and the temporary facts base which contains the context of the current analysis of air pollution. The facts base contains the facts that are taken from the databases of the monitoring systems (environmental and meteorological) and the predictive facts. From the study it is found, with the help of knowledge-based decision support system, it is possible to improve the air quality in urban regions.

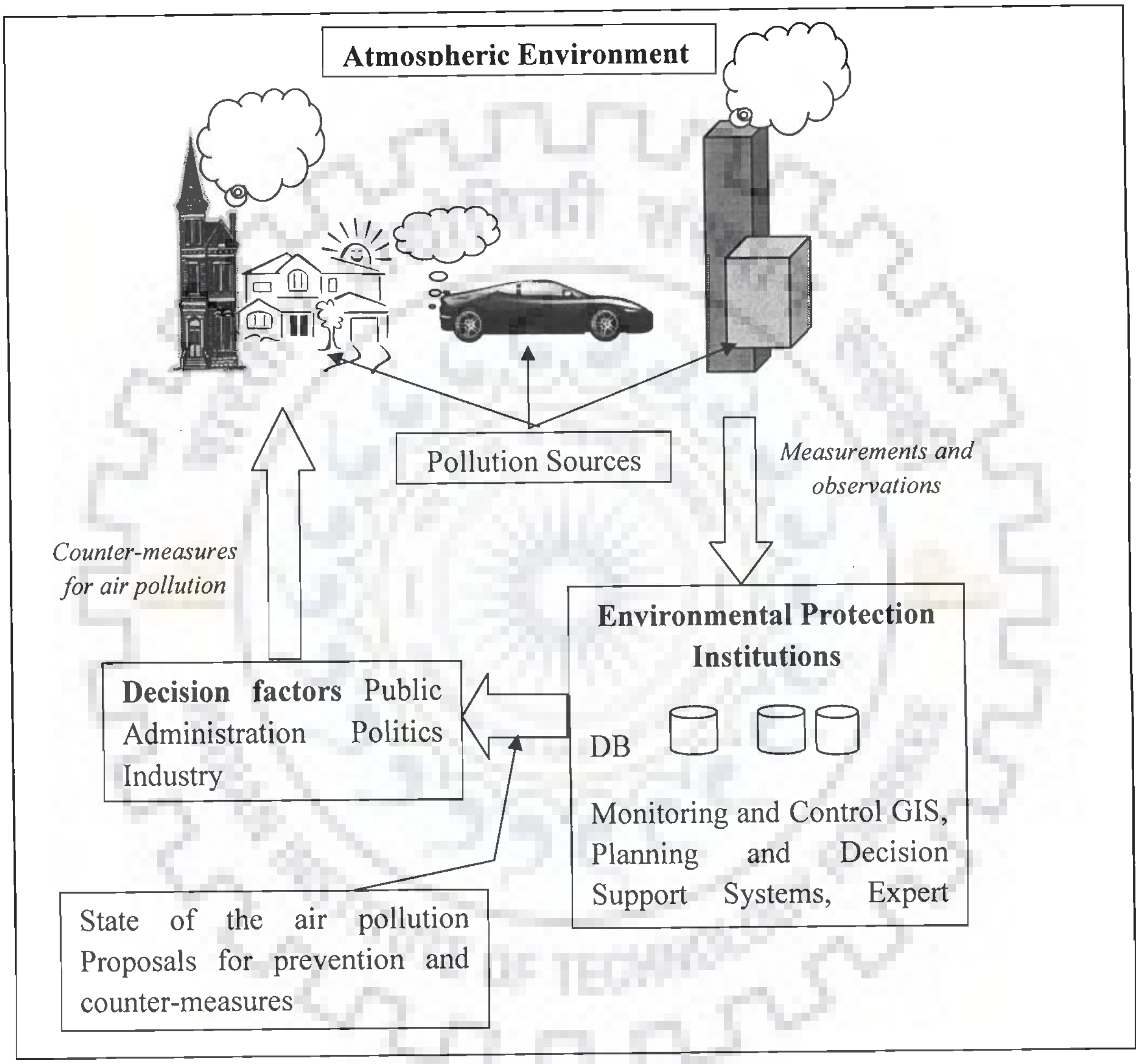


Figure 2.1: Air Pollution Control – Feedback from Decision Factors to the Atmospheric Environment

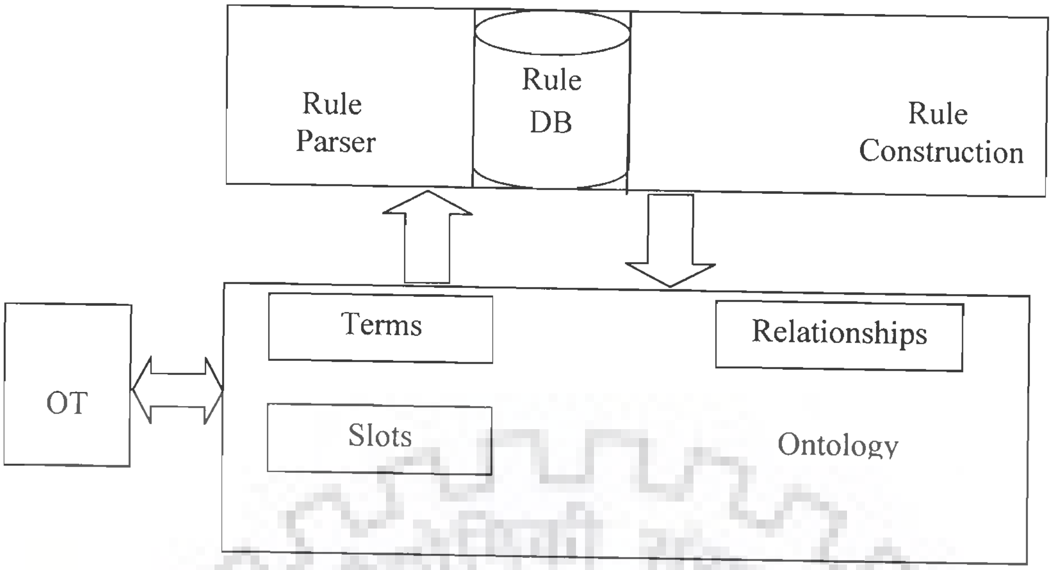


Figure 2.2: AIR POLLUTION Ontology Module

Rubenstein (2000) suggests means for improving the effectiveness of urban information systems. This is accomplished by shifting emphasis from the computerized tools developed to support urban planning to true urban knowledge systems. Such systems are designed within the context of knowledge management where the technical, computerized aspects of the systems comprise one attribute among many integrated factors for providing urban planning support. Montano asserted that the emphasis on formalized information is insufficient for truly effective urban information systems. Findings from the emerging field of knowledge management will be used to support this claim. In fact, a shift from urban information systems to urban knowledge systems is warranted based on the ideas behind knowledge management. He reviewed existing urban information systems with an emphasis on knowledge-based systems. Knowledge management in urban planning has also been presented including an examination of systems thinking due to its relevancy of knowledge management. Along with this a comprehensive knowledge management framework for urban planning has been designed. This framework shows particular promise for improving planning activities because of the people-oriented focus and variable nature of most urban planning initiatives. Public planning is typically characterized by social/political issues and objectives as well as interpersonal activities. It is found that the cultural factors influences the knowledge management and plays very important role in planning activities

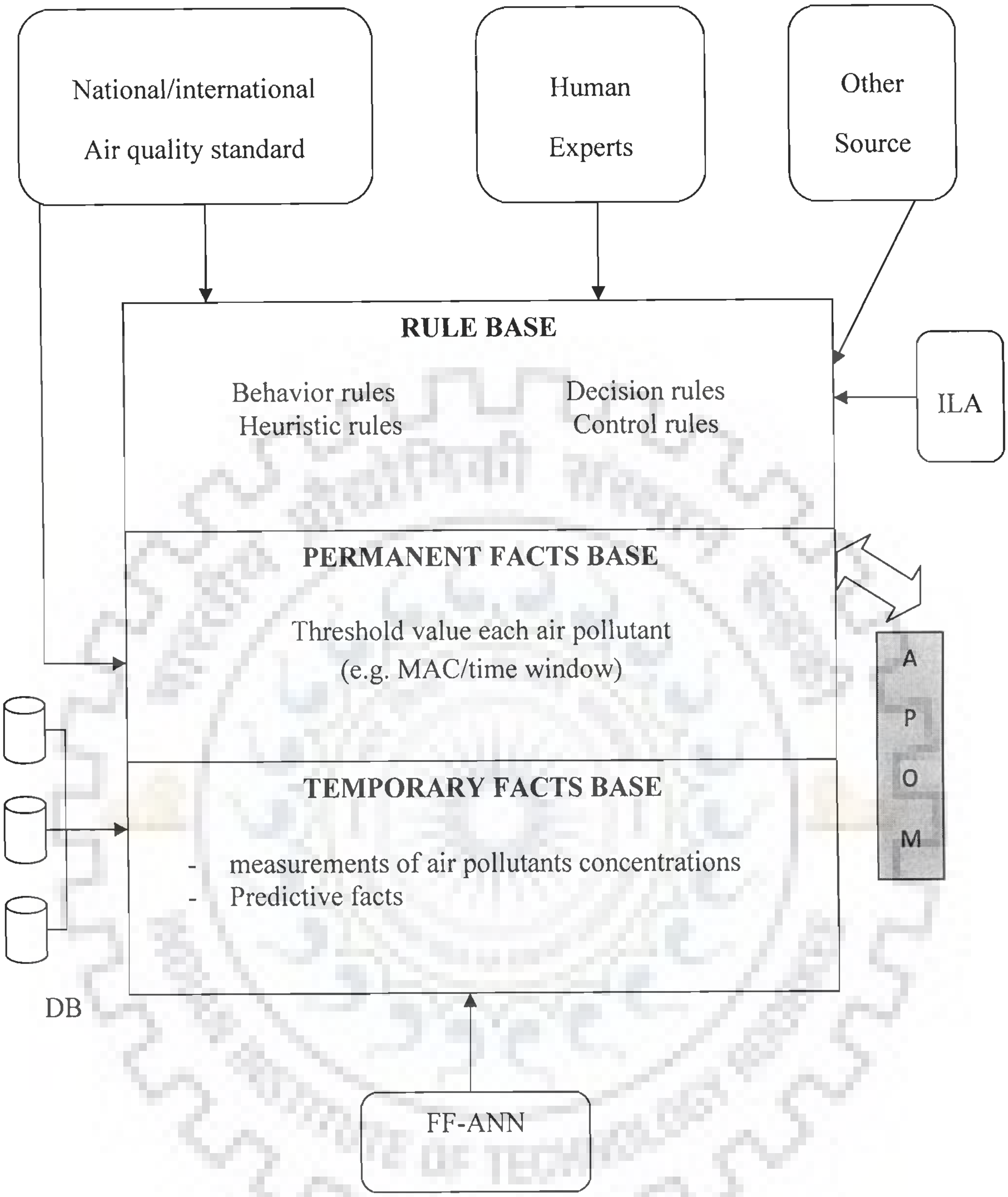


Figure 2.3: The Structure of Knowledge Base

A variety of computerized tools have been used for urban planning. **Han and Kim (1989)** term these systems Urban Information Systems (UIS) and classified UIS in a manner consistent with their decision support nature Decision Support Systems (DSS), Group Decision Support Systems (GDSS), Spatial Decision Support Systems (SDSS), Expert Systems (ES) and Knowledge-Based Decision Support Systems (KBDSS). The geographical nature of urban planning continues to stimulate the development of SDSS, especially those employing a geographic information system as the model base. SDSS and KBDSS tools have also been integrated as hybrid tools (**Klungboonkrong & Taylor, 1998; Mitrovic *et al.*, 1994**). Table 2.1 provides a sampling of recent knowledge-based Urban Information System.

KBDSS is a hybrid tool that implements several approaches to decision support, is most appropriate for complex problem (**Zadeh, 1994**). **Rubenstein and Zandi (1999)** have designed a hybrid KBDSS that employs a genetic algorithm, simulation modelling and the analytic hierarchy process (AHP). Both screening and prioritizing alternatives are important mechanisms for allowing decision makers to represent the social, political, environmental and economic interests of stakeholders not directly involved in decision making (**Anandalingam and Olsson, 1989**). Figure 2.4 depicts the schema of the KBDSS.

Table 2.1: Examples of Knowledge-Based Urban Information Systems

Developer (s)	Computational technique*	Description
Amin, Rodin, Liu & Rink (1998)	ANN	Traffic prediction
Erikson	Classifier system	Spatial data classification
Esposito & Lanza (1996)	Evolutionary computation	Land use
Feng & Xu (1997)	ANN	General urban planning
Feng & Xu (1999)	ANN, fuzzy logic	General urban planning
Ferraris (1995)	Intelligent agents	Transportation planning (road management)
Klungboonkrong & Taylor (1998)	Rule based reasoning, GIS, fuzzy logic	Transportation planning
Lin & Malasri (1994)	Evolutionary computation	Solid waste management: solid waste collection
Mitrovic, Radenkovic & Mitrovic (1994)	GIS	General urban planning and spatial analysis
Murnion (1996)	ANN	Spatial analysis (land use planning)
Park & Yang (1994)	ANN	Transportation planning (traffic control)
Roadknight, Balls, Mills & Palmer-Brown (1997)	ANN	Modeling environmental data
Rodrigue (1997)	ANN	Land use modeling (including transportation planning)
Rolland-May (1991)	Fuzzy logic	Spatial planning
Rubenstein-Montano & Zandi (1999)	Evolutionary computation	Solid waste management (policy planning)
Sarne & Postorino (1994)	ANN	Transportation planning (traffic flow)
Wu (1996)	Fuzzy logic	Sustainable development (interface between rural and urban land uses)

ANN, artificial neural network; GIS, geographical information system

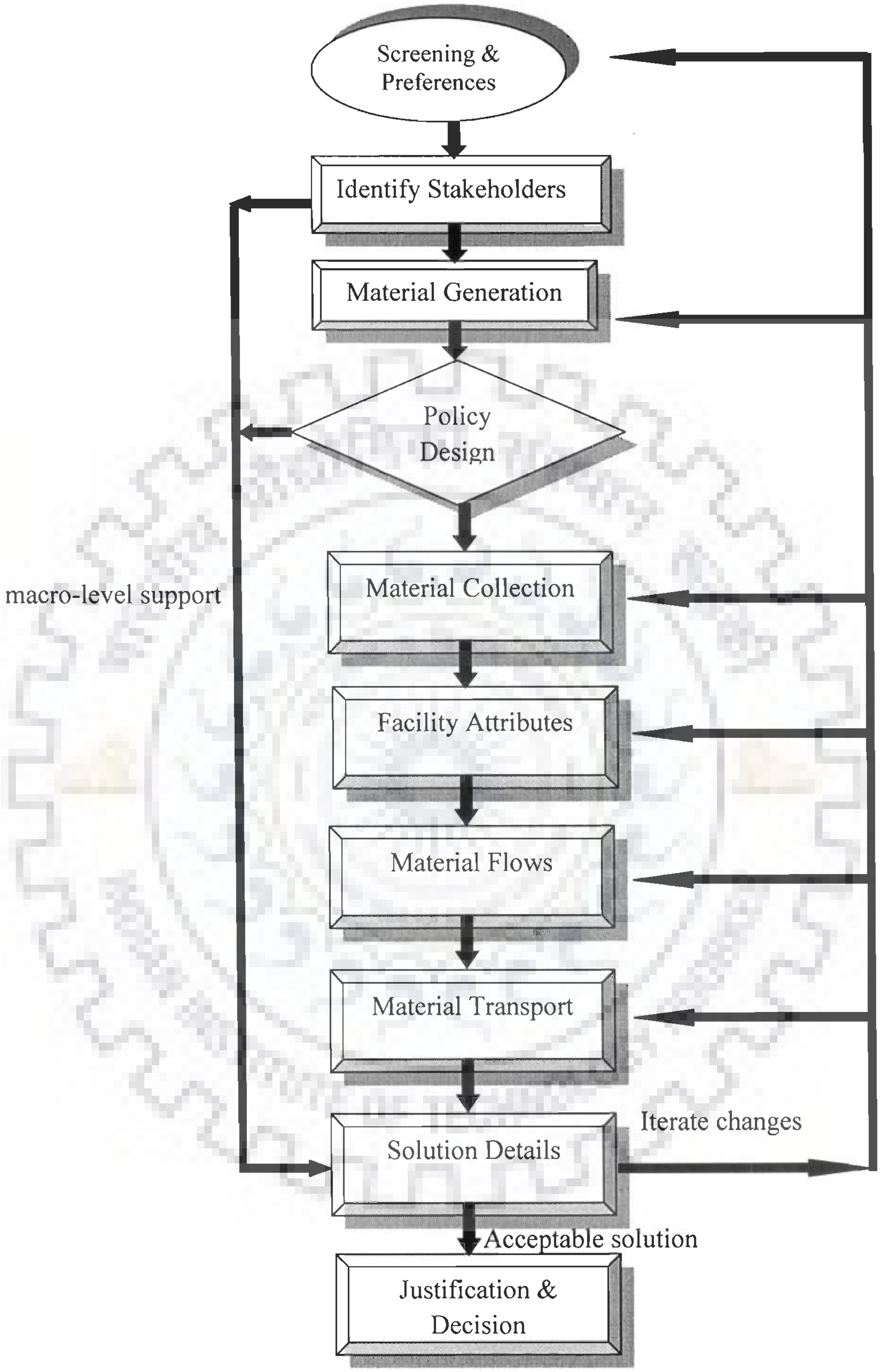


Figure 2.4: Schema of a Knowledge-Based Decision Support System (KBDSS) for Solid Waste Management

Zinn (1993) asserted that existing UIS have yet to achieve their intended purpose of supporting the planning process. Two suggested ions derive from these findings: first to develop UIS within the context of systems thinking; and second to develop UIS consistent with the principles of knowledge management. Figure 2.5 illustrates the shift towards urban knowledge systems. Essentially, such systems are characterized by handling increasingly complex problems and including systems thinking and knowledge management principles to a greater degree than other approaches to decision support.

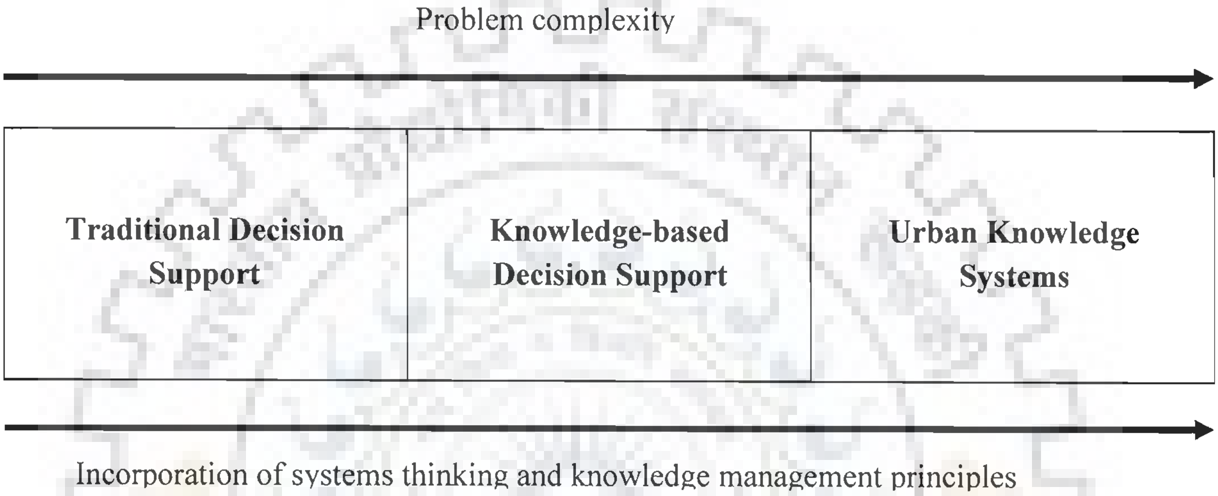


Figure 2.5: Taxonomy of Decision Support for Urban Systems

The arrows indicate increasing levels of problem complexity and systems thinking and knowledge management principles. The levels can range from "little, if any" to "very high". Tacit knowledge is ultimate and key component required for shifting the KBDSS to an Urban Knowledge System (UKS). It is related to cultural attributes in that it is distinct from the technological infra structure. Because tacit knowledge is difficult to express, it is also difficult to capture and distribute for use by others. Currently, story telling (**Snowden, 1999**) and best practices databases **(Niemyjski and Wolford, 1999**) are two of the more common methods for sharing tacit knowledge. Figure 2.6 illustrates the taxonomy of support tools within the context of knowledge modelling.

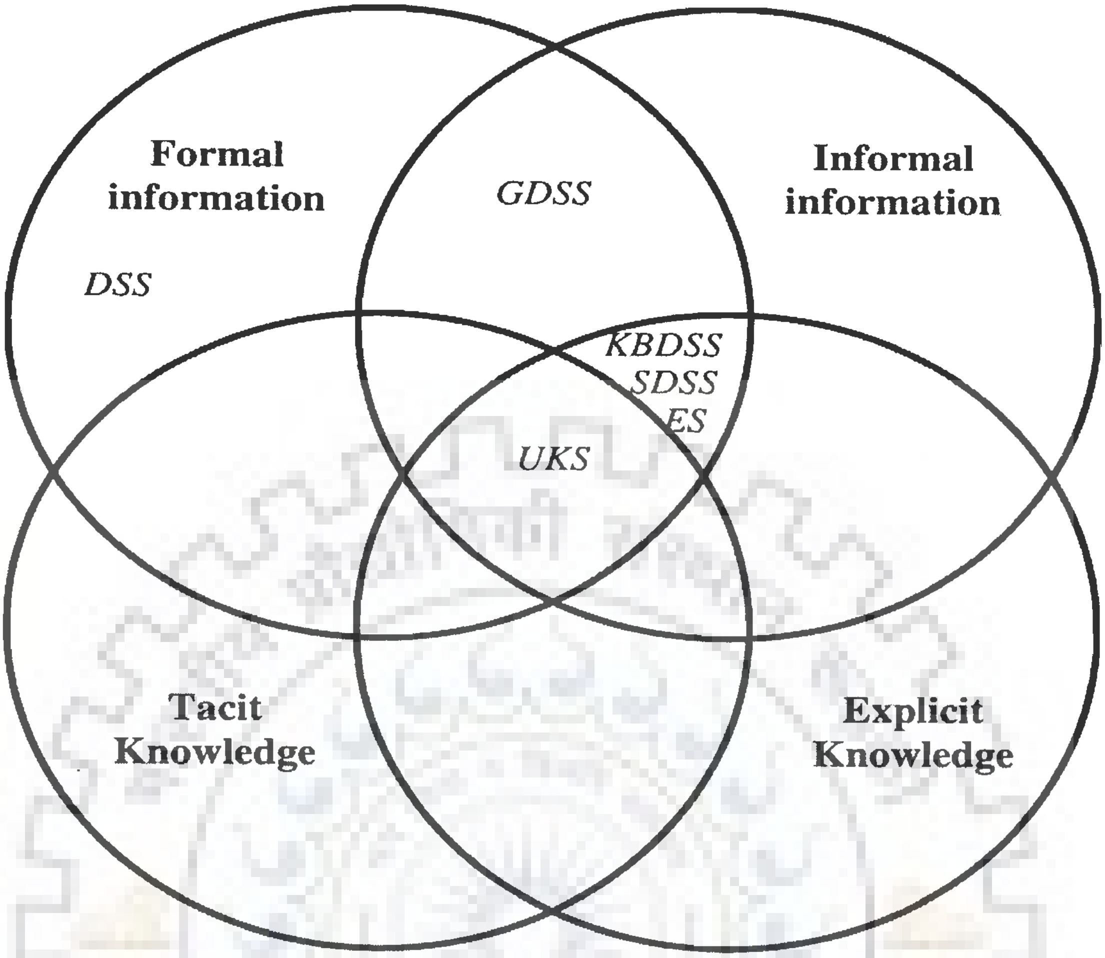


Figure 2.6: Decision Support Tools in Knowledge Modelling

The circles represent different types of information and knowledge to be modelled. The tools are shown in the circle (or intersection of multiple circles) that correspond to the type of knowledge that can be handled by the particular tool i.e. Decision Support System (DSS); Group Decision Support System (GDSS); Knowledge-Based Decision Support System (KBDSS); Spatial Decision Support System (SDSS); Expert System (ES) and Urban Knowledge System (UKS).

Cheung *et al.* (2007) presented a systematic approach for knowledge auditing which is composed of a number of stages (orientation and background study, cultural assessment, in-depth investigation, building knowledge inventory and knowledge mapping, knowledge network analysis and social network analysis, recommendation of knowledge management strategy, deploying KM tools and building collaborative culture and continuous knowledge re-auditing) with the focus on the establishment of an overall framework and customized tools for knowledge auditing has been used in transportation sector i.e. railway company.

The results revealed that the systematic knowledge auditing approach yields a number of potential benefits that include the identification of the critical knowledge and the subsequent recommendations of KM strategy that can be used for better managing the knowledge of business process in the railway company.

Cortés *et al.* (2001) discussed environmental decision support systems. On the basis of study, they concluded that EDSS tools can be used to understand the environment and to design the development of societies to be sustainable.

Sveiby and Simons (2002) suggested that collaborative climate is one of the major factors influencing the effectiveness of knowledge. Collaborative climate depends on age, gender, education, size, power position, distance and type of organization. Human infrastructure has also been proposed for knowledge sharing and knowledge creation. In this paper, it is found that collaborative climate in the private sector is generally better than in the public sector. **Ventre and Case (1971)** suggested various non KM and KM practices to control noise pollution. The non KM practices are:

- The public, manufacturers and policy makers should be educated concerning noise as an annoyance, a health hazard and, more generally, as an environmental pollutant.
- Pollution control administrators should be established at the local, regional and state levels and should focus attention on environmental pollution, including noise pollution.
- Placing more significance on noise as a design constraint in transportation systems planning

The KM practices having the potential to reduce transportation noise or its effects include:

- incorporating acoustical insulation requirements in building codes
- adding acoustical treatment to existing hospitals, schools and other noise-sensitive structures that are found to be in need of such soundproofing

Ossowski *et al.* (2005) designed a method for the construction of agent-based Decision Support System (DSS). Setting out from an organizational and communicative model of decision support environments, an abstract architecture for multiagent DSS had been presented by them. They presented how the architecture is instantiated for real-world problems by means of two prototypes for transportation management. They implemented DSS prototypes for the problems of road traffic management in the greater Bilbao area, as well as bus fleet management scenarios pertaining to the Spanish town of Malaga. DSS provide assistance to humans involved in complex decision making processes. Early DSS were conceived as simple databases for storing and retrieving decision-relevant information. After some attempts at improving the organization and presentations of such data by means of additional deductive facilities, it soon became apparent that the key problem for a decision-maker (DM) is not much has to access pertinent data but rather to understand its significance. The fundamental task for modern DSS is to help decision-makers (DMs) to build up and explore the implications of their judgements and then take decisions based on understanding. Knowledge-based DSS are particularly relevant in domains where human operators have to take operational decisions in a continuous and recurrent manner. This is the case of DMs (often also called operators) that need to manage complex environmental or industrial processes. DSS are becoming particularly relevant as traffic networks and demands grow, giving rise to increasing volumes of decision-relevant data and a decreasing time horizon for effective management decisions.

Air pollution is an environmental problem of great importance for each city as well as for the whole nature. Growth of motor vehicles and industry in regions has contributed to aggravation of the situation during the last year. The pollutants emission influences air quality very significantly. The deterioration of air quality causes susceptibility to lung infections and respiratory diseases of population in the regions. Motor vehicles and industry cause air pollution which depends on different types of cars and industry emission, on geographical location, meteorological conditions such as temperature, wind, and other factors.

Frankovič *et al.* (2004) presented an ontological approach to create air pollution control knowledge base. The main advantage of ontology utilization is that the created ontology can be reused in many similar application areas and for solution of other environmental problems. The main reasons behind the use of this approach for air pollution control systems is that a symbolic knowledge-base can express the domain expert′s knowledge without the risk that the implicit knowledge will be lost in a huge amount of available historical data. The problem of air pollution control is highly distributed. Due to the involvement of several monitoring stations from different regions, there were a lot of redundancies. The information collected was noisy and imprecise. Constructing ontology helps overcome some problems connected with the above-mentioned aspects. The air quality management systems consist of environmental models and modules for data management and processing and problem solving components. A knowledge-based approach offers an alternative to the numerical models, integrating multiple sources of knowledge in a knowledge base used by an inference engine that can deal with uncertainty. Using an ontology approach, a coherent, consistent and non-redundant knowledge base may be designed.

The domain of traffic management has experienced a significant demand of advanced information technology. Control centers for traffic management are on-line connected to different devices like detectors on roads, cameras, traffic lights, etc., making possible that operators supervise the state of the road by consulting data bases with recent information from detectors and modify the state of control devices. The use of these traffic monitoring and management facilities requires sophisticated support tools for on-line operators, to help them in dealing with the information complexity and diversity of sensors and control devices.

Figure 2.7 shows the typical information infrastructure for real-time traffic control that can be found in different cities. There are sensors on major roads recording several traffic magnitudes such as speed (km/h), flow (vehicle/h) and occupancy. The distance between successive sensors on a freeway is usually about 500 meters. This information arrives periodically to the control centre in every minute. The control centre receives information about the current state of control devices. Control devices include traffic signals at intersections, traffic signals at sideways entry-ramps, variable message signs (VMS) that can display different messages to drivers (like warning about existing congestions or alternative path recommendation), radio advisory systems to broadcast messages to drivers and reversible lanes i.e. freeway lanes whose direction can be selected according to the current and expected traffic demand. In the control centre, operators interpret sensor data and detect the presence of problems and their possible causes. Problems are congested areas at certain locations caused by lack of capacity due to accidents, excess of demand like rush hours etc. In addition to this operators determine control actions to solve or reduce the severity of existing problems. For instance, they can recommend increasing the duration of a phase at a traffic signal, or they may suggest displaying certain messages on some VMSs to divert traffic.

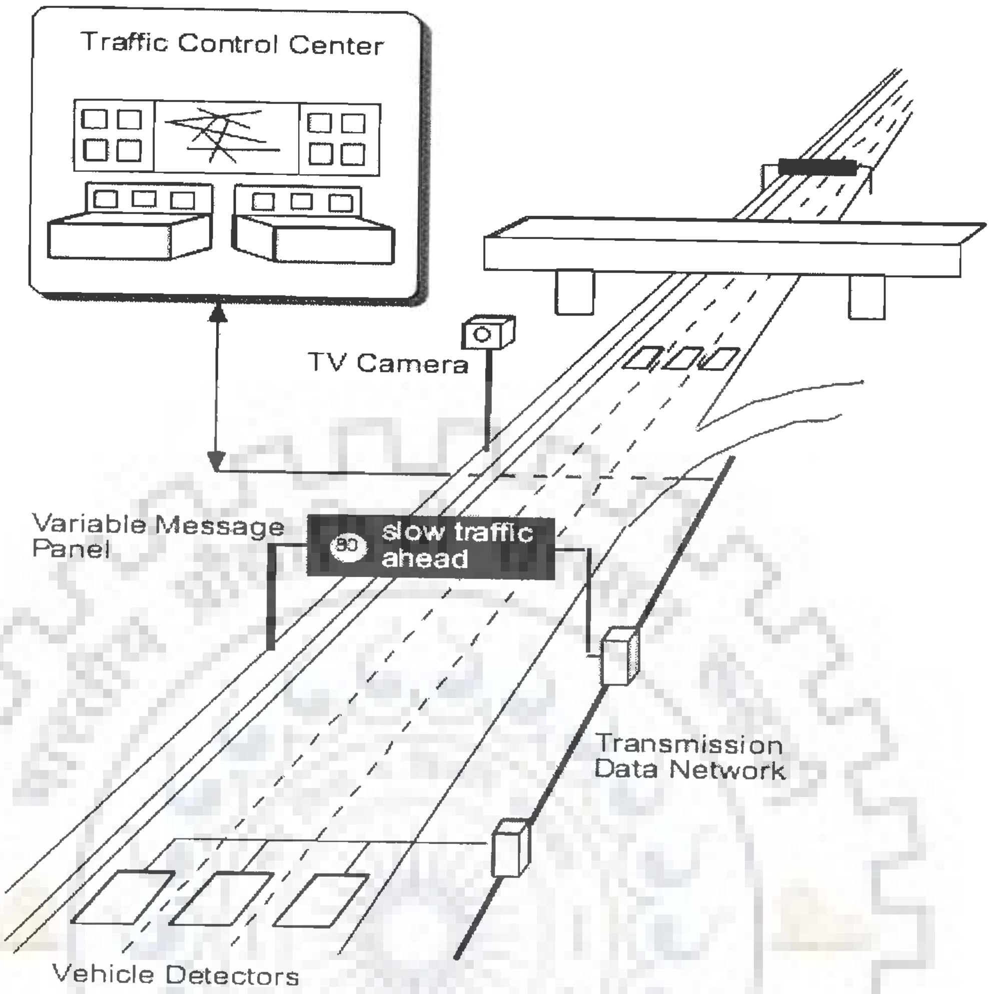


Figure 2.7: Typical Information Infrastructure for Real-Time Traffic Control

A real-time decision support tool that helps operators in detecting traffic problems and choosing appropriate control actions to generate information to satisfy three types of queries (**Cuena *et al.*, 1996**) i.e. what kind of problem in currently occurring in traffic network, what type of pertinent events may occur in the future if some exterior conditions change according to assured hypothesis and finally what type of control actions should be applied in order to improve the current traffic state. In the 1980's more adaptive system was introduced i.e. SCOOT (**Hunt *et al.*, 1981**) where intelligence for understanding traffic situations in real time was designed and integrated with a model for decision making. **Hernández *et al.* (1999)** presented an approach for real time traffic management using knowledge-based models named TRYS. It is a knowledge representation environment supporting models to perform traffic management at a strategic level in urban, interurban and mixed areas. There is a need to apply the current automatic traffic control systems to overcome various traffic related problems. For this, it is required an additional intelligent layer to help operators to understand traffic problems and to make the best choice of strategic control actions. The need for an open architecture is stated, in order to allow users to modify decision criteria according to their experience. The TRYS model was applied to develop several urban motorway control systems installed in the traffic control centers of different Spanish cities. With the help of TRYS, it has been proved that knowledge based models designed for on-line use can be developed to be integrated as components of advanced Traffic Control Centers (TCCs) in order to improve traffic monitoring and management capabilities of current traffic control system. The models identified an additional strategic level in current TCCs, a traffic knowledge processing layer developed on top of the available traffic control facilities. This layer allows the development and use of models of knowledge and expertise of traffic operators in controlled area, providing additional traffic analysis and management criteria that can complement currently applied, optimization-based automatic traffic control. TRYS has been developed as a modelling environment to support development and application of knowledge based models for network management. This model provides traffic monitoring functions and control actions.

Huag *et al.* (2009) conducted an interview of managers and engineers and by the application of environmental knowledge circulation process; they evaluated the success of environmental knowledge management in China Steel Corporation, Taiwan. From the study it is found that company continually improves its environmental and financial performance through environmental knowledge creation, environmental knowledge accumulation, environmental knowledge sharing, environmental knowledge utilization and environmental knowledge internalization. In addition to this, water pollution and air emissions have also reduced year on year and total energy consumption has reduced by 20 % from 1979 to 2006. On the other hand, China Steel Corporation also makes a profit and reduces cost through energy sold, by-products and recycling.

Maisonneuve *et al.* (2010) presented a novel approach to monitor noise pollution involving the general public. They provided a low cost solution (Noise Tube) for the citizens to measure their personal exposure to noise in their everyday environment and participate in the creation of collective noise maps by sharing their geo-localized and annotated measurements with the community. The aim of this approach was to develop a participative noise pollution monitoring platform to enable citizens as well as governmental bodies and non-governmental organizations to gain awareness and insight into the problem of urban noise pollution. This approach allowed the empowerment of citizens in the pollution assessment by raising awareness about their environmental conditions through the use of their mobile phones. As a new source of information, Noise Tube goes beyond traditional noise maps due to the new nature of the collected data – real, local and personal exposure measurements with additional semantic information by highlighting factors outside the scope of a simulation-based noise map.

Cuena *et al.* (1995, 1996) described a TRYS approach for real time traffic management support using knowledge based models. The technology of knowledge-based systems may help in designing and implementing suitable knowledge structures to formulate conceptual models for traffic analysis and management and for on-line strategic traffic management operations. From the study, it is concluded that such an approach is feasible, and is compatible with existing state of the art traffic control systems.

Kirschfink *et al.* (2000) presented an overview on intelligent management system for traffic control and coordination tasks. The concepts of Intelligent Traffic Management Systems (ITMS) were designed to act as intelligent assistants that cooperated with the traffic engineer in the task of defining and applying traffic management decisions. This management decision support took place on different management levels. On control level, ITMS support the operation of traffic control systems by a comprehensive analysis of the current and expected traffic situation. On management level, ITMS can support the decision makers to manage complex or intermodal traffic situations. The acquisition of the knowledge needed of decision support systems as well as the training of traffic engineers and traffic operators to handle such kind of systems.

Chen and Mohamed (2006) studied an empirical research investigation into the interaction between different KM activities within the context of construction contracting organizations. The different KM activities include: responsiveness to the knowledge of business environment, knowledge acquisition, knowledge dissemination, and knowledge application. A questionnaire survey was administered to investigate the opinions of construction professionals regarding the intensity of activities currently implemented by their organizations to facilitate knowledge capturing, sharing and application. A total of 149 responses were used to statistically examine the inter-relationships between the different KM activities as practiced by contracting organizations in Hong Kong. The empirical study reported revealed that the interactions between different categories of KM activities in construction organizations operating in Hong Kong were in line with the theoretical propositions. Knowledge acquisition and application play paramount roles in the development of the organizational knowledge asset; the higher level of these two types of activities creates a larger knowledge pool that demands greater knowledge dissemination capacity and also enables more active response to the knowledge in both the internal and external environment **(Nonaka and Takeuchi, 1995)**. For the moment, the greater dissemination capacity and more vigorous response to knowledge facilitate and stimulate acquisition and application of knowledge **(Gold *et al.*, 2001)**.

El-Diraby and Kashif (2005) discussed distributed ontology architecture for knowledge management in highway construction. The architecture was built as an extension to the e-COGNOS ontology. The architecture classified highway concepts into processes, projects, products, actors, resources, and technical topics. The ontology was developed using Web Ontology Language (OWL), which was designed as the main tool for enabling semantic web. This provided easier link to other domain ontologies. This was the first ontology that aimed at covering the whole highway construction domain. The ontology was developed in a distributed way to allow for future expansions and customization of its terms and relationships to suit proprietary data structure systems of each individual organization. In this regard, the proposed architecture allowed each organization to link its enterprise model directly to the concepts of the ontology. In addition to proposing a semantic knowledge representation model, the contribution of this research includes applications of such semantic systems in knowledge management. The research presented a system for integrating traffic management with highway construction as a means to illustrate the possible impacts of semantic knowledge representation. With highways being the backbone of all other infrastructure, the proposed architecture could act as the basis of infrastructure ontology. Like any theoretical modelling initiative, the proposed architecture is not the only way to model highway engineering and construction. The architecture was validated through input from domain experts.

A real-time Knowledge-Based System (KBS) for decision support to Traffic Operation personnel in the selection of integrated traffic control plans after the occurrence of non-recurring congestion has been presented by author **(Logi and Ritchie, 2001)**. In this paper, the ability of TCM (Traffic Congestion Manager) to cooperate with the operator has been discussed by handling different sources of input data and inferred knowledge. The paper has focused important features of the TCM approach:

- Data fusion provides the means for representing the different levels of reliability and uncertainty associated with different sources of data for a better understanding of existing traffic situations.
- The ability to present the operator with the characteristics of a traffic problem i.e. it's possible causes and its expected impact over traffic as well as probable relationships and effects with other parallel problems. This facilitates the process of understanding and acceptance of the solution suggested by Traffic Control Manager and its possible improvement by the operator.
- It is a procedure that estimates the future impacts of control solutions. This feature allows the system to determine the control plan that looks most promising based on currently available data and projected future traffic conditions. The continuous monitoring of the implemented plan allows the system to purify or amend such plan on the availability of new information or unexpected events.
- Compatibility criteria between problems, goals and control solutions are explicitly represented. This avoids the selection of conflicting strategies and control plans.

A TCM has been organised as a structured compilation of task-solving modules for the analysis of non-recurring congestion, the selection and implementation of integrated control plans for signal control and traffic diversion and the monitoring of the implemented response. Figure 2.8 depicts the internal structure of TCM.

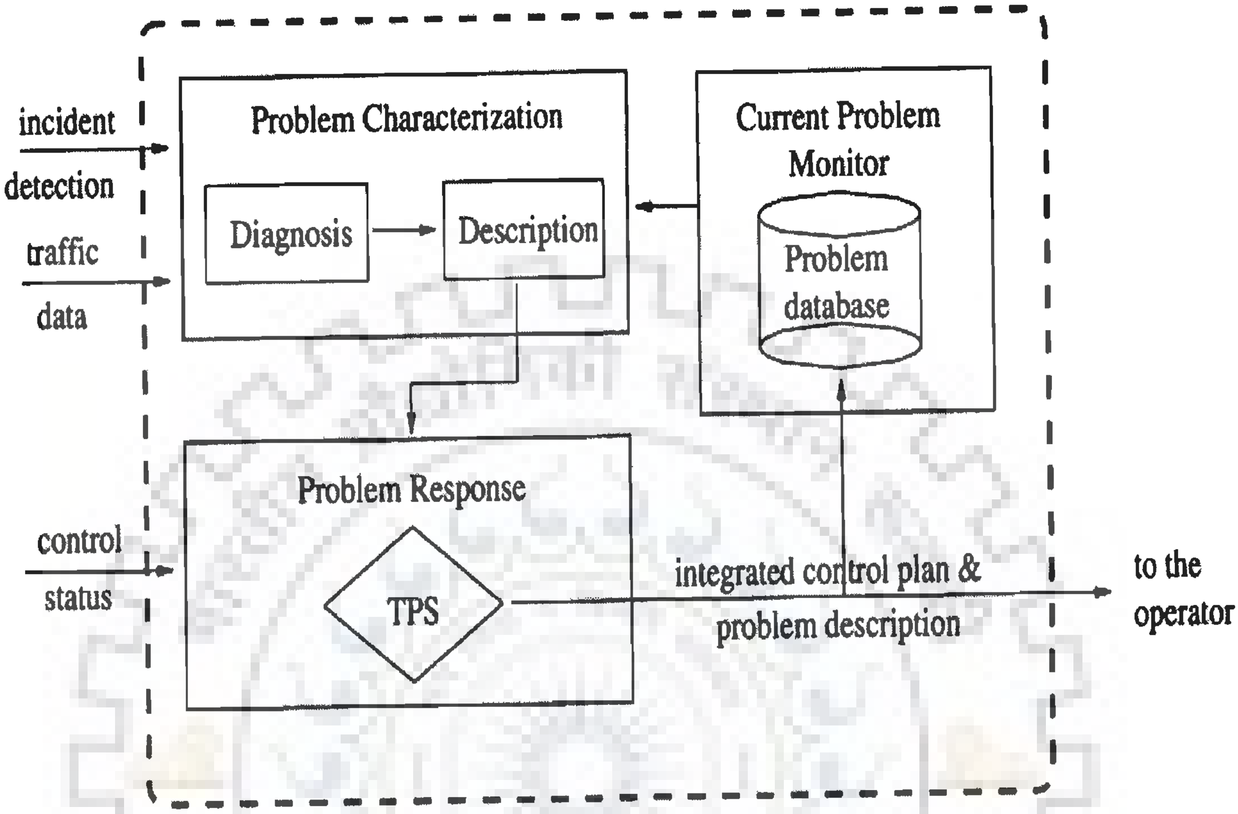


Figure 2.8: Internal Structure of TCM

TCM receives a real-time traffic data (volume, occupancy and speed) and control data from the Traffic Operations Center (TOC) data management system (Figure 2.9). It also has an interface to receive and process input data from external Automatic Incident Detection (AID) algorithm and to accept incident data and control acknowledgements from the operator via an interactive, user-friendly Graphical User Interface (GUI). The system continuously monitors the network state until one or more of the input data sources send an alarm. After that TCM starts a reasoning process that analyses the current and past network state and suggests a set of alternative control plans. The operator is able to select or edit the plan considered most effective using the explanation of the reasoning process and the assessment of the solutions expected benefits provided by TCM. The selected directives can be automatically transmitted to the traffic control system.

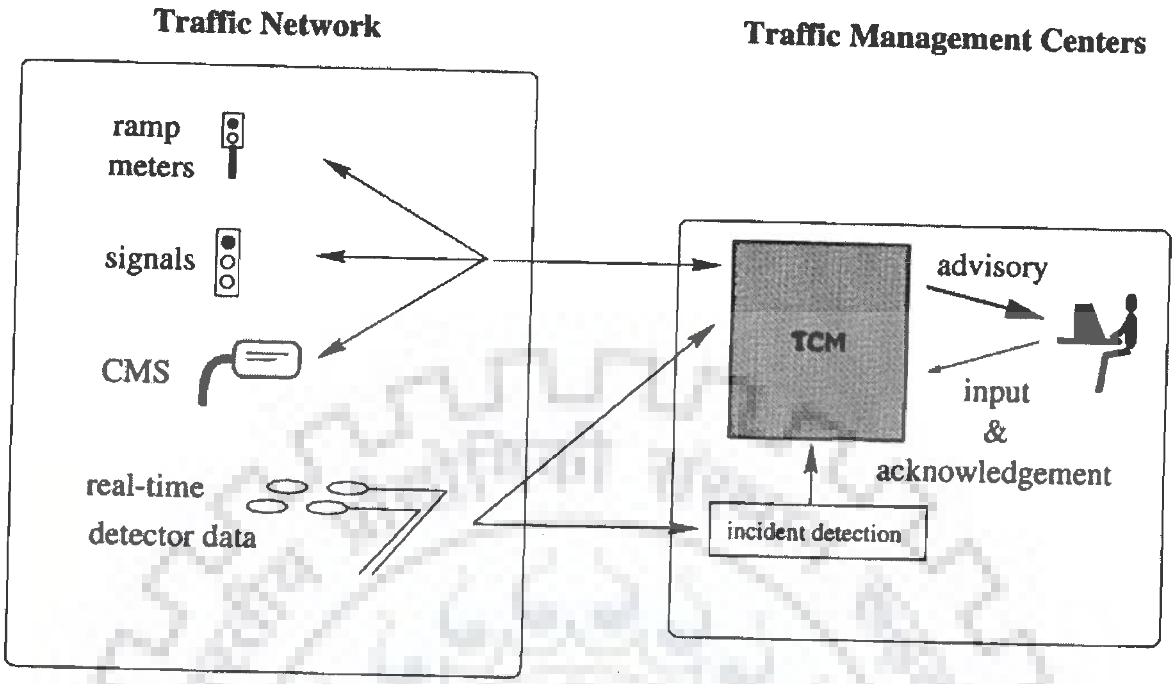


Figure 2.9: A Schematic Representation of Input and Output Configuration

TCM uses both heuristic knowledge and conventional algorithms for the estimation of delay and the expected congestion duration and estimates the time required for the dissipation of congestion. This time is known as recovery time interval, corresponds to the time during which TCM monitors the evolution of congestion. Unexpected events may occur during recovery time that are caused by or may affect the current control. When that occurs, the original problem is analysed once again and revised control plan may be submitted to the attention of the operator. The assessment of the results indicates the capability of TCM to reduce congestion through the formulation of traffic diversion and control schemes. Active control is performed by selecting plans for signalised intersections and metered freeway ramps. Traffic diversion is achieved through a sparse system of Changeable Message Signs (CMS).

Liyanage et al. (2009) proposed a process model for knowledge transfer in using theories relating knowledge communication and knowledge translation.

Mahdavi *et al.* (2010) also developed a KM based tool i.e. a simulation based DSS to facilitate decision making process in a stochastic flexible job shop manufacturing system.

Jeon *et al.* (2011) identified the factors and relationships that influence community of practice members' knowledge-sharing attitudes, intentions and behaviours. During the study, they employed Planned Behavior model, Motivation Theory and the Triandis model. For empirical validation, 282 responses from four Korean companies were collected. It is found that both extrinsic motivational and intrinsic motivational factors positively influenced attitude toward knowledge-sharing behaviors, intrinsic motivational factors are found more influential in this regard.

2.7 Summary

This chapter presents a comprehensive literature review on traffic noise pollution and its scenario in all over the world as well as in India. Along with noise pollution problem, vehicular emission and its related various literature have also been discussed in this chapter. Due to increasing problems of traffic related pollution, it is very essential to implement the environmental knowledge among people as well as current transport system. By keeping in view all these existing issues, different knowledge management practices and its application in transportation system have been covered by this chapter.

Chapter 3

TRANSPORT NOISE AND AIR POLLUTION MODELS

3.1 General

Vehicular traffic is one of the major sources, responsible for the deterioration and degradation of environmental quality in urban areas. Traffic noise and air pollution can be assessed either by monitoring or by modelling. Various noise and air pollution models have been developed and used in all over the world but limited works have been reported for Indian conditions with KM applications. A broad review of different traffic noise and air pollution models has been presented in this chapter.

3.2 Review of Traffic Noise Modelling

A number of road traffic noise models have been formulated through out the entire world. These models are differing from each other in some respects but overall the methodology is similar for the prediction of traffic noise. Noise production is reliant on a number of factors like vehicle speed, vehicle type, engine size, type of tier, type of road surface and the road geometry. It is essential to adopt algorithms based on statistical sound emission levels determined from a large number of field measurements. In most countries, the *A*-weighted energy equivalent level $L_{A,\,eq}$ is the preferred descriptor used to assess impact from traffic noise. All traffic noise forecast algorithms are essentially of the same form. The value $L_{A,\,eq}$ is determined from:

$$L_{A,\,eq} = L_0 + \Sigma L_i \quad \text{.... (3.1)}$$

where:

L_0 = basic sound level for a stream of vehicles under specific standard conditions

L_i = corrections to take into account the number of vehicles, type of vehicles (passenger, medium, heavy), reflections, road surface type, road gradient, speed, angle of view of the road, barriers, vegetation and the like.

3.2.1 The FHWA highway traffic noise prediction model

The Federal Highways Administration model (FHWA) is the US model. The Federal Highway Administration has developed a highway traffic noise prediction model for the prediction of traffic noise. It predicts the 1-hour average sound level for a flow of vehicles traveling along an infinitely long line. It calculates the noise level through a series of adjustments to a reference sound level. This is the energy mean emission level and can be decided through field measurements of the individual vehicle. The predicted level is the L_{eq} energy means emission sound level and is calculated individually for three different classes of vehicles: Road vehicles are acoustically grouped into five types

1. Automobiles (A): vehicles with two axles and four wheels, having weight less than 4500 kilograms.
2. Medium trucks (MT): vehicles with two axels and six wheels, having gross mass of more than 4500 kilograms and less than12000 kilograms.
3. Heavy trucks (HT): vehicles with three or more axles and having gross weight exceeding 12000 kilograms.

During the use of FHWA model, it requires

i. hourly flow rate for each type

ii. average operating speed of each vehicle type

iii. distance of the receiver from the road edge

The total hourly equivalent sound level is computed from the following equation-

$$L_{eq}(h) = 10 \log\left(10^{\frac{L_{eq}(h)_A}{10}} + 10^{\frac{L_{eq}(h)_{MT}}{10}} + 10^{\frac{L_{eq}(h)_{HT}}{10}}\right) \quad \text{.... (3.2)}$$

Where for each class of vehicle *i*, the hourly equivalent sound level is calculated from the following equation-

$$L_{eq}(h)_i = (L_0)E_i + \Delta_f + \Delta_d + \Delta_r + \Delta_s \quad \text{.... (3.3)}$$

here,

$(L_0)E_i$ is reference energy

Δ_f is the traffic flow adjustment

Δ_d is the distance adjustment

Δ_r is the finite roadway adjustment

Δ_s is the shielding adjustment

3.2.1.1 Reference energy mean emission level

The reference energy mean emission levels of the different category of vehicle can be calculated from the following equations:

i. Automobiles (A) $(L_0)_E = 38.11 \log V - 2.4$ .... (3.4)

ii. Medium trucks (MT) $(L_0)_E = 33.9 \log V + 16.4$ .... (3.5)

iii. Heavy trucks (HT) $(L_0)_E = 24.6 \log V + 38.5$ .... (3.6)

Here V is the average operating speed in km/hr.

3.2.1.2 Traffic flow adjustment

$(\Delta_{flow}) =$

$$10 \log \left(\frac{N_i \pi D_0}{S_i T}\right) = 10 \log \left(\frac{N_i D_0}{S_i}\right) - 25 \quad \text{.... (3.7)}$$

where,

N_i is the number of vehicles / hour in the i^{th} class

D_0 is the reference distance equal to 15 meters and

T is the reference time equal to 1 hour

3.2.1.3 Distance adjustment

It is equal to:

$$\Delta_d = 10 \log \left(\frac{D_0}{D}\right)^{1+\alpha} \quad \text{.... (3.8)}$$

where:

D = perpendicular distance between the centerline of the travel lane and the observer (D>15 meters).

But in case of roads with multiple lanes,

$$D_E = \sqrt{D_N D_F} \quad .... (3.9)$$

Here D_N and D_F are the perpendicular distance from the observer to the centerline of the nearest and farthest lane respectively.

α = site parameter and its value depend upon the following site conditions (Table 3.1):

Table 3.1: Selection of Distance Attenuation Parameter α

Site condition	Ground type	Value of α
All situations in which the source or receiver are located 3 m above the ground or whenever the line of sight averages more than 3 meters above the ground	Hard	0
All situations involving propagation over the top of a barrier 3 meters or more in height	Hard	0
Where the height of line of sight is less than 3 meters and there is clear view of the highway and the ground is hard and there are no intervening structures	Hard	0
Where the height of line of sight is less than 3 meters and the view of the highway is interrupted by isolated buildings and clumps of bushes, scattered trees or the intervening ground is soft or covered with vegetation	Soft	0.5

For the hard sites and infinitely long straight roads, the predicted noise level is:

$$L_{eq}(h)_A = 28.1\log S_A + 10\log N_A - 10\log D - 3.9 \quad .... (3.10)$$

$$L_{eq}(h)_{MT} = 23.9\log S_{MT} + 10\log N_{MT} - 10\log D + 14.9 \quad .... (3.11)$$

$$L_{eq}(h)_{HT} = 14.6\log S_{HT} + 10\log N_{HT} - 10\log D + 37.0 \quad .... (3.12)$$

For soft sites

$$L_{eq}(h)_A = 28.1\log S_A + 10\log N_A - 15\log D + 0.8 \quad \text{.... (3.13)}$$

$$L_{eq}(h)_{MT} = 23.9\log S_{MT} + 10\log N_{MT} - 15\log D + 19.6 \quad \text{.... (3.14)}$$

$$L_{eq}(h)_{HT} = 14.6\log S_{HT} + 10\log N_{HT} - 15\log D + 41.7 \quad \text{.... (3.15)}$$

3.2.1.4 Shielding adjustment

Shielding adjustment (Δ_s) is the barrier attenuation supplied by barriers, rows of houses, densely wooded areas etc. The adjustment for buildings depends on percent cover i.e. portion of the row occupied by buildings. The following adjustments are made (Table 3.2):

Table 3.2 Adjustments for Buildings

Row	Coverage (%)	Adjustment A_B (dB A)
First	<40	0
First	40 to 65	-3
First	65 to 90	-5
First	100	Use Fresnel theory
Additional rows		-1.5/row
Limit of total adjustment for coverage < 100%		-10

3.2.1.4.1 Woods

In case of very dense woods and if the height of trees extends at least 5 meters above the line of sight and the wooded distance is greater than 30 meters, then 5 dB (A) attenuation per 30 meters length of woods is provided up to a maximum of 10 dB (A).

3.2.1.4.2 Rows of Buildings

Attenuation is a function of the built-up density précised by the fraction built or screened along the road. For the first row of houses, the excess attenuation is 0 dB (A) for less than 40% built-up, 3 dB (A) for the range 40-65% and 5 dB (A) otherwise. 1.5 dB (A) is provided for each additional row of houses up to a total of 10 dB (A). The combined effect of both woods and rows of buildings is not to exceed 10 dB (A).

3.2.1.4.3 Barriers

The barriers are constructed in the form of beams, fences, walls, large buildings and hills. If a noise barrier is continuous, free of cracks and holes, and fairly dense, then the noise energy transmitted through the barrier is likely to be insignificant when compared to the noise energy that arrives at the other side of the barrier by diffraction. Barrier attenuation is predicted as a function of Frsnel number which is defined as:

$$N = 2\left(A + B - C\right)/\lambda \qquad \text{.... (3.16)}$$

where:

N = Fresnel number

$A + B$ = path length over the barrier

C = path length through the barrier

λ = wavelength of the sound

The attenuation provided by the barrier for the ith class of vehicle is then:

$$\Delta_{B_i} = 10 \log \left[\frac{1}{\Delta \phi} \int_{\phi_L}^{\phi_R} 10^{-\frac{\Delta_i}{10}} \, d\phi \right] \qquad \text{.... (3.17)}$$

where:

$$\Delta_i = \begin{cases} 0 \\ 5\left(1 + 0.6\varepsilon\right) + 20 \log \dfrac{\sqrt{2\pi |N_0|_i \cos\phi}}{\tan \sqrt{2\pi |N_0|_i \cos\phi}} \\ 5\left(1 + 0.6\varepsilon\right) + 20 \log \dfrac{\sqrt{2\pi |N_0|_i \cos\phi}}{\tan \sqrt{2\pi |N_0|_i \cos\phi}} \\ 20\left(1 + 0.15\varepsilon\right) \end{cases}$$

Δ_i is the point source attenuation for the ith class of vehicle,

$$N_i = |N_0|_i \cos\phi$$

ε is 0 for a freestanding wall and 1 for an earth berm,

$|N_0|_i = 3.21 \times$ path length difference (meters)

The path length difference is computed by assuming the following source heights above the pavement for different vehicle classes like 0 meters for automobiles, 0.7 meters for medium trucks and 2.44 meters for heavy trucks.

3.2.1.5 Gradient adjustment

Heavy trucks tend to produce higher noise levels when ascending hills. Table 3.3 gives suggested adjustments.

Table 3.3 Adjustments for Grade

Grade (%)	A_G (dBA)
≤2	0
3 to 4	+2
5 to 6	+3
>7	+5

3.2.1.6 Finite segment adjustment

The basic traffic noise prediction model applies to a straight highway subtending an angle of approximately 180° as viewed by observer. If the roadway is curved, or if conditions vary along its length, then it is analyzed in segments. Figure 3.1 shows a finite highway segment, where angle ϕ is positive to the right of the perpendicular and negative to the left.

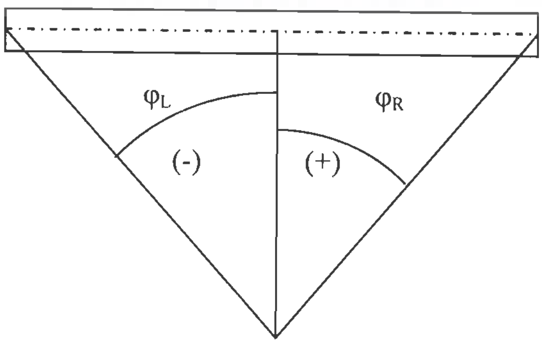


Figure 3.1: Finite Roadway Segment

For acoustically soft sites,the finite segment adjustment is given by

$A_F = 10 \log(\phi_2\text{-}\phi_1/180^o)$ .... (3.18)

where,

A_F= finite segment adjustement(dBA)

$\phi_2\text{-}\phi_1$ = The total angle suntended by the segment as seen by the observer (degrees)

For acoustically soft sites,the adjustment is given by

$$A_F = 10 \log(\Psi/180^o); \quad .... (3.19)$$

where,

$$\Psi = \int_{\phi 1}^{\phi 2} (\cos\phi)^{\alpha} \, d\phi$$

3.2.1.7 Barrier adjustment

When a solid barrier is placed in between the source and receiver there will be reduction in noise level due to diffraction of rays. There are two factors which affect the barrier attenuation.

- Frequency content of noise
- Fresnel number which depends on path difference

Barrier attenuation is predicted as a function of Fresnel number and is defined as follows

$$N = 2(A+B-C)/\lambda \quad .... (3.20)$$

where,

N = Fresnel number

A+B = path length over the barrier

C = path length through the barrier

λ = wave length of the sound and is given by

$$\lambda = cT \quad .... (3.21)$$

where,

c = speed of sound propagation in m/sec

c =√(C+273)

where,

C = air temperature in degrees Celsius

T = time period in sec. and

T=1/f

where,

f = frequency in Hzs

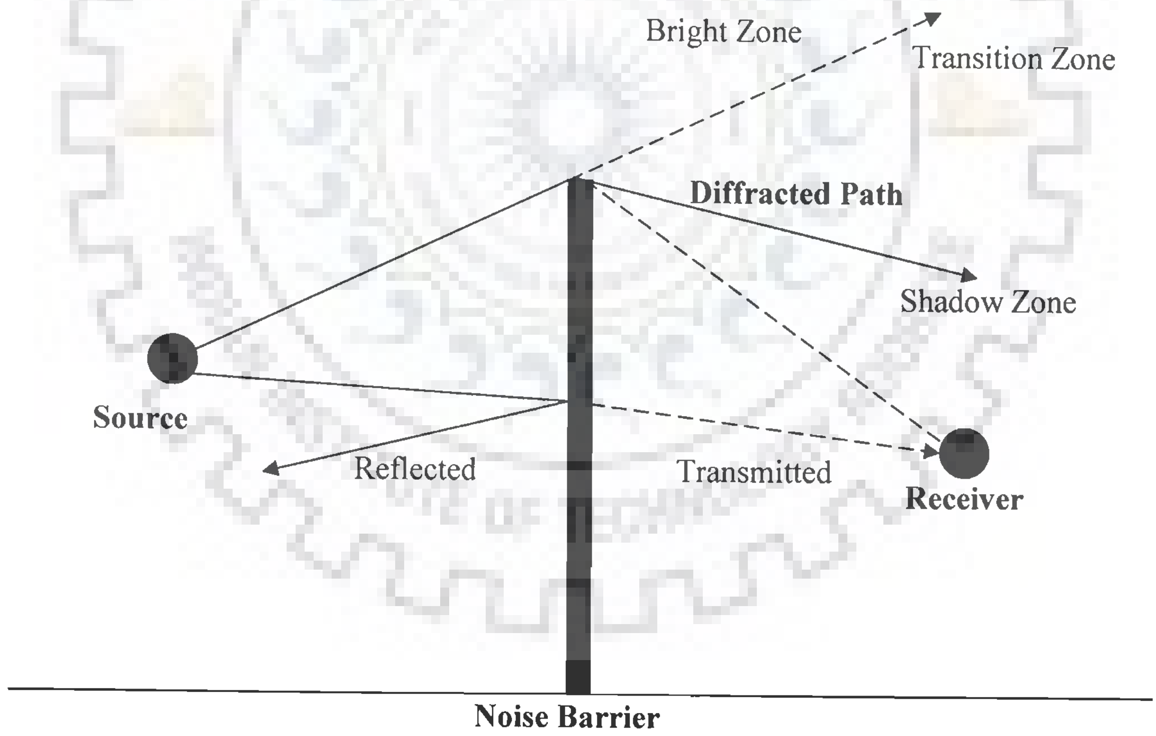


Figure 3.2: Working Principle of Noise Barrier

The barrier adjustment for a class of vehicles is found by integrating the energy loss due to the barrier over the barrier length. It is given by

$$\Delta_B = 10 \log \left(1/(\phi_2-\phi_1) \int^{\phi 2}_{\phi 1} \right) \quad .... (3.22)$$

where,

Δ_B = barrier adjustment

ϕ_L = angle subtended by barrier to the left of the observer in radians

ϕ_R = angle subtended by barrier to the right of the observer in radians

3.2.2 CORTN method-calculation of road traffic noise (UK)

This model was developed by U.K. Department of Environment in 1975. This model can determine $L_{10\ (18\ hour)}$ (0600-2400) and the $L_{10\ (1hour)}$ noise level. It required different traffic parameter like volume, speed, road surface, percentage of heavy vehicles and grade. The vehicles are deemed as being either passenger vehicles or heavy vehicles (unladen weight exceeding 1525 kg). A mean speed of all vehicles is used in the calculation. The L_{10} noise level at receiver point can be calculated as-

$$L_{10} = L_0 + \Delta_f + \Delta_g + \Delta_p + \Delta_d + \Delta_s + \Delta_a + \Delta_r \quad .... (3.23)$$

where,

L_0 = basic noise level

Δ_f = traffic flow adjustment

Δ_g = gradient adjustment

Δ_p = pavement type adjustment

Δ_d = distance adjustment

Δ_s = shielding adjustment

Δ_a = angle of view adjustment

Δ_r = adjustment for reflection

3.2.2.1 Basic noise level

The basic noise level hourly is predicted at 10 meters away from the nearside carriageway.

$$L_{10}\text{ (hourly)} = 42.2 + 10\log_{10} q, \text{ dB A} \quad \text{.... (3.24)}$$

Basic noise level in terms of total 18-hour flow is

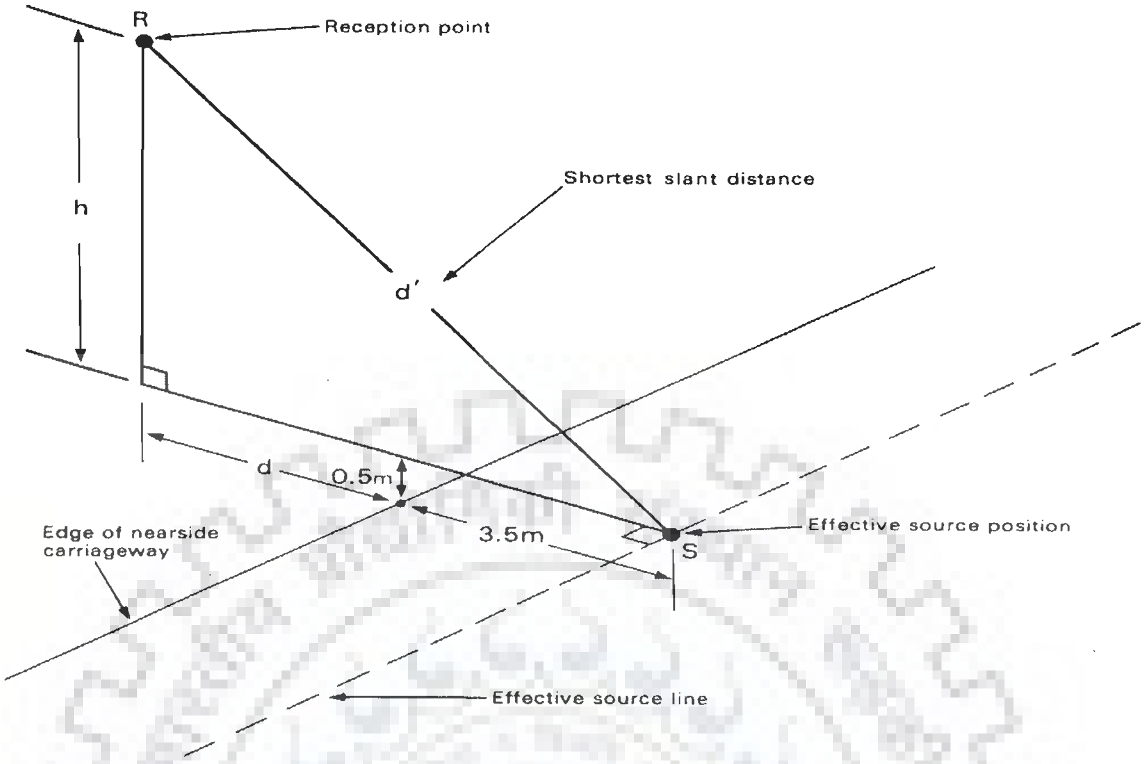
$$L_{10}\text{ (18 - hour)} = 29.1 + 10\log_{10} Q, \text{ dB A} \quad \text{.... (3.25)}$$

where,

q= hourly traffic flow (vehicles/hour)

Q = 18-hour flow (vehicles/hour), respectively.

It is also assumed that the source line is 3.5 m from the nearside edge of the road for carriageways separated by less than 5.0 meters (Figure 3.3).



$$d' = [h^2 + (d+3.5)^2]^{1/2}$$

Figure 3.3: An Illustration of Shortest Slant Distance between a Reception Point and an Effective Source Line Representing a Flow of Traffic

3.2.2.2 Traffic flow adjustment

The correction for traffic speed and composition of heavy vehicles is determined as follows:

$$\Delta_f = 33\log\left(S + 40 + \frac{500}{S}\right) + 10\log\left(1 + \frac{5p}{S}\right) - 68.8\rangle dB(A) \quad \text{.... (3.26)}$$

here,

S = mean speed of all traffic in km/h
p = percentage of heavy vehicles

3.2.2.3 Correction for road gradient

Gradient correction takes into account the reduction in average speed and the increase in noise level generated by vehicles traveling up a ramp. This adjustment is applied only for the upward flow.

$$\Delta_g = G(0.73 + 2.31(1 - \frac{p}{200}).\frac{p}{100}) \quad .... (3.27)$$

where:

p = percentage of heavy vehicles

G = percentage gradient

3.2.2.4 Correction for pavement type

For pavement adjustment the, the corrections are mentioned in Table 3.4. In this table texture depth (TD) indicates the sand patch texture depth in units of mm.

Table 3.4: Correction Factors for Pavement Surfacing

Correction Factors for Pavement Surfacing	
SURFACE TYPE	Δ_p
Open graded asphalt	– 3.5
Impervious surfaces *S* 75 kph	– 1.0
Cement Concrete *S* > 75 kph	$10log(0.9TD+0.3)$
Bituminous Concrete *S* > 75 kph	$10log(0.1TD+0.6)$

3.2.2.5 Distance correction

For the reception points located at distances d ≥ 4.0 meters from the edge of the nearside carriageway, the distance correction is given by

$$\Delta_d = -10\log_{10}(d'/13.5) \quad .... (3.28)$$

where,

d' =shortest slant distance between the effective source and the receiver

3.2.2.6 Ground cover correction

The ground surface between the edge of the nearside carriageway of the road or road segment and the reception point is totally or partially of an absorbing nature, (e.g. grass land, cultivated fields or plantations) an additional correction for ground cover is required.

This correction is progressive with distance and particularly affects the reception points close to the ground.

$$\Delta_{GC} = 5.2I \log_{10}\left(6H\text{-}1.5/\ d+3.5 \right), \text{ if } 0.75 \leq H \leq d+5/6 \quad \text{.... (3.29)}$$

$$\Delta_{GC} = 5.2I \log_{10} \qquad , \text{ if } H<0.75 \quad \text{.... (3.30)}$$

where,

d= distance from edge of nearside carriageway

H= average height of propagation and is given by H=0.5(h+1)

I = proportion of absorbent ground

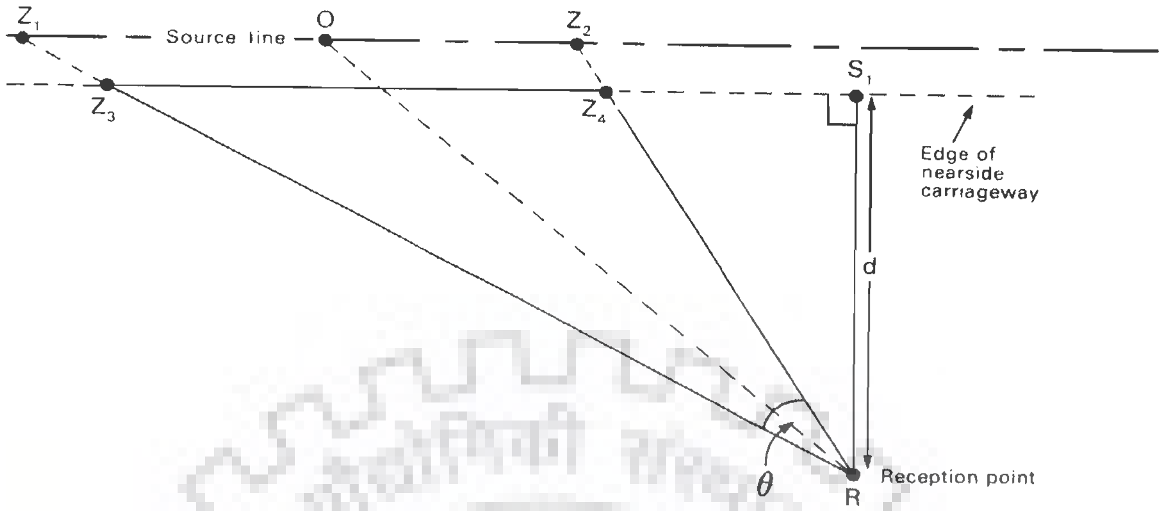
Where the intervening ground cover is non-absorbing, e.g. paved areas, rolled asphalt surfaces, water, the value of I is zero and not ground cover correction is applied.

In certain cases, where the intervening ground cover is a mixture of absorbing and non absorbing areas cannot be separated, and then the ground cover correction should be calculated (Figure 3.4) in accordance with expressions, but with the value of I as shown in Table 3.5.

Table 3.5: Values of I

% of Absorbent ground with in the segment	Value of I to be used
<10	0
10-39	0.25
40-59	0.5
60-89	0.75
≥90	1.0

a. For a simple road segment R Z_1 Z_2

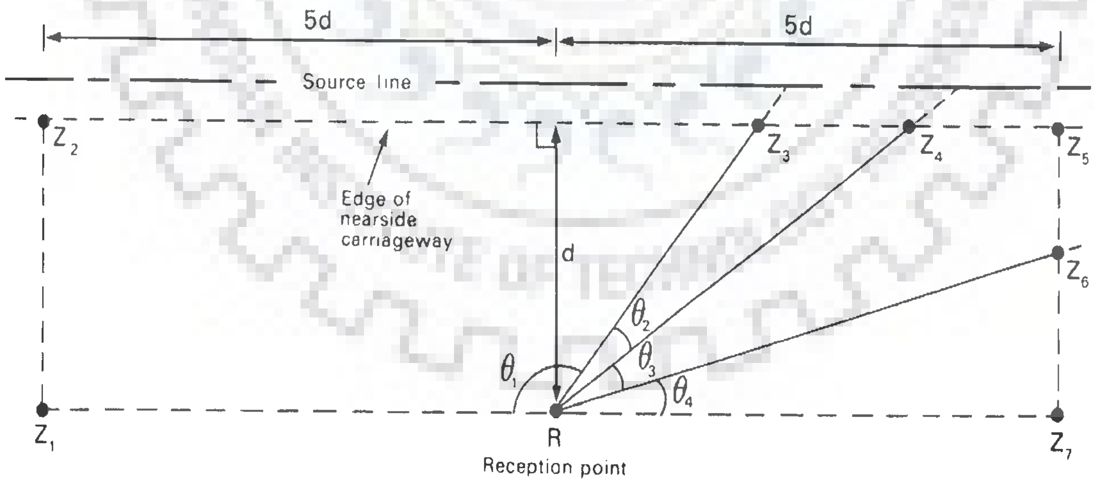


(i) The value of H (average height of propagation) is calculated along the line RO which bisects the segment angle θ

(ii) The area of ground cover to be considered when evaluating I is contained within the area defined by R Z_3 Z_4

(iii) The value of d is calculated along the shortest horizontal distance between the reception point R and extended edge of the nearside carriageway (RS_1).

b. For large segment areas



(i) For segment with angle θ_1: the ground cover area is R Z_1 Z_2 Z_3

(ii) For segment with angle θ_2: the ground cover area is R Z_3 Z_4

(iii) For segment with angle θ_3: the ground cover area is R Z_4 Z_5 Z_6

(iv) For segment with angle θ_4: the ground cover area is R Z_6 Z_7

Figure 3.4 Calculation of Ground Cover Correction

3.2.2.7 Barrier adjustment

The screening effect of intervening obstructions such as buildings, walls, purpose-built noise barriers etc. needs to be taken into account. The degree of screening depends on the relative positions of the effective source position S, the reception point R and the point B where the diffracting edge along the top of the obstruction cuts the vertical plane (Figure 3.5), i.e. normal to the road surface, containing both S and R. The region between the obstruction and the reception point is divided into the illuminated zone and shadow zone by the extended line SB as shown in Figure 3.5.

The degree of screening is calculated from the path difference, d, of the diffracted ray path SBR and the direct ray path SR

$$d = SB + BR - SR = SB + BR - d' \quad \text{.... (3.31)}$$

The path difference is used to calculate the potential barrier correction

A= å $A_i x_i$ .... (3.32)

where $x = \log_{10}\delta$, the coefficients A_i and the value n for the shadow and for the illuminated zones are given in Table 3.5.

If the barrier not parallel to the source line then the potential barrier correction will vary along the barrier length. In this case it may be necessary to divide the barrier into a number of smaller segments within each the variation in the barrier correction is less than 2 dB A. If barriers are installed then the ground cover correction is ignored since the ground rays are obstructed. Outside the above ranges of validity as depicted in Table 3.6, the potential barrier correction is defined in Table 3.7.

Table 3.6: Values of Coefficients

A_i	Shadow zone	Illuminated zone
A_0	-15.4	0
A1	-8.26	+0.109
A_2	-2.787	-0.815
A_3	-0.831	+0.479
A_4	-0.198	0.3284
A_5	+0.1539	+0.04385
A_6	+0.12248	
A_7	+0.02175	
Range of validity	$-3 \le x \le +1.2$	$-4 \le x \le 0$

Table 3.7: Potential Barrier Correction

Shadow zone	Illuminated zone
For $x < -3$, A= -5.0	For $x < -4$, A=-5.0
For $x > 1.2$,A= -30.0	For $x > 0$, A=0

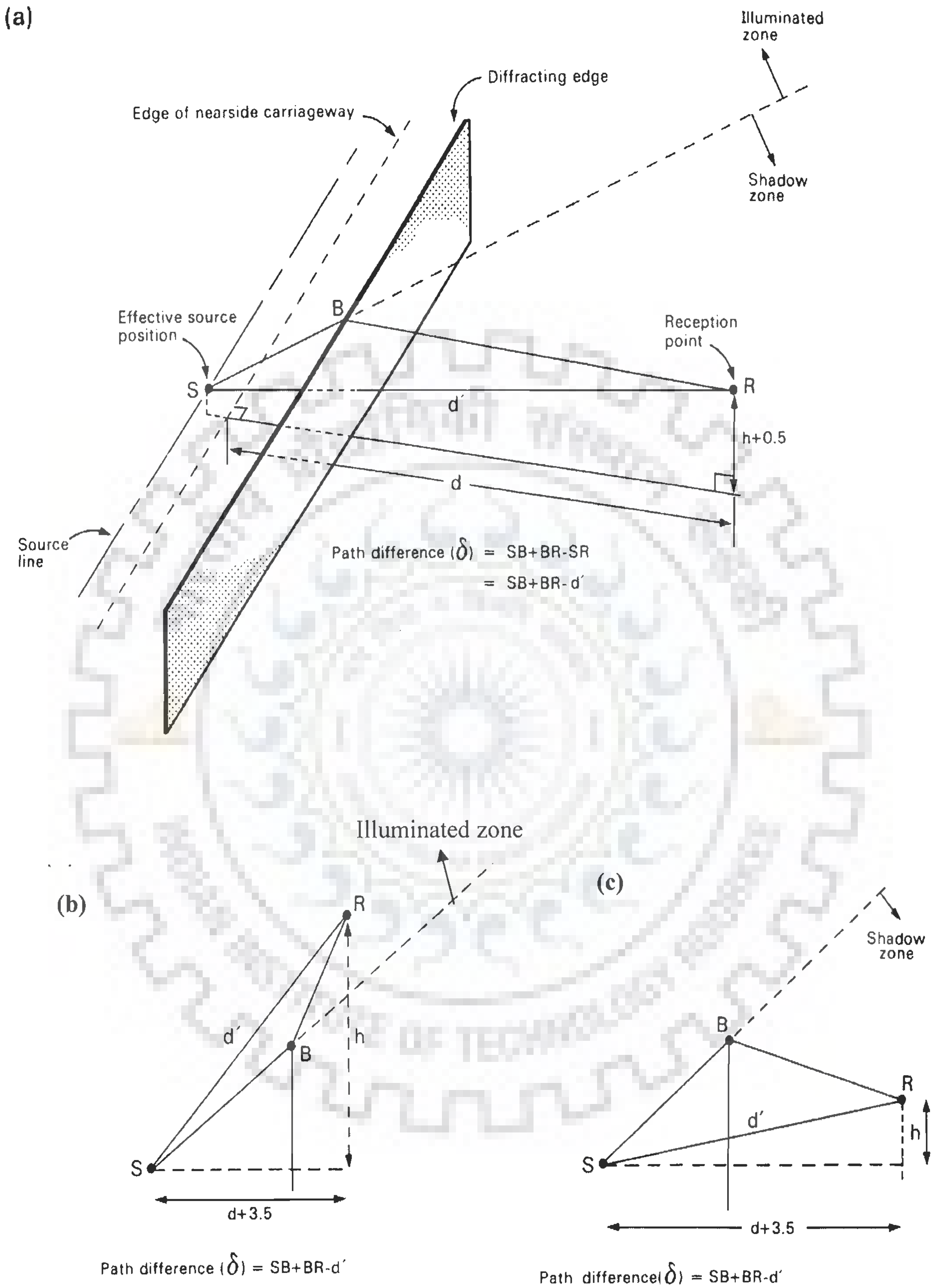


Figure 3.5 Barrier Screening and Bright and Shadow Zones

3.2.2.8 Site layout adjustment

The effects of reflections from buildings and other rigid surfaces result in increase in the noise level and need to be considered. If the receiver is 1 m in front of a façade, then a correction of 2.5 dB A is added to the basic noise level. Calculations of noise levels along side roads lined with houses but away from the facades also require the same addition of the 2.5 dB A. If there is a continuous line of houses along the opposite side of the road, then a correction for the reflections is required. The correction only applies if the height of the reflecting surface is at least 1.5 m above the road surface. The layout of correction for reflection from opposite façade is presented in Figure 3.6 and the equation is mentioned below.

$$\Delta_{OF} = 1.5\ (\theta '/\theta) \qquad \text{.... (3.33)}$$

where,

$\theta '$=sum of the angles subtended by the reflecting facades on the opposite side of the road facing the receiver,

θ = the total angle subtended by the source line at the reception point

This correction is required in addition to the 2.5 dB A façade correction detailed above.

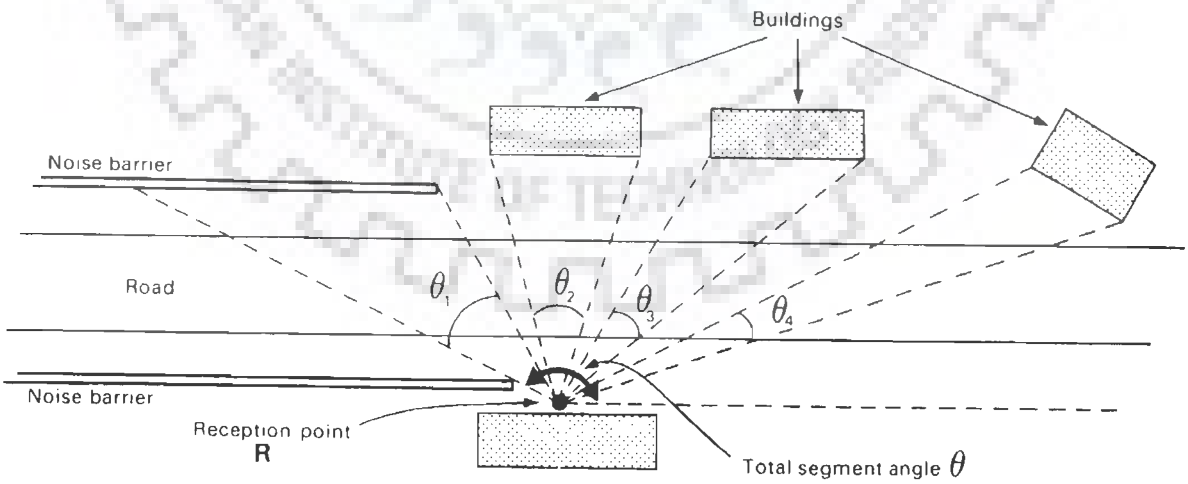


Figure 3.6: Calculation of the Reflection Correction from the Opposite Facades

Reflection correction = +1.5 (θ'/θ) dB A .... (3.34)

Where $\theta' = \theta_1 + \theta_2 + \theta_3 + \theta_4$

and θ = Total segment angle

3.2.2.9 Finite segment adjustment

The noise level at the reception point from the segment of the road scheme depends upon the angle *q* (degrees) subtended by the segment boundaries at the reception point .This angle is often referred to as the angle of view. The correction for angle of view is obtained using the expression

$\Delta_s = 10 \log_{10} (\theta/180)$

3.2.2.10 Total hourly sound level

$L_{10\ 1hr} = L_{10} + \Delta_{p,v} + \Delta_G + \Delta_{TD} + \Delta_D + \Delta_{GC} + \Delta_B + \Delta_{OF} + \Delta_S$............ .... (3.35)

where,

L_{10} = basic hourly or 18-hour level predicted for the i-th segment

Δ_i = various corrections

3.2.2.11 Combined contribution of noise from all segments

The final stage of the calculation process, to arrive at the predicted noise level, requires the combination of noise levels contributions from all the source segments, which comprise the total road scheme. For a single road segment road scheme there is no adjustment to be made. For road schemes consisting of more than one segment the predicted level at the reception point shall be calculated by combining the contributions from all segments using the following expression

$L_{10}^{Total} = 10 \log_{10} [\Sigma\ 10^{(L_{10}^{i}/10)}]$.. .... (3.36)

where,

$L_{10}^{i} = L_{10} + \Delta_{p,v} + \Delta_G + \Delta_{TD} + \Delta_D + \Delta_{GC} + \Delta_B + \Delta_{OF} + \Delta_S$ .... (3.37)

3.2.3 The national cooperative highway research programme method

This model is based on the statistical descriptors L_{50} & L_{10}. Predictions are based on only two vehicle types, autos (A) and trucks (T). For field identification, four-wheeled vehicles are considered automobiles and vehicles with six more wheels are considered trucks (Wilson, 1989).

The contributions to median sound level on an infinite, level roadway are predicted as follows:

Autos:

$$L_{50(A)} = 10 \lg V - 15 \lg D + 20 \lg S + 10 \lg \left[\tanh \left(1.19 \times 10^{-3} V \frac{D}{S} \right) \right] + 29 \quad \ldots (3.38)$$

Trucks:

$$L_{50(T)} = 10 \lg V - 15 \lg D - 10 \lg S + 10 \lg \left[\tanh \left(1.19 \times 10^{-3} V \frac{D}{S} \right) \right] + 95 \quad \ldots (3.39)$$

where,

L_{50} = median sound level due to a single lane of autos or trucks (dB A)

V = volume (vehicles/hr)

D = distance from observer to roadway centerline (ft)

S = speed (mi/hr)

The 10% exceeded levels for each vehicle class are determined by applying the following adjustment:

$$L_{10} - L_{50} = 10 \lg \left\{ \frac{\cosh \left(1.19 \times 10^{-3} \frac{VD}{S} \right)}{\cosh \left(1.19 \times 10^{-3} \frac{VD}{S} \right) - 0.951} \right\} \quad \ldots (3.40)$$

Where $L_{10} - L_{50}$ = the adjustment to be added to median sound level for each vehicle class to obtain the 10% exceeded level (dB A). The above adjustment is sometimes inconsistent with field data, particularly for low traffic volume. When measurements of L_{10} and L_{50} are possible, the measured difference may be used to adjust predicted L_{50} values based on projected highway traffic for future years.

The contributions are combined to procedure predicted noise level at the observer as follows:

$$L_{combined} = 10 \lg \left(\sum_{i=1}^{n} 10^{\frac{L_i}{10}} \right) \quad \text{.... (3.41)}$$

where,

$L_{combined}$ = $L_{10combined}$ for the combined contributions on a two-lane roadway (dB A)

n = 4, the number of contributions

L_i = the individual L_{10} contributions from autos and trucks in the near and far lanes

The NCHRP model may be of use when updating older noise impact statements. However, the FHWA model will usually be found more accurate, partly due to the use of three vehicle classes, since the medium truck-heavy truck mix in cities tends to differ from that on interstate highways. An important feature of the FHWA model is the use of equivalent sound level as a descriptor. L_{eq} may be readily extended to a 24-hour period. In addition, day-night sound level may be obtained from the FHWA model. Thus, the results obtained from the FHWA model are essentially consistent with descriptors used by the Environmental Protection Agency.

3.2.4 ASJ road traffic noise prediction method-1975

This noise prediction method is based on a simple model called "uniform – spacing and identical-source model". L_{50} has been commonly used as the noise descriptor for general environmental noises including road traffic noise in Japan. The basic equation of this method is:

$$L_{50} = L_w - 8 - 20 \log_{10} l + 10 \log_{10} \left(\frac{\pi l}{d} \tanh \frac{2\pi l}{d} \right) + \alpha \quad \text{.... (3.42)}$$

Where:

L_w = sound power level of vehicles

l = perpendicular distance from the receiver to the centre of the road

d = spacing [d=1000V/Q, V is the vehicle speed (km/h) and Q is the traffic volume (vehicles)].

α = correction term

L_w is calculated from the following equations:

a. In case of two-types classification of vehicles:

$$L_w = 87 + 0.2V + 10\log_{10}(a_1 + 10a_2) \quad \text{.... (3.43)}$$

Where, a_1 and a_2 are the ratios of small vehicles and large vehicles, respectively.

$(a_1 + a_2 = 1)$

b. In case of three-types classification of vehicles:

$$L_w = 85 + 0.2V + 10\log_{10}(b_1 + 3.2b_2 + 1.6b_3) \quad \text{.... (3.44)}$$

where,

b_1, b_2, and b_3 are the ratios of passenger cars, small trucks and large trucks respectively.

$(b_1 + b_2 + b_3 = 1)$

This method is applicable in following conditions:

1. Road construction: straight roads of simple construction (bank, depressed, level and elevated)
2. Traffic volume: more than 1000 vehicles/hr
3. Vehicle speed: 30km/h to 100 km/h (stable flow)
4. Distance from the road: up to 100 m

3.2.5 ASJ road traffic noise prediction method-1993

This model has been widely used for the road traffic noise assessment in Japan. This method can provide both of L_{50} and L_{Aeq}.

Estimation of L_{Aeq}

$$L_{Aeq} \; 10\log_{10}\left[\sum_{i=1}^{k} 10^{U_i/10} \Delta t N / T\right] \quad \text{.... (3.45)}$$

where:

N = traffic volume (vehicles/h)

U_i = sound pressure level at the receiver from the i-th sound source

Δt = ΔD/V (ΔD is the interval between the adjacent sources points in meter)

V= vehicle speed (km/h)

$T = 3600$ (seconds)

Estimation of L_{50}

$$L_{50} = L_{Aeq} + ax + b$$

In this equation the coefficients a and b can be obtained from the Table 3.8.

$X = d / l$

here:

d is the spacing (m)

l is the distance from the centre of the road to the receiver (m)

Table 3.8: Coefficients a and b for Each Road Construction

Road structure	a	b
Level, bank	-1.0	-1.0
Depressed road	-0.6	-0.6
Elevated road	-0.6	-1.4

This model can be applied in following conditions:

Road structures: general types of road of straight and simple construction

Traffic volume: no limit (when L_{50} is estimated from L_{Aeq} it must be more than 500 vehicles per hour in total traffic volume)

Vehicle speed: 60 km/h to 120 km/h (freely flowing traffic at a constant speed)

Distance from the road: up to 100 m

Meteorological conditions: neutral condition

3.2.6 Bangkok model

Pichai Pamanikabud and Chaisri Tharasawatpipat (1999) carried out simulation of urban traffic noise with the help of a mathematical model of stop and go traffic noise for the road network in the city centre of Bangkok. They collected the data related to traffic characteristics and its noise levels and analyze those data. They also measured the geometrical dimensions of road section at each data collection location. They analysed the characteristics of traffic noise from different types of vehicles including motorized tricycle taxis and motorcycles. Characteristics of traffic noise levels and data on other traffic noise parameters were used to analyze and subsequently construct the stop and go traffic noise simulation model. Ultimately, the resultant stop and go traffic noise models, which are separated into acceleration and deceleration lane models and their statistical goodness of fit tests, are presented.

3.2.6.1 Traffic characteristics

The data related to traffic characteristics include traffic volume, traffic composition and average spot speed of vehicles. Traffic composition comprises automobiles, trucks, buses, motorcycles and motorized tricycle taxis.

3.2.6.2 Geometric dimensions of road section

The measurement of geometrical dimensions of each location involved identifying the number of lanes and their width, width of median and sidewalk and the curb to facade width. The distance of sound level meter from the nearest intersection was measured in addition to recording the direction of traffic flow on each side of the road's median.

3.2.6.3 Noise level from different vehicle types

The noise level data in L_{eq} was collected randomly from the real road running condition of a single vehicle passing by a noise level meter set at the reference distance of 15 m from the centerline of the traffic lane. The spot speed of that particular vehicle was also collected on a simultaneous basis by setting the noise meter at the middle of the course length.

The characteristics of individual noise at an overall mean vehicle speed was used to identify the proportional weighting scale of the noise levels generated per unit of each vehicle type in relation to an automobile unit.

3.2.6.4 Traffic Volume Calculation

Traffic volume can be computed from the following equation:

Traffic volume = (AU) + 1 1.04(LT) + 1 1.12(MT + TT) + 1 1.14(HT) + 1 1.09(MC + BU + MB) .... (3.46)

where:

AU = automobile, HT = heavy truck, LT = light truck, MC = motorcycles, MT = medium truck, BU = bus, TT =Tuk-Tuk and MB = minibus

Two approaches are employed for the analysis of modeling:

3.2.6.5 Single model analysis

This approach was firstly applied to build a single stop-and-go traffic flow noise model. This model can be applied to both sides of an urban roadway. The analysis was done by utilizing all of the data collected from roadway sections for every parameter in the model. The layout plan of every parameter on a typical road section for the single model approach is shown in Figure 3.7.

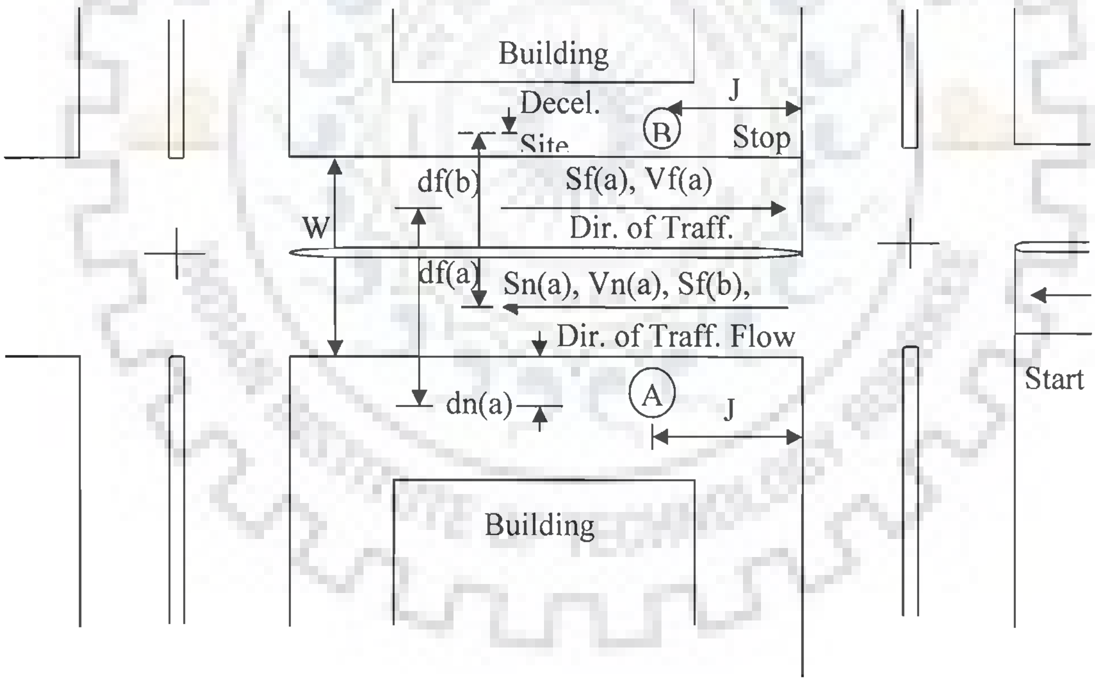


Figure 3.7: Road Section and Parameters Layout of Single Lane Model Approach

Finally the developed model from thois approach is given in following equation:

$L_{eq} = 71.05 + 0.10S_n + 0.95 \text{ Log } V_n + 0.04S_f + 0.015 \text{ Log } V_f - 0.111D_g$ .... (3.47)

where:

L_{eq} = equivalent traffic noise level in 1 h (dB A)

S_n = mean speed of traffic on nearside of observer (both sides of road)(km/h)

S_f= mean speed of traffic on farside of observer (both sides of road)(km/h)

V_n = volume of traffic for nearside of observer (both sides of road)(vehicles/h)

V_f= volume of traffic for farside of observer (both sides of road)(vehicles/h)

D_g = geometric mean of road section (m)

$$D_g = \sqrt{d_f \times d_n}$$

d_f= distance from observer to centerline of far-side roadway (m)

d_n = distance from observer to near side roadway curb (m)

3.2.6.6 Separated model or dual model analysis

This approach concede the difference in traffic noise characteristics between an acceleration lane and deceleration lane on both sides of the urban road when vehicles leave an intersection on a green traffic light and come to a stop on a red traffic light. The acceleration lane model was built using data generated from the noise level meter placed on the side-walk near the acceleration lane of the roadway when traffic leaves the intersection. Figure 3.8 shows the layout of this model and after the analysis they got the final acceleration and deceleration models which is given in following equations:

Acceleration lane interrupted traffic noise model

$$L_{eq} = 56.91 + 0.09S_n(a) + 5.22 Log V_n(a) + 0.04S_f(a) + 0.02 Log V_f(a) - 0.006D_g(a)$$

.... (3.48)

Deceleration lane interrupted traffic noise model

$$L_{eq} = 71.12 + 0.07S_n(b) + 0.42LofV_n(b) + 0.08S_f(b) + 0.44LogV_f(b) - 0.061D_g(b) \quad \dots (3.49)$$

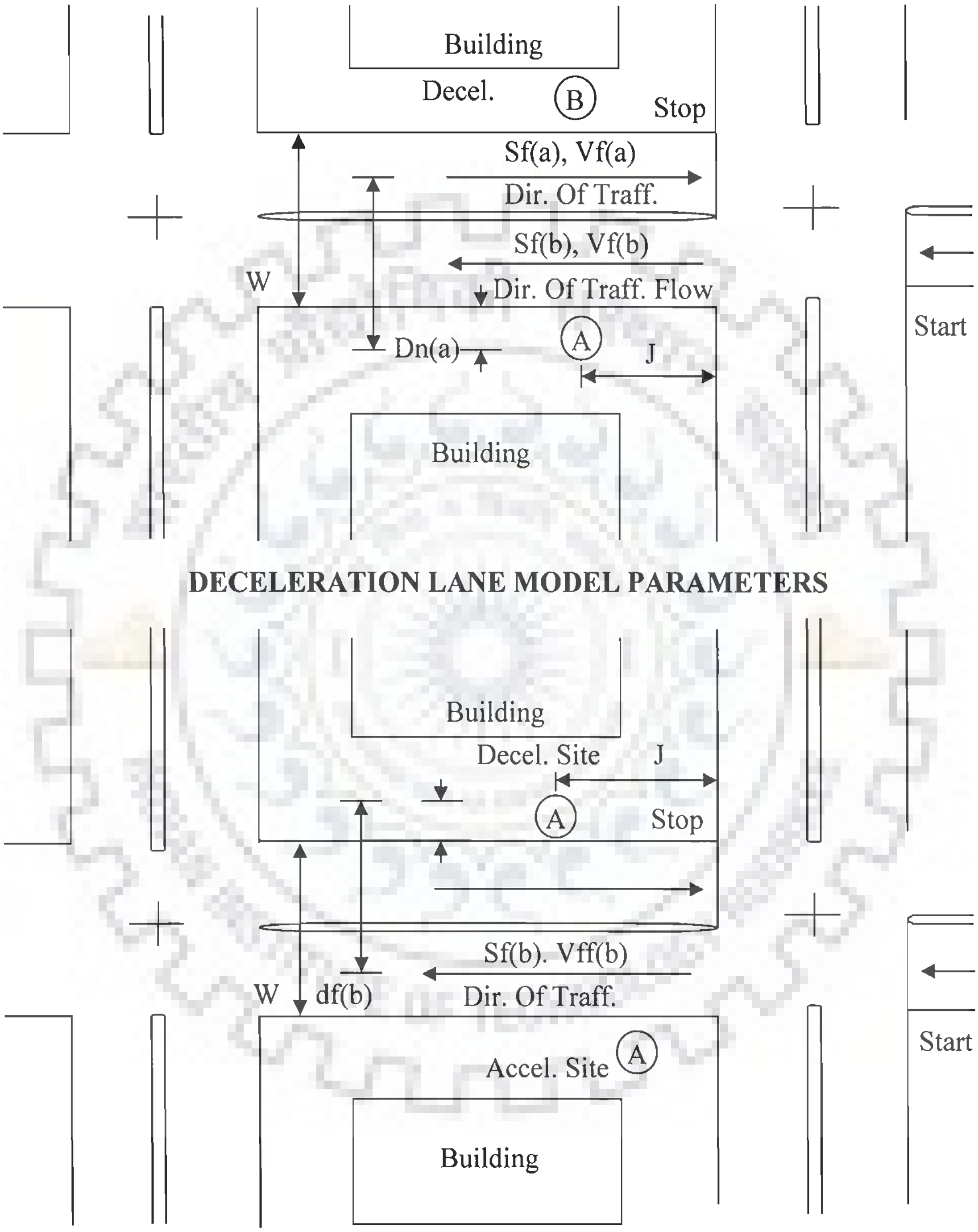


Figure 3.8: Road Section and Parameters Layout of Separated Lane Model Approach

3.2.7 Numerical models

These models have also been developed for the prediction of traffic noise. The details about various numerical models are given below:

3.2.7.1 Edinburgh model

This model is helpful in the prediction of interrupted flow traffic noise in the United Kingdoms. This model is used in the early stage of investigation and model development of this study. The following equation presents this model:

$$L_{10} = 55.2 + 9.18 \log Q(1 + 0.09PH) - 4.2 \log V_y 2.3T \quad \text{.... (3.50)}$$

here:

L_{10} = traffic noise level in dB (A) that exceed 10% of the measuring time period (1 hour)

Q = traffic volume (vh/hr)

PH = proportion of vehicles exceeding 1.5 tons

T = index of dispersion (ratio of variance to the mean of number of the vehicle arriving in each 10 second interval)

V = mean speed of traffic (km/hr)

Y = carriageway width (meters)

3.2.7.2 Sheffield model

The mathematical formula of the model:

$$L_{10} = 51.51 + 10.5 \log Q(1 + 0.04PH) - 5.71 \log(d_k + 0.5y) + 2.38 \log G \quad \text{.... (3.51)}$$

In this equation:

L_{10} = traffic noise level in dB (A) that exceed 10% of the measuring time period (1 hour)

Q = traffic volume (vh/hr)

PH = proportion of vehicles exceeding 1.5 tons

Y = carriageway width (meters)

d_k = distance from noise meter to edge of kerb (meters)

G = 1 or percentage gradient whichever is larger

3.2.7.3 Gilbert model

The formula for this model is:

$$L_{10} = 43.3 + 11.2\log(L + 9M + 13H) - 0.43y + 2.42 / d_f \quad \text{.... (3.52)}$$

where:

d_f= distance from the near side kerb to near side façade (m) and df > 1

L = number of light vehicles (< 1525 kg), (veh/hr)

M = number of medium goods vehicles (< 1525-4500 kg) (veh/hr)

H = number of heavy goods vehicles (> 4500 kg) (veh/hr)

3.2.7.4 Australian model

The following formula is used to predict the L_{10} of traffic noise in South Australia:

$$L_{10} = 64.4 + 10.9\log V - 20.3(\log D + 16) + 0.26T \quad \text{.... (3.53)}$$

here:

V = total traffic volume per hour

S = mean vehicle speed

T = percentage of heavy vehicles

D = distance of the nearest lane

3.3 Software for Estimating Traffic Noise Pollution

A number of software has been developed to evaluate traffic noise, industrial noise and rail noise. A brief description of commercially available software capable of modeling industrial noise, traffic and rail noise is given below:

3.3.1 SOUND PLAN

SOUNDPLAN is a regulation and standards based noise pollution modeling software used to evaluate any type or size of noise pollution scenario. It offers noise modeling solutions for both traffic and industrial situations. It is the only noise control software package that has implemented and tested both calculation methods (TNM and Nord 2000) that evaluate the phase relationship between the direct line of sight transmission and the phase sifted ground reflection. All relevant objects (highways, railroads, obstacles, a real sound source, places of emission etc.) are stored as files in the Geo-database. Each object may have up to 255 files so the user can also handle investigations covering larger sites. Sound sources can be defined as points, lines or planes. Ground topography and reflecting surfaces are input in the Geo-database. The calculation is carried out automatically with the aid of a search-beam procedure - a ray tracing algorithm scans the topography looking from the receiver. For every ray the program evaluates, the propagation over the terrain automatically calculates the effects of distance, diffraction, ground absorption and reflections. The results are fed into a sound level diagram that visualizes the noise situation at the receiver with direct and reflected sound. It is possible to select any number of intersections with emitter axes and obstacles, where the search beam meets a reflecting surface, a further search beam is radiated from the point of reflection. Up to 5 such multiple reflections can be accommodated in the one calculating operation. Plotter output includes sound level spectra, and reflection diagram, at each reflection location (façade noise map) and noise contours.
Automatic barrier wall calculations are provided – for this purpose, one only needs to locate the plan of the wall structure and the program will calculate the height of the barrier to achieve a given noise reduction. Highway traffic and rail modules are available with no restriction on the number of emitters processed. The individual sound levels of the various emitters are listed in a result table for specific scenarios. An INFACIL module is also available for industrial, leisure and sports situations. Calculations can be carried out for centre frequencies, one-third octave or octave spectra.

3.3.2 ENM

The Environmental Noise Model (ENM) simulates outdoor sound propagation and predicts noise levels from known noise sources for close and distant locations. The model calculates noise levels using algorithms which mathematically express factors which affect the loss of sound energy along its propagation paths. It caters for attenuation due to noise source enclosures and other noise control measures, for distance from the source to the receiver, for the noise source radiation patterns, for barriers and natural, topographical features and for sound absorption in the air. It also takes into account differences in sound propagation from noise sources of various shapes and sizes. Source and surface data include power levels, directivity, source direction cosines (to orient the source), surface transmission loss and absorption; coordinate information, source type and size and other information. Meteorological data includes temperature, humidity, wind speed and direction and vertical temperature gradient. Various scenarios may be studied by simply including the relevant filenames in the calculation module. This is especially useful when examining noise from open cut mine sites for which the ground topography is continually changing. Calculations may be performed at selected points in a regular grid (multiple point calculation) or at an individual point. In case of multiple point calculation, a contour plot of the dB (A) value is available, in the case of single point calculation; detailed results are printed for each source and algorithm.

3.4 Non-Highway Surface Transportation Noise Prediction Models

Rail noise is in many ways treated similarly to traffic noise but no one is generally interested in predicting noise from a specific train type but one looks at the total noise exposure to receivers over a relative by long period of time. Noise impact from trains can in many cases be considered a secondary problem compared with traffic mainly because there is far less new train tracks being built compared with roads. One view is that noise from new developments can cause significantly more impact that the same level of noise in existing situations. However, on the other hand, noise from high speed trains such as the French TGV and the Japanese Shinkansen are current important topics as is sleep disturbance caused by trains running at night. In most countries, the L_{eq} descriptor again is utilized to examine noise impact from rail traffic. However, the L_{max} is also an important descriptor especially in consideration of sleep and health effects. Rail noise models are similar in all parts of the world but perhaps the most advanced are the French and the Scandinavian models. From a modeling point of view, the Scandinavian algorithms are only graphically based model. Due this the more emphasis is on French model.

3.4.1 French model

This model describes a method for the prediction of noise from rail traffic. Both the $L_{A,eq}$ and L_{max} noise levels are predicted. The modeling procedure, as for traffic, seeks to divide the rail route into segments which are treated separately but which one long enough to contain the whole train length. In the first instance, the L_{max} level from the train for each segment is calculated. Next, the L_{eq} of a particular train type is determined and finally, the L_{eq} of a mix of trains passing a given receiver is calculated.

The model is valid for distances up to 250 m and train speeds from 40-200 km/hr in a free field over hard ground assuming infinitely long and straight tracks on concrete sleepers in good condition of repair. The influence of track type and condition, air absorption, ground attenuation, screening to due barriers and built-up areas and reflection by buildings and cuttings is not considered. The types of train considered in this model are:

- **Short distance trains:** suburban trains (one or more cars each approximately 80m in length giving a total train length of 160-200m. Train speeds upto 120 km/hr. This category includes several types of metros;
- **Express passenger trains**: diesel or electric traction with a total length of about 250 m, speeds of upto 200 km/hr but mostly limited to 160 km/hr;
- **Freight trains**: from 400-750m in length and speeds from 80-100 km/hr;
- **Single engined trains and railcars**: 50-100 m in length with speeds of upto 160 km/hr or 120 km/hr for diesel railcars.

The maximum sound level of a passing train is:

$$L_{A.max} = L_0 - k\log\left(\frac{d}{d_0}\right) + 30\log\left(\frac{v}{v_o}\right) - k_d - 10\log\left[(\cos\alpha + \cos\beta)/2\right] \quad \text{.... (3.54)}$$

where,

L_0 is the reference sound level emitted by a train of a particular type traveling at speed v_0, a distance of d_0 from a receiver as shown in Table 3.9.

Table 3.9: Reference Sound Level L_0 for Trains of Different Type

Train Type	**Speed V_0 Km/Hr.**	**Reference Sound Level L_0 dB (A)**			**Length Correction (k)**
		Reference Distance D_0 Metres			
		7.5	**15**	**25**	
Short-distance trains	60	79	75	72	17
Subways					14-16
Intercity train					
High speed train	200	104	100	97	
Express	140	97	94	92	15
Freight Trains					
Goods	80	93	89	86	
Post	100	96	92	89	12
Single Engines	120	92	88	85	
Diesel Rail Cars	155	96	91	89	20

The value L_0 may vary ±5 dB (A) depending upon the state and type of track and from train to train. The values shown in the table above are valid in a free field along ground-laid tracks in good condition.

$K\log(d/d_0)$ is the distance correction for a receiver at a distance d from the train computed from the length correction factor k given in the table above. This correction takes into consideration the fact that the train is not a point source but a finite length sound source.

$30\log(v/v_0)$ is the speed correction for a speed v in km/hr.

k_d is a correction for vertical directivity and is determined from Table 3.10.

Table 3.10: Vertical Directivity Correction Factor K_d

Source – Receiver Angle Relative to Horizontal	k_d dB (A)
10	0
20	0
30	0
40	1.5
50	3
60	4.5
70	6
80	7.5
90	9

$10\log[(\cos\alpha + \cos\beta)/2]$ is the 'finite length' correction which is used whenever part of the track is screened from the receiver. The angle α and β are described in the following Figure 3.9.

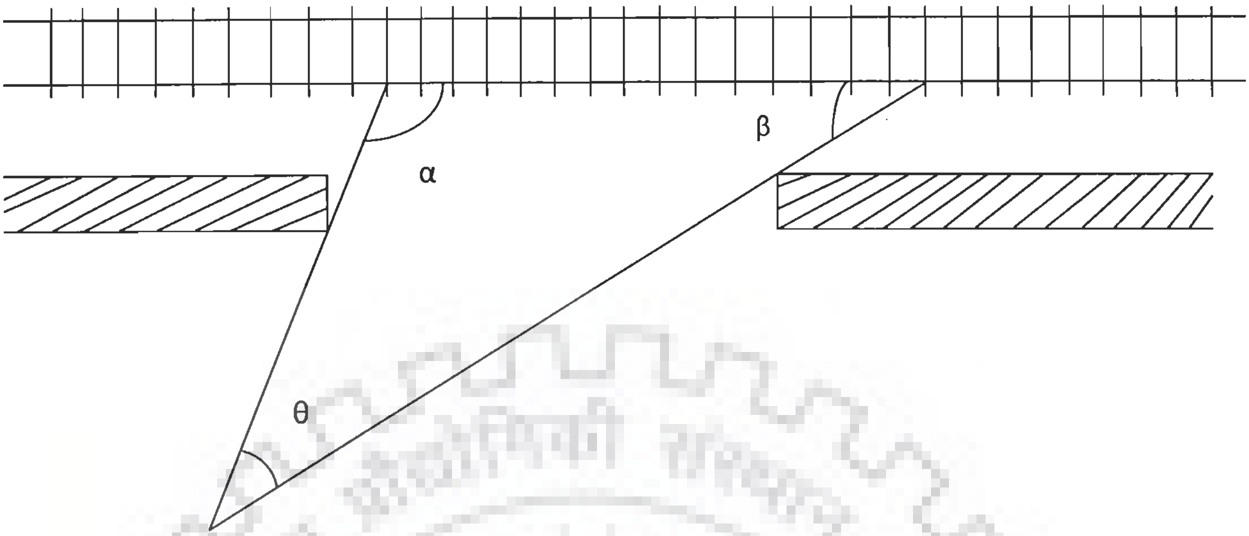


Figure 3.9: Correction for Finite Length

Having determined the $L_{A,max}$ value, the equivalent sound level of a passing train of a given type is determined from the following equations –

$$L_{A.eq} = 10\log\left[\frac{t_e}{T}.\,10^{\frac{L_{A.max}}{10}}\right] \quad \text{.... (3.55)}$$

where

$$t_e = \frac{3.6\,\ell}{v} + 6\,\frac{d}{100} \quad \text{.... (3.56)}$$

is the duration of exposure of the subject train in seconds defined as the time for which $L_A = L_{A.max} - 10$ dB i.e. the time between the '10 dB down' points. In this equation, ℓ is the length of the train in metres, v is the speed of the train in km/hr, d is the distance from receiver to track in metres. T is the time interval for which $L_{A,eq}$ is calculated in seconds (e.g. daytime, night time).

The equivalent sound level of all railway traffic utilizing the track is calculated from the number of trains n_i of different type i passing in the reference period T.

$$L_{A,eq} = 10\log\sum\left[n_1 10^{\frac{L^{(1)}_{A,eq}}{10}} + n_2\,10^{\frac{L^{(1)}_{A,eq}}{10}} + \ldots\ldots + n_N 10^{\frac{L^{(1)}_{A,eq}}{10}}\right] \quad \text{.... (3.57)}$$

3.4.2 Railway noise prediction: national bureau of standards model

This model is based on a single infinite straight track at grade level, and three train classes, freight, conventional passenger, and rapid transit. A diesel-electric train is modeled as two distinct sources, the locomotive and the cars. Rapid transit trains and all-electric passenger railway trains are considered to generate noise primarily by wheel/track interaction. It is assumed that equivalent sound level decreases by about 5 dB A per doubling of distance from a diesel-electric locomotive. For freight and passenger cars, all-electric locomotives, and rapid transit cars, the equivalent sound level is assumed to decrease by about 6 dB A per doubling of distance. The empirically derived assumptions are valid for distances of 150 ft or more from the railway (Wilson, 1989).

Reference noise level versus speed for diesel-electric locomotives and attenuation versus distance relationships for diesel-electric locomotives and railway cars were determined. The following approximate relationship for diesel-electric locomotive noise level is:

$$L_{loc} = 105 - \frac{S}{12} \quad \text{.... (3.58)}$$

Where L_{loc} = reference noise level for diesel-electric locomotives (dB A at 100 ft)

S = speed (mi/hr) for $10 \leq S \leq 100$ .... (3.59)

The distance adjustment data for diesel-electric locomotives may be related to the base-ten logarithm of distance as follows:

$$A_{DL} = 33.7 - 16.4 \lg D \quad \text{.... (3.60)}$$

Where A_{DL} = distance adjustment for diesel-electric locomotives (dB A)

D = distance (ft) for $D \geq 150$ .... (3.61)

For railway cars, the following equation gives a reasonable fit to available data:

$$A_{DC} = 39.3 - 19 \text{ kg } D \quad \text{.... (3.62)}$$

Where A_{DC} = distance adjustment for railway cars (dB A), which may be used for rapid transit cars as well.

Using data from Bender *et al.* (1974), noise levels may be related to speed for railway cars and rapid transit vehicles. The relationship for railway cars is

$$L_C = 32 + 31 \lg S \quad \text{.... (3.63)}$$

Where L_C = reference noise level for railway cars (dB A at 100 ft)

S = speed (mi/hr) for $10 \leq S \leq 100$ .... (3.64)

The noise level versus speed relationship for rapid transit vehicles is

$$L_{RT} = 23.5 + 31 \lg S \quad .... (3.65)$$

Where L_{RT} = referenced noise level for rapid transit vehicles (dB A at 100 ft).

The following corrections are made for track characteristics. This adjustment is applied if the track variation occurs within a distance of 2D on either side of the track from the point closest to the observer, where D is the distance from the observer to the track (Table 3.11).

Table 3.11: Traffic Characteristics with Different Adjustments

Track Characteristics	Adjustment A_{track} (dB A)
Straight machine-welded track	0
Straight jointed track	4
Presence of switches or grade crossing	4
Tight radius curve	
Radius < 6000 ft	4
600 ≤ radius < 900 ft	1
900 ft ≤ radius	0
Presence of bridge	
Concrete	0
Steel girder with concrete deck	5
Steel girder with open tie deck	5
Steel girder with steel plate deck	14

Additional adjustments are required for the number of passbys during a specified time interval, for the duration of a passby, and for shielding by building and barriers. The following corrections are suggested.

3.4.2.1 Barriers: Path difference is calculated for barriers as in the previous section. It is assumed that the noise source location for diesel-electric locomotives in the exhaust outlet, about 15 ft above the rails. The noise source location for railway cars, all-electric locomotives, and rapid transit vehicles is assumed to be at the level of the rails. Fresnel number is given by

$$N = \frac{2D_P}{\lambda} \quad \text{.... (3.66)}$$

where,

N = Fresnel number

D_P = path difference

λ = c/f = the wavelength of sound

c = 343 m/s = 1125 ft/s = the speed of sound propagation at 20°C (68°F)

It is assumed that the actual frequency spectra of the sources can be represented by sounds at the following frequencies :

f = 125 Hz for diesel locomotives

f = 500 Hz for railway cars, all-electric locomotives, and rapid transit vehicles

The adjustment of barriers $A_{barriers}$ may be calculated from the following equations:

(1) Railway cars, all-electric locomotives and rapid transit vehicles:

$A_{barrier}$ = 0 for $D_P' \leq 0.075$ ft.

= $-8.4 - 7.5 \lg D_P'$ for $0.075 < D_P' < 3$ ft.

= -12 for $D_P' \geq 3$ ft

where,

$A_{barrier}$ = barrier adjustment (dB A)

D_P' = path difference (ft)

(2) Diesel-electric locomotives:

$$A_{barrier} = 0 \quad \text{for} \quad D'_P \leq 0.3 \text{ ft.}$$

$$= -3.9 - 7.5\, D'_P \quad \text{for} \quad 0.3 < D'_P < 12 \text{ ft.}$$

$$= -12 \quad \text{for} \quad D'_P \geq 12 \text{ ft}$$

These barrier adjustments may be used for determining the effect of free standing walls, earth barriers and railway cuts on noise levels at 150 ft. or more from the source. These calculations do not treat reflections due to barriers or noise levels in railway cars and subway tunnels.

3.4.2.2 Buildings

For railway cars, all-electric locomotives and rapid transit vehicles, the effect of shielding due to buildings is about the same as for highway noise. Due to the source location for diesel-electric locomotives, it will be assumed that shielding correction $A_s = 0$ for low buildings in the presence of diesel-electric locomotive noise. Even for rows of buildings which interrupt line-of-sight noise transmission from diesel-electric locomotives, attenuation will be limited due to the energy content in the low-frequency bands. This is a result of greater diffraction of sound with long wavelengths. If field measurements are unavailable, the following estimates may be used for rows of buildings which interrupt line-of-sight noise transmission. Various adjustments for buildings in the path of railway noise are given in Table 3.12.

Table 3.12: Adjustments for Buildings in the Path of Railway Noise

Row	Coverage (%)	Adjustment, A_s (dB A)	
		Diesel-electric locomotives	**Railroad cars, electric locomotives**
First	< 40	0	0
First	40 to 65	0	−1 to −3
First	66 to 90	−1 to −2	−4 to −5
First	100	Treat as barrier	Treat as barrier
Additional rows		− 1/row	−1.5/row
Limit of total adjustment for <100% coverage		− 5	−10

3.4.2.3 Passbys

Noise energy is proportional to the number of contributions of each type (diesel-electric locomotives, trains of railway cars, etc.). The passby adjustment is given by

$$A_{dur} = -1.8 + 10 \lg \left(\frac{T_L}{S} \right) \quad \text{.... (3.67)}$$

where,

A_{dur} = passby duration adjustment (dB A)

S = speed (mi/hr)

T_L = train length (ft)

If train length is unknown, it may be estimated by assuming that the average freight car is 55 ft. long and the average passenger car and rapid transit vehicle 75 ft. long. All-electric locomotives may be treated as passenger cars and added to train length.

3.4.2.4 Time Interval

The reference noise levels are based on a 1-s contribution to equivalent sound level. The time interval correction is given by

$$A_{int} = -10 \lg t = -10 \lg (3600\ T) \qquad \text{.... (3.68)}$$

where, A_{int} = time interval adjustment (dB A)

t = time (s)

T = time (hr)

Thus, the correction is:

A_{int} = -35.6 for L_{eqH}, the hourly equivalent sound level

= -44.6 for L_{eq8}, the 8-hr equivalent sound level

= -49.4 for L_{eq24}, 24-hr equivalent sound level

= -49.4 for L_{DN}, day-night sound level

Equivalent sound level and day-night sound level due to railway and rapid transit noise can be calculated from the equations given below:

The sound level contribution due to a given source type is given by

$$L = L_{red} + A_D + A_{track} + A_{barrier} + A_{passby} + A_S + A_{dur} + A_{int} \qquad \text{.... (3.69)}$$

where,

L = the sound level contribution due to a given source type (diesel-electric locomotives, railway cars or rapid transit vehicles) (dB A)

L_{ref} = the reference level for that source type (dB A)

$A_{()}$ = the adjustments for distance, track condition, barriers, number of passbys, building shielding, passby duration and time interval (dB A)

Combined sound level at the selected observer point is given by

$$L_{eq} = 10 \lg \sum_{i=1}^{n} 10^{L/10} \qquad \text{.... (3.70)}$$

where, L_{eq} = combined sound level L_{eqH} or L_{eq24} or L_{DN} (dB A), depending on the time period and weighting of nighttime passbys used to obtain the adjustments above n = the number of source types which affect sound level at the observer

3.4.3 Federal transit administration

Federal Transit Administration (FTA) Guidelines has been used to calculate the change in noise and vibration levels to determine impact. The default FTA reference source levels are used to estimate project-specific noise levels at sensitive receptor locations. Reference noise levels for various proposed transit sources are presented in Table 3.13.

Table 3.13: Reference Noise Levels and Sound Exposure Levels

	Group	**Description**	**Lmax**	**SEL**
1	RAIL	Rapid transit car passbys	80	82
2		Rapid transit car horns	90	93
3		Locomotives - diesel	88	92
4		Locomotives – electric	86	90
5		Commuter rail car passbys	80	82
6		Locomotive horns	105	108
7		Wheel squeal	100	136
8		Aux. equip. – rapid transit	67	103
9		Locomotive idle	80	116
10		Aux. equip. – commuter car	65	101
11		Grade crossing signal	73	109
12		Maintenance facility	82	118

Reference FTA maximum noise levels (or Lmax) or sound exposure levels (or SEL) are reported in A-weighted decibels (dB A) at a reference distance of 15.24 meter and 50 mph (for mobile sources only).

Criteria propagated by FTA are used to estimate impacts at noise-sensitive receptor locations. The Federal Transit Administration's "Transit Noise and Vibration Impact Assessment" Guidance Manual sets forth the basic concepts, methods and procedures for evaluating the extent and severity of noise impacts from transit projects. The guidelines assess impacts of noise based on the selected land-use's sensitivity to noise. FTA does not consider most commercial and industrial receptors sensitive to transit-related noise. As exposed in Figure 3.10, FTA noise impact criteria are defined by two curves that allow increasing project noise levels as existing noise increases up to a point, beyond which impact is determined based on project noise alone. FTA noise criteria are delineated into two categories: moderate impact and severe impact. Table 3.14 represents FTA land use categories and noise metrics.

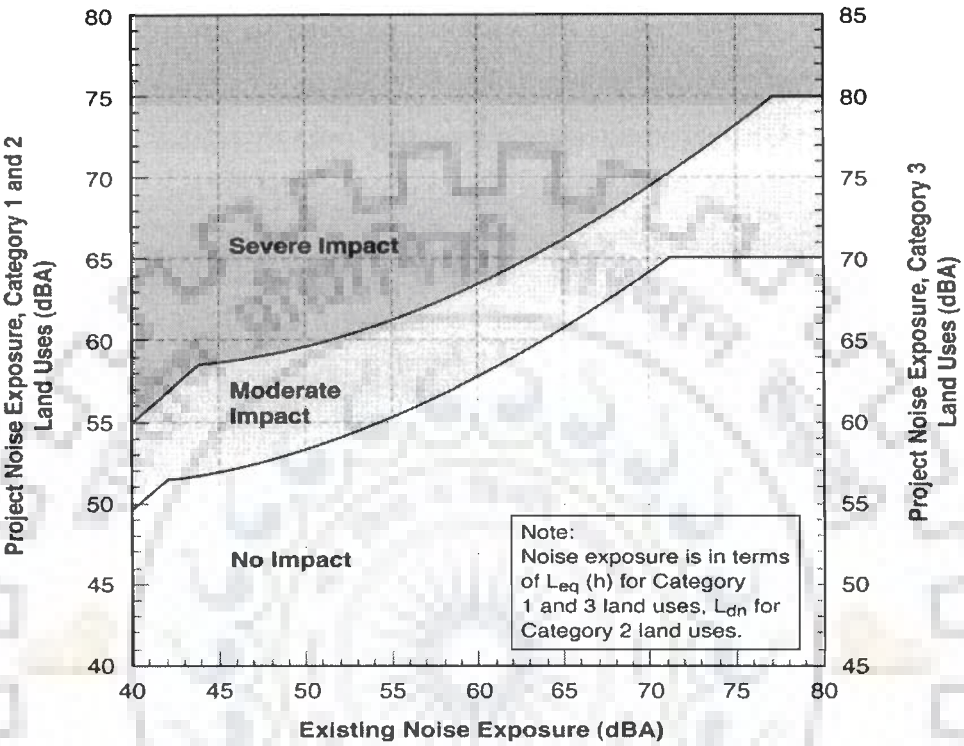


Figure 3.10: FTA Noise Impact Criteria for Transit Projects

Source: Federal Transit Administration, 2006

Table 3.14 FTA Land-Use Categories and Noise Metrics

Land-use category[1]	Noise level[2]	Description
1	Leq (h)	Tracts of land set aside for serenity and quiet, such as outdoor amphitheatres, concert pavilions, and historic landmarks
2	Ldn	Buildings used for sleeping include residences, hospitals, hotels and other areas where nighttime sensitivity to noise is of utmost importance.
3	Leq (h)	Institutional land-uses with primarily daytime and evening uses include schools, libraries, churches, museums, cemeteries, historical sites and parks, and certain recreational facilities used for study or meditation.

1 Land-Use categories are based on sensitivity to noise intrusions

2 The criteria threshold noise limits range from an hourly equivalent noise level (or Leq(h)) for Category 1 and 3 receptors to the day-night noise level (or Ldn) for Category 2 receptors.

3.5 Review of Traffic Air Emission Modelling

The models can be used to assess the air pollutant from vehicular source along the urban road network.

3.5.1 Deterministic Model

Deterministic models are based on analytical approach. The model can estimate pollutant concentration from emission inventory and meteorological variables, according to the solutions of various model equations, representing the relevant physical processes. For the first time, Waller *et al.* (1965) informed about the deterministic vehicular pollution modeling (DVPM). Chen and March (1971) proposed the analytical method for the estimation of pollution levels from motor vehicles. An analytical way out to a two dimensional transport and diffusion equation was originated by Dilley and Yen (1971). Further Peter and Klinzing (1971) portrayed two detach equations for ground level as well as elevated line source and also analyzed the effects of diffusion coefficient in line source dispersion. Lamb and Neiburger (1971) developed a model for computing pollutant concentration coming from point and line sources. A hypothetical model for finite line source was developed by Csanday (1972). This model was applicable in perpendicularity of wind to the roadway. He assumed a hypothetical line source existing along the direction perpendicular to that of the wind. Due to this line source the concentration of pollutant at receptor is given by the following equation:

$$C' = \frac{Q}{2\pi\sigma'_y\sigma'_z\bar{u}}\left[\exp\left\{-\frac{1}{2}\left(\frac{z-H}{\sigma'_z}\right)^2\right\}+\exp\left\{-\frac{1}{2}\left(\frac{z+H}{\sigma'_z}\right)^2\right\}\right]\times\int_{-L/2}^{L/2}\exp\left[-\frac{1}{2}\left(\frac{Y'_1-Y_1}{\sigma'_y}\right)\right]dY'_1 \quad \text{(3.71)}$$

where:

Q = source emission rate per unit length

z = height of the receptor above the ground

H = height of the line source

$\bar{u}$ = mean ambient wind speed at source height H

σ'_z = vertical dispersion coefficients

σ'_y = horizontal dispersion coefficients

The study about the upshot of oblique wind on line source pollution dispersion near roadway was done by Calder (1973). Dabberdt *et al.* (1973) offered a practical multipurpose urban diffusion model (APRAC-1A) for the prediction of inert vehicular pollutant concentration. Sharma and Myrup (1975) proposed a model for the diffusion of pollutants from a line source in an urban atmosphere. Stukel *et al.* (1975) prepared a line source dispersion model for the calculation of particulate or gaseous pollutant concentration in urban roadways. For the prophecy of CO concentration, Nicholson (1975) developed a scalar budget box diffusion model. Cadle *et al.* (1976) reported the General Motor (GM) corporation experimental data and these data were used for the understanding traffic influences on adjoining roadways. Chock (1977a) performed a number of experiments to assess the influence of traffic on dispersion of pollutants near urban roadways. The United State Environmental Protection Agency (USEPA) developed so many air pollution models like CALINE, EGAMA, and HIWAY for highway. Chock (1977b) and Noll *et al.* (1978) assessed the CALINE, EGAMA and HIWAY models and conclude that the EPA-HIWAY model overestimate pollutant concentrations adjoining to the highway. Ward *et al.* (1977) and Benson (1979, 1989) developed the improved version of CALINE model, viz. CALINE-2, CALINE-3 and CALINE-4. This model was based on Gaussian diffusion equation. In addition to this the model uses a mixing zone to characterize the dispersion of pollutants over roadway. It can predict the pollutant concentrations for receptors sited within 500 meter of the roadway. The CALINE 4 model separate individual highway links into a series of elements from which incremental concentrations are computed and then summed to form overall concentration estimates for a particular receptor position as represented in figure. Each element is modeled as an “equivalent finite line source” positioned normal to the wind direction and centered at the element midpoint. The emission occurring within the element is modeled using the cross finite line source Gaussian equation. Concentration due to source of segment of length dy is given by:

$$dc = \frac{qdy}{2\pi U\sigma_y\sigma_z}\left\{\exp\left[-\frac{y^2}{2\sigma_y^2}\right]\right\}\times\left\{\exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]+\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right]\right\} \quad \text{.... (3.72)}$$

Where *dc* is the concentration of the source segment at receptor (x, y, z) ($\mu g/m^3$), *U* is wind speed at effective release (μg/m/sec), *q* is line source strength, *H* is effective source height, σ_y, σ_z is horizontal and vertical dispersion coefficients in y and z directions respectively and d_y is source segment length (m).

Chock (1978) described the downwind dispersion of pollutant near the roadway. Based on an infinite line source approach, this model specifies the dispersion parameters as a function of wind road orientation and the distance from the source to the receptor. It also includes plume rise over the highway due to heated exhaust under stable and high wind conditions. The pollutant concentration 'C' at a point (x, z) relative to the line source at x=0 is given by:

$$C_{(x,z)} = \frac{Q}{\sqrt{2\pi}U\sigma_z}\left\{\exp\left[-\frac{1}{2}\left(\frac{z+h_0}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z-h_0}{\sigma_z}\right)^2\right]\right\} \quad \text{.... (3.73)}$$

where:

$C_{(x,z)}$ = concentration at point (x, z) relative to the line source

Q = emission rate per unit length

U = effective cross road wind

σ_z = vertical dispersion parameter

h_0 = plume centre height distance x from the road.

This model was found to have the highest correlation with the observed concentration for all wind-road angles, except when the wind is parallel to the road.

Rao *et al.* (1980a) evaluated four Gaussian models, i.e. GM, HIWAY, AIRPOL-4 (Carpenter and Clemena, 1975), CALINE-2 and three numerical models like DANARD (Danard, 1972), MROAD-2 (Krisch and Mason, 1975) and ROADS (Pitter, 1976). On the basis of their study it is concluded that GM model simulations were more specific than any other model. Peterson (1980) proposed an updated version of HIWAY model, i.e. HIWAY-2, which was liberated by EPA in May 1980. Rao and Keenan (1980) modified the

Pasquill-Grfford dispersion curves built in the EPA-HIWAY model and got that the modified HIWAY model (HIWAY-3) had better performance than the original HIWAY model. Further the next modified version, HIWAY-4 was discovered by integrating dispersion curves and an aerodynamic drag factor to the original HIWAY model. Chang *et al.* (1980a) again evaluated EPA rollback model (EPARM) and Generalized Rollback Model (GRM) and these models showed the similar prophecy on giving identical inputs. Munshi and Patil (1981) employed analytical models for the evaluation of vehicular pollutant dispersion on Indian urban roadways having heterogeneous traffic. Hickman and Colwill (1982) explained an effective method by using Gaussian dispersion theory and empirical modifications for the calculation of the pollutant concentration around highways. Rodden *et al.* (1982) appraised five line source emission models, i.e. CALINE-3, CALINE-2, AIRPOL-4, HIWAY and TRAPS-IIM (Bullian *et al.* 1980). Nelli *et al.* (1983) expanded the Texas Instrumentation model (TEXIN) for the prediction of air quality near roadway intersection. Further he compared the TEXIN model predictions with three intersection models namely Inter Section Midblock Model, Program MICRO and Indirect Source Guidelines and found the better performance of TEXIN predictions. Segal (1983) proposed a Graphical Input Microcomputer Model (GIMM) for the prediction of CO concentration from different types of line sources. Cohn and Gaddipati (1984) recommended an interactive graphics method for highway air pollution analysis. Beiruti and Al-Omishy (1985) proposed a digital computer model for the simulation of traffic flow. Hlavinka *et al.* (1987) described TEXIN-2 model, an improved version of TEXIN model. Khalil and Rasmussen (1988) devised a chemical mass balance (CMB) model and applied this model for CO distribution among residential wood burning sources and automobile sources in Olympia, Washington.

Luhar and Patil (1989) developed a Gaussian diffusion equation based GFLS model for heterogeneous traffic condition. This model was based on Gaussian diffusion equation. The utility of this model is to handle the all orientations of wind direction with road. This model is very helpful for long term concentration prediction of pollutants and the modified GFLSM can predict the concentration of particulate matter near the near roadway. On the basis of the comparison with other models it is revealed that GFLSM performs well in Indian condition. The following equation can be used to predict the concentration of air pollutants.

$$C = \frac{Q}{2\sqrt{2\pi}\sigma_z \overline{u_e}} \left[\exp\left\{ -\frac{1}{2}\left(\frac{z - h_0}{\sigma_z} \right)^2 \right\} + \exp\left\{ -\frac{1}{2}\left(\frac{z + h_0}{\sigma_z} \right)^2 \right\} \right]$$
$$\times \left[erf \left| \frac{\sin\theta (L/2 - y) - x\cos\theta}{\sqrt{2}\sigma_y} \right| + erf \left| \frac{\sin\theta (L/2 + y) + x\cos\theta}{\sqrt{2}\sigma_y} \right| \right]$$

where: .... (3.74)

$\frac{Q}{\sin\theta}$ = emission rate per unit length in line coordinate system

σ_y = function of downwind distance

σ_z = function of stability class

A separate model for the prediction of particulate matter concentration developed by incorporate two corrections in above equation i.e. the earth's reflection component of emission was neglected and the decrease in plume rise due to gravitational fallout of particulates caused by its self weight. The following equation can be used in this regard.

$$C = \sum_{i=1}^{N} \frac{w_i Q}{2\sqrt{2\pi}\sigma_z \overline{u_e}} \times \exp\left(-\frac{1}{2} \left[\frac{z - \left(h_o - \frac{V_{t_i} x}{(\overline{u} + u_0)(A + B\sin\theta)} \right)}{\sigma_z} \right]^2 \right)$$
$$\times \left[erf \left| \frac{\sin\theta (L/2 - y) - x\cos\theta}{\sqrt{2}\sigma_y} \right| + erf \left| \frac{\sin\theta (L/2 + y) + x\cos\theta}{\sqrt{2}\sigma_y} \right| \right]$$

.... (3.75)

Where, N is number of particle size classes, V_{t_i} is settling velocity corresponding to the average particle size of ith size class, w_i = weight fraction of particulates in the ith size class and A and B are stability dependent.

Kono and Ito (1990a) presented a microscale dispersion model, i.e. OMG volume source model. Kono and Ito (1990b) again compared the measured SF6 concentration results of OMG volume source model, JEA model, Tokyo model and EPA-HIWAY-2 model and found the superiority of OMG volume source model. Singh *et al.* (1990) proposed an IITCO analytical dispersion model for computing CO concentration for Indian and Kuwaiti traffic conditions and the results were compared with those of the pollution episodic model (PEM) and intersection mid block model. They found that IITCO model gives better predictions for Indian traffic conditions. Benson (1992) studied the CALINE-3 and CALINE-4 models and stated the better performance and predictive capability of CALINE-4 model. Alcxopolos *et al.* (1993) presented a model for spatial and temporal estimation of traffic emission in metropolitan areas. By using observed data Qin and Kot (1993) described an operational model to simulate the dispersion of vehicular emission in street canyons. Akeredoiu *et al.* (1994) implement the CALINE-4 model for the prediction of CO concentration at a roadway intersection.

Chan *et al.* (1995) evaluated four dispersion models namely APRAC, GZE (Guangzhou empirical), CALINE-4 and PWILG (Parallel wind and infinite line source Gaussian) models by comparing the predicted CO and NOx concentrations with the measured values in street canyons in Gauangzou city. The simulation of these models was found reasonably well. They found that CALINE-4 model over predicted the vehicular emission pollution in narrow street canyons if long cumulating link lengths were used. PWILG under predicted the same if only one reflection on each side was calculated. GZE performed significantly better than APRAC in predicting windward side concentration of pollutants in narrow street canyons.

Yu *et al.* (1996) came out with a mathematical model for evaluating trends in CO emission by using traffic counts and fleet composition.

Chock and Winkler (1997) contrasted the impact on air quality predictions by employing a fixed-layer depth and a varying-layer depth structure in the urban airshed model (UAM).

Khare and Sharma (1999) assessed the applicability of General Finite Line Source Model (GFLSM) by comparing the predicted CO concentration with the measured values obtained from CPCB, New Delhi. With the help of CPCB data, Delhi Finite Line Source Model (DFLSM) has been developed by modifying the GFLS model for traffic and meteorological conditions of Delhi city. With the Delhi finite line source model, the pollutant's concentration 'C' can be presented as given in equation below.

$$C = \frac{Q}{2\sqrt{2\pi\sigma_z u_e}}\left[\exp\left\{-\frac{1}{2}\left(\frac{z-h_0}{\sigma_z}\right)^2\right\} + \exp\left\{-\frac{1}{2}\left(\frac{z+h_0}{\sigma_z}\right)^2\right\}\right] \quad \text{.... (3.76)}$$

Various parameters of this equation have already been explained in previous equations.

To identify street canyon and vehicle wake effects on transport of air pollution from urban road microenvironments, Karim and Matsui (1998a) and Karim *et al.* (1998b) presented a computer model consisting of emission dispersion, wind distributions and modified Gaussian equation. Goyal and Ramakrishna (1999) again performed a comparative study of Indian Institute of Technology Line Source Model (IITLS) and California Line Source Dispersion Model (CALINE-3). They estimated the NO_2 concentration at various locations in Delhi and compared against observed air quality data. On the basis of study it is concluded that IITLS model may be more preferred because of Indian conditions than CALINE-3 model. The IITLS model can be implemented for pollutants prediction due to vehicular traffic in urban cities of India. The evaluation of four Gaussian dispersion models, namely, GM, CALINE-3, PAL-2 and ISCST-2 was done by Sivacoumar and Thanasekaran (2001) for Indian conditions. Nagendra and Khare (2002) focused the use of Line Source Emission Models in the study of vehicular exhaust emissions and favored the LSEM as a useful tool for the prediction of urban air quality.

3.5.2 Numerical models

Line source numerical models come under deterministic modeling technique which is based on numerical approximation of partial differential equations representing atmospheric dispersion phenomenon. Danard (1972) came out with a two-dimensional Eularian model named as DANARD. It is based on the solution of mass conservation equation using numerical methods. This model was initially used to predict CO concentration near highways. In addition to this the other models are MROAD-2 and ROADS proposed by Krisch and Mason (1975) and Pitter (1976). MROAD-2 is an Eulerial, two dimensional model, based on the mass conservation equation, whereas The ROADS is also two-dimensional mass conservation model, which predicts the concentration reasonably well. Another numerical model is also developed by Chock (1978) to resolve advection diffusion equation for a line source. Eskridge *et al.* (1979) suggested a finite difference highway model. This model has capability to determine the atmospheric structure along the roadway. Again Eskridge and Thompson (1986) formulated the ROADWAY model, a finite difference model for the prediction of pollutant concentration near roadway. Further Eskridge and Thompson (1982) developed a ROADCHEM model, a version of ROADWAY model. This model includes the chemical reactions involving NO, NO_2 and O_3 as well as advection and dispersion phenomena. Maddukuri (1982) portrayed a numerical for the estimation of vehicular exhaust (CO) dispersion. A modified version of ROADWAY model by using eddy diffusion coefficients has been developed by Eskridge and Rao (1986). Dutch National Institute of Environmental Health (RIVM, 1991) and Dutch Institute of Applied Scientific Research (Van *et al.*, 1989) presented a method to calculate air pollution from road traffic (CAR) model. Eerens *et al.* (1993) developed CAR model to calculate the average concentration and concentration percentiles in streets for inner pollutant as well as nitrogen dioxide (NO_2) by using accessible input data. From their research, they concluded that CAR model is a satisfactorily consistent and viable technique for the calculation of traffic exhaust air pollution in urban streets. CAR-FMI (Harkonen *et al.*, 1995, 1996) is a road network dispersion model, developed by the Finnish Meteorological Institute. Karppinen *et al.* (1997, 1998) depicted the function of CAR-FMI model in evaluating the contribution from mobile sources in predicting the emission, dispersion and chemical transformation of NOx in an urban area. Choi *et al.* (2006) applied 3D Eulerian air quality model, MODELS-3/CMAQ to simulate high particulate matter events over the sister cities of Douglas (AZ) and Agua Prieta (Sonora), located in the US–Mexico border. Model evaluations showed acceptable PM predictions, while demonstrating the need for including the interaction between meteorology and emissions in an interactive mode in the model. Sensitivity studies on boundary influence indicate an insignificant regional contribution of PM to the study area. Choi and Farnando (2008) implemented a time-dependent entrainment parameterization for windblown dust in the CMAQ/MM5/SMOKE modeling system with the aim of improving PM predictions. Comparison of model predictions with observational data taken at a pair of US/Mexico border towns showed a clear improvement of model performance upon implementation of the dust emission flux parameterization.

3.5.3 Stochastic models

These models compute the pollutant's concentration by statistical methods after an appropriate relationship establishment between predicted and observed concentrations of air pollutants. Simple regression, multiple regression are some of key methods in statistical modeling. It also consists neural network models which are based on "learning by example" process.

McGuire and Noll (1971) learned the relationship between maximum concentration and average time for CO, NOx and NO_2 pollutants collected at 17 monitoring stations in California City. Mc Collister and Wilson (1975) employed the B-J type models for short term prediction of oxidant and CO in Los Angeles basin. Chock *et al.* (1975) executed a univariate analysis of the weekly averages of the daily maxima of oxidant, CO, NO_2 and total HC for riverside. To predict the daily maximum concentration of CO, Aron and Aron (1978) developed stochastic model. Ledolter and Tiao (1979) proposed a statistical model that evaluated the CO concentration on both side of the freeway in Los Angles. Regresssion analysis technique had been used by Chang (1980) to determine the relative impact of mobile and stationary sources on ambient NO_2 concentrations. Zamurs and Piracci (1982) presented a multiple linear regression model to estimate CO concentration at selected intersections. Miles *et al.* (1991) recommended a hybrid approach for evaluating air quality implications of urban planning. This approach was the combination of deterministic and statistical model. Jakeman *et al.* (1991) utilized a hybrid (deterministic + stochastic) model to forecast the seasonal extremes of 1-h average CO concentration. US. Glen *et al.*, (1996) presented an empirical model of monthly CO for long-term trend assessment. Comrie and Diem (1999) observed the affiliation between meteorology, traffic patterns and CO concentration at seasonal, weekly and diurnal time scales in Phoenix. Sharma and Khare (2001b) proposed a stochastic model to estimate the CO concentration for Delhi heterogeneous traffic conditions. A general additive model for concentration prediction of PM10, PM2.5, NOx and NO2 due to vehicular emission has been proposed by Aldrin and Haff (2005). They predicted the concentration of these gases at four locations in Oslo city and compared with the observed value and obtained a good agreement between theses two values. In dispersion phenomenon of SPM and gaseous pollutants, the traffic and wind are found as a dominating factor. Artificial neural network model (ANN) is a kind of statistical modeling technique. It proffers several advantages over traditional phenomenological or semi-empirical models. This requires known input data set without any assumptions. By using readily available inputs NNM (Neural Network Model) automatically develops its own internal model and subsequently forecasts the output. According to Moseholm *et al.* (1996), for line source emission modeling, the multilayer perceptron (MLP) structure of the neural network is the most suitable for the prediction of vehicular exhaust emissions. Dorzdowicz *et al.* (1997) presented a line source neural network model for forecasting hourly mean concentrations of CO in the urban area of Rosario city. Gardner and Dorling (1999) came out with a MLP (Multi Layer Perceptron) neural network model using hourly NOx and NO_2 and meteorological data of central London. Nagendra and Khare (2004) proposed one-hour average artificial neural network based CO models for two air quality control regions in Delhi city namely a traffic intersection and an arterial road. The study illustrate that the neural network models are proficient to elucidate the consequences of traffic wake on the CO dispersion in the near field regions of the roadway. Grivas and Chaloulakou (2006) focused to estimate the potential of different neural network models to offer reliable evaluations of PM_{10} hourly concentrations. For their study they selected four locations within the Greater Athens Area and covered the period of 2001-2002 for used data. Through their study of evaluation of models they conclude that the performances of examined neural network models are superior in comparison with multiple linear regression models.

3.5.4 Hybrid models

Hybrid models are used to assess the complex composition of pollutants in vehicular emission. In this modelling approach two or more models are used simultaneously for the estimation of pollutants concentration. Such types of models show better performance than the individual models as they possess the strengths of all the component models. A hybrid class of model CAL3Q has been developed by TRB (Transportation Research Board), USA in 1985 to predict the concentration of different pollutant near urban intersection, based upon the signalized intersection analysis and the deterministic queuing theory. A computer based model was developed by Karim and Matsui (1998 a) and Karim *et al.* (1998 b). The model consists wind flow characteristics, which is simulated in the street canyon and analysed considering a two dimensional flow pattern. The data are used in improved Gaussian model to predict the background pollutants concentration. Along with this by using the same data in stochastic model, the background pollutants concentration has also been estimated. Miles *et al.* (1991) recommended a hybrid approach for evaluating air quality implications of urban planning. This approach was the combination of deterministic and statistical model. Jakeman *et al.* (1991) utilized a hybrid (deterministic + stochastic) model to forecast the seasonal extremes of 1-h average CO concentration. Kumar *et al.* (2004) used factor analysis-multiple regression (FA-MR), a receptor modeling technique for apportioning the contributing sources. This model was used in conjunction with dispersion models to estimate effective emission factors using an inverse modeling approach. From the study, it was found that there is considerable improvement in the prediction capabilities of dispersion model while using the effective emission factor derived through the hybrid approach. The concept was also applied to derive effective emission factor for gaseous component NO. The study indicates that application of a hybrid; receptor cum dispersion model, approach is one possible way to evaluate effective emission factors for vehicles which are in different operating conditions like those at traffic junctions. Gokhale and Khare (2005) presented a hybrid model to forecast the CO concentration distribution at one of the intersections. The used model include two components, one GFLSM (General Finite Line Source Model) as deterministic component and other one is LLD (Log Logistic Distribution) model as statistical component. They employed this model at ITO intersection in Delhi. On the basis of their study and validation of that model they concluded that the performance of the developed model is fairly well in 10-95 percentile range and thus the hybrid model exhibits intrinsic suppleness in the modeling implementation and its consistent prophecy precision. An emission factor based traffic related air pollution model has been employed by Xia and Shao (2005). By using this model, he computed the emission rates of different air pollutants like carbon monoxide (CO), oxides of nitrogen NOx) and particulate matter (PM_{10}). The required traffic data for dispersion model is obtained by using Lagrangian traffic flow model. The correlation analysis reveals that the modeled and observed data sets are well correlated. Schmitz (2005) applied Chilean Air Pollution Dispersion Model (CADM), a three-dimensional Eulerian chemical transport model consisting of the meteorological mesoscale model MM5 and a photochemical transport module, CTM for simulation of air pollution dispersion during summer in the Santiago basin. The CTM, driven by the MM5 meteorological outputs has been applied for the simulations of the dispersion of CO in the Santiago basin. By means of model simulations, the horizontal and vertical dispersion patterns have been identified and afterward the direction and quantum of transport of pollutants in the complex terrain have been explained. Goyal *et al.* (2006) applied three statistical models to forecast daily averaged concentration of RSPM in urban Delhi and Hong Kong. Model 1 is based on multiple linear regressions of meteorological parameters, model 2 is based on Box-Jenkins time series auto regressive integrated moving average (ARIMA) model and model 3 is a combination of the two. A detailed analysis of results of these models shows that the model 3 gives better results in comparison to model-1 and model-2 separately. The study also suggested that the model can be used reliably for future predictions. Chelani and Devotta (2006) proposed a hybrid model using combination of autoregressive integrated moving average model, to predict the air pollutant concentration, which deals with linear patterns and nonlinear dynamical model. The individual linear and nonlinear models were also applied in order to examine the performance of the hybrid model. The performance of the model is compared for one-step and multi-step ahead forecasts using the mean absolute percentage error and relative error. It is found that hybrid model outperforms the individual linear and nonlinear models and it can be used as an effective tool to forecast the air pollutant concentrations instead of applying individual models.

3.6 Software for Estimating Pollutant Emission

3.6.1 IVEM Model

The International Vehicular Emission (IVE) model was developed jointly by International Sustainable Systems Research Centre and the University of California at Riverside (Guo *et al.*, 2007). This is a java-based computer model that estimate vehicle emissions for any area. To calculate emission, it requires basically three kind of inputs i.e. the engine technology and add-on control distribution in the vehicle fleet, driving behaviour of the different types of on-road vehicles travelling on local roadways and vehicle emission factors specific to the local vehicles. In addition to this vehicle soak distribution and meteorological factors are also necessary to tailor the model to the local situation. The IVEM is highly complex model and consists several factors, vehicles and fuel types. It can be used to estimate emission at any scale (micro to macroscale). Along with this model is also very helpful to forecast future emission by changing required inputs. More than seven hundred technologies have been incorporated in this model. Each technology is allocated a base emission running factor and a base emission start factor. These factors are defaults in the model and have been developed from existing information mostly from the U.S., but some data are also collected from Thailand, China, and India. The mechanics of this model is simple and similar to other conventional model. The result obtained from this model, can simply be incorporated into a city or country emission inventory to assess the air quality. After the establishment of baseline emission inventory in any city or country, various policy decisions related to transport planning, motor vehicle growth, fuel changes and emission control system can be evaluated. This model permits for a comprehensive assessment of the air quality impacts from potential regulatory and growth scenarios.

3.6.2 COPERT Model

CORINAIR working group began in 1987 with the aim of developing a methodology for the estimation of vehicle emission in the reference year 1985. This methodology had been transformed into the computer programme "COPERT" (Computer Programme to Calculate Emission from Road Traffic), which was released in 1989 (Eggleston *et al.*, 1993). This model is used in many European countries and it brings together the results of several studies carried out in both individual EU member states and at the European level.

COPERT-III computes hot running fuel consumption rate and CO, HC, PM and NOx emission factors, expressed as g/km, as a direct function of travel speed. Different statistical models i.e. linear, exponential, logarithmic, polynomial, are incorporated in COPERT for several technology classes of light-duty vehicles, heavy duty vehicles and motorcycles. COPERT specifies separate models for the prediction of cold start and evaporative emissions. It also provides emission factors for a range of non-regulated pollutants such as speciated hydrocarbons, N_2O, NH_3 and PAHs. Speed correction is incorporated for three ranges of travel speeds for start emissions, but no speed correction is considered for non-regulated pollutant emissions and evaporative running loss emission. In addition to this, correction factor algorithms are specified in COPERT to adjust hot running emission factors for in-use deterioration, fuel consumption, road gradient and heavy-duty vehicle load.

3.6.3 CALINE 4

Benson (1989) proposed the latest version of CALINE series i.e. CALINE4 model. This is a line source model. This model is developed by California Department of Transport. This model can estimate the concentration CO, NO2 and aerosols. This model also includes an option for modeling intersections. This model uses a modified Gaussian plume approach with new provisions for lateral plume spread and vehicle induced thermal turbulence. This model also comprises sub models for CO model emissions and reactive plume chemistry.

CALINE 4 divides the highway into a series of elements and each element represents a section of the road. Each element is modeled as an 'equivalent' finite line source positioned normal to the wind direction and centered at the element midpoint. Element size increases with the distance from the receptor to improve conceptual efficiency. Incremental downwind concentrations are computed by using the cross-wind Gaussian formula for a line source of finite length:

$$C_{(x,y)} = \frac{Q}{\pi \sigma_z u} \int_{y_1 - y}^{y_2 - y} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) dy \quad \text{.... (3.77)}$$

where:

Q = linear source strength

u = wind speed

σ_y = horizontal Gaussian dispersion parameter

σ_z = vertical Gaussian dispersion parameter

y_1 and y_2 = FLS endpoint y-coordinates

Every element is separated into one central sub element and two peripheral sub elements. The strength of lineal source is computed assuming uniform emissions throughout the element. The peripheral sub elements emissions are modeled as decreasing linearly to zero at the ends of the FLS.

3.6.4 HIWAY-2 model

Peterson (1980) proposed that HIWAY-2 model is a steady-state Gaussian model. This model can be applied to determine air pollution concentrations at receptor locations downwind of 'at-grade' and 'cut-section' highways located in relatively uncomplicated terrain. For an at-grade highway, each lane of traffic is modeled as a continuous line source and for the cut-section highway; the top of the cut is considered an area source. The simulation of area source is done by using ten line sources of equal source strength. The total source strength equals the total emission from the lane in the cut. Every lane of traffic is modeled as though it ware a straight, incessant, finite line source with a uniform emission from the lanes in the cut. The air pollution concentration at a downwind receptor location is found by numerical integration along the length of each lane together with a summing of the concentrations from each lane. This model is unable to consider complex terrain or large obstructions to the flow. In this version of the model, no pollution emission module is included. In general line source strength is a function of traffic rate, average vehicle speed and traffic mix.

3.7 Review of KM Modelling in Transport Management System

Since the current traffic management system show limitations when facing critical traffic conditions and congestion. So the knowledge based system to traffic management operation may act as an effective tool. The concept of knowledge based systems was established at the end of the 1970s with several well known applications such as DENDRAL (Lindsay *et al.*, 1981), MYCIN (Buchanan and Shortliffe, 1984) and PROSPECTOR (Duda *et al.*, 1979). Traffic congestion is a frequent problem in mega cities in India. Such type of situation required the development of more strategic and high level control systems. The knowledge based system can act as intelligent assistants that cooperate in the task of defining and applying traffic control decisions. This is known as Intelligent Traffic Management System (ITMS). ITMS is a system that personifies a knowledge model of traffic behaviour at a strategic level. Traffic management is a very important asset of urban transport systems because proper traffic management and control can reduce the traffic problems like congestion, travel time and environmental problems in terms of noise and air pollution and fuel consumption. In earlier system the traffic management was based on a library of signal plans applied on-line in predefined situations according time-base criteria or to the traffic data collected by traffic actuated systems. But this system was not so successful because of the lack of conceptual granularity required by the system. Then in 1980, more adaptive systems were introduced and the initiation of this approach starts from the introduction of SCOOT model.

3.7.1 SCOOT model

This model was developed by Hunt *et al.*, 1981. This model is very useful in understanding the traffic situation in real time and it can be integrated with the model for decision making. This model is very useful for limited time interval congestion. But in case of continuous or persistent congestion, the operator intervention required because of the evaluation of the traffic situation by the system may be biased due to the insufficient understanding of the sensors about congestion process. Every problem area in transport sector requires analysis of situation using knowledge about traffic behaviour and control criteria.

3.7.2 KITS approach

This system was developed in the period 1992-1994 under the European Community (EC) research programme. This is a knowledge based modelling environment supporting knowledge acquisition and on-line operation of knowledge based management tools. A general architecture of this model is given in Figure 3.11 (Cuena *et al.* 1995). This approach is guided by two fundamental structuring principles-

(a) **Functional organization:** - for the solution of specific type of problem typical in the domain.

(b) **Topological organization:** - based on the hierarchical approach to traffic network analysis and control.

From the application of these two principles, any KITS supported application model consists of a structured collection of knowledge units, providing specialized knowledge and reasoning mechanisms required to deal with the different types of traffic management activities and reflecting the functional and topological knowledge structuring views. In this model three types of knowledge units are considered i.e. Agents, Actors and Supervisors.

Agent, Actor and Supervisor units provide the building blocks for the KITS knowledge architecture and identify the basis compositional levels underlying the architecture of any application model. In this model KITS Agents act as lowest level knowledge units and representing the basic functional capabilities of the model. In this model several types of agents have been designed with the aim of building up a 'library' of generic tasks to support traffic network supervision and management. These address several of the main chores and operations underlying the decision process, including:

1. **Data completion:** This type of Agent executes the interpretation of the available data and information on traffic in the area. Knowledge models are required to complete the partial picture conveyed by monitoring equipments. Data completion can be understood in two respects:
   (i) for rejecting incorrect or implausible data (due to malfunctioning of sensors)
   (ii) for information estimation when data is not available
2. **Problem identification:** In this the Agent appraises and interprets the available information, including both data collected by automated operations and information provided by inference. This knowledge agrees to understand the current situation, with the aim of identifying current or potential short-term problems and involves heuristic classification criteria based on a priori historical knowledge about recurring traffic problems in the area.
3. **Flow behaviour modelling and causal analysis:** This Agent performs a short term prophecy like evolution and causal explanation of identified problems supported by deeper models of traffic behaviour.
4. **Local control decision:** This type of Agent mainly support decision processes generating suitable control actions local to a problem area based on knowledge.
5. **Inconsistency detection:** This identifies inconsistent combinations of control actions related to overlapping problem area.
6. **Strategy completion:** This Agent generates control plan proposals for the whole traffic network which depends on the general view of the situation in the network as a result from the synthesis of local analyses and control proposals obtained from problem areas.

KITS Actor is a knowledge unit which is focused towards the traffic evaluation and management within a particular area in the traffic network. Actors are linked to problem areas. They meet the topological decomposition view within the KITS knowledge modelling approach. There are some basic elements which characterize an Actor:

a. the problem area managed by Actor
b. the set of Agents providing functional capabilities and knowledge required by the tasks to be solved in the area
c. an inference structure describing the reasoning strategy implemented by the Actor
d. an inference engine interpreting the inference structure to obtain Actor conclusions

KITS Actors are essentially combinations of various Agents and reasoning strategies. An Actor may be specific or generic depending on the type of problem to be solved. The Supervisors of KITS model represent the highest level task. They are responsible for building up an overall, consistent interpretation of conditions of the traffic network and for achieving a synthesis of decisions and action proposals produced at the level of problem areas by the relevant Actors. Supervisors are also knowledge units introduced to reflect the topological distribution of traffic analysis and management knowledge. KITS has developed three conceptual approaches: a strong version of the Supervisor concept – where the Supervisor acts in a prescriptive way imposing decisions to the Actors in case of conflicting proposals generated by different local units, a weaker version – means supervisor as a Mediator – where the Supervisor tries to negotiate conflicting proposals coming from different Actors by presenting further constraints for local decisions and tries to facilitate convergence to a common solution, then weakest version – means the Supervisor as a Facilitator – where the Supervisor acts as an information manager who has the knowledge about which Actor has the external knowledge eventually required by each other Actor to perform local tasks.

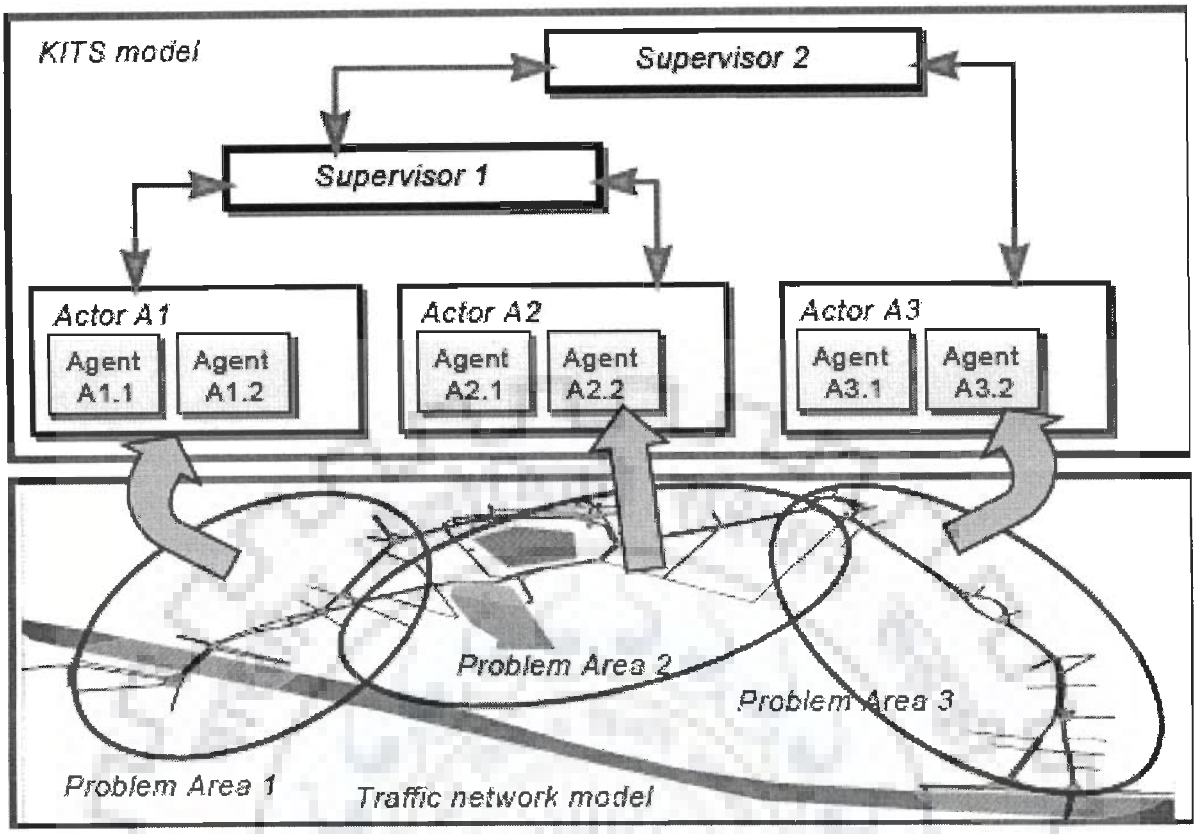


Figure 3.11: KITS Model Architecture

Source : Cuena *et al.*, 1995

3.7.3 TRYS model

This is a knowledge representation environment supporting model. The basic structure of this model is presented in Figure 3.12 (Cuena *et al.*, 1995). This model performs traffic management in urban, interurban and mixed areas. In this model the city or traffic network where traffic has to be supervised is divided in several sections called problem areas. The decomposition of the city into problem areas allows a better analysis and understanding of the causes and evolution of traffic problems. A problem area is a part of a city where traffic behaviour is locally studied and suitable control actions may be defined to improve the traffic state. Every problem area is supervised by an agent who understands the traffic conflicts that may appear the usual behaviour of vehicles in the area and the signal or VMS (variable message sign) actions that can improve the traffic. The control proposals generated by every agent are received by a higher level agent, called the co-ordinator, whose aim is to produce global proposals for the whole city by putting together the local proposals provided by the agents and removing the inconsistencies among them. Figure 3.13 shows the organization of a set of agents. The basic concept of this model is to organize the control knowledge in a set of local control entities named agents and a co-ordinator to synthesize the proposals. The model includes an agent to diagnose the traffic problems present in a local area and to propose control actions for available signal devices to improve traffic conditions. The knowledge of an agent is distributed in the following way:

Physical structure: It includes the knowledge about the behaviour of the traffic network of the problem area. This represents both static information about the network structure of the problem area and the dynamic aspects of this structure.

Traffic problems: It consist the knowledge about the detection and diagnosis of the presence of incidents or congestion.

Control actions: It comprises the knowledge about the definition of control strategies adequate to solve the different problems. Its objective is to find recommendations (warnings of slow traffic, warnings of congestion, recommended paths etc.) that decrease traffic on the set of problem paths.This model requires-

- A set of data base: it explains the physical structure of a problematic area.
- A collection of data frames: it represents the prototypical problematic situations.
- A knowledge base to support control decisions organized as a collection of control frames.

On the way of using this frame base, it may be applied in two reasoning modes:

(i) in the prediction mode to evaluate the possible impact of a set of messages on the traffic state. In this mode messages are premises and focus states or conclusions.

(ii) in the control mode to identify which frames produce a significant change in state of problem focus with respect to current situation. In this mode, the change in the state of the problem focus is input and messages to be displayed are output.

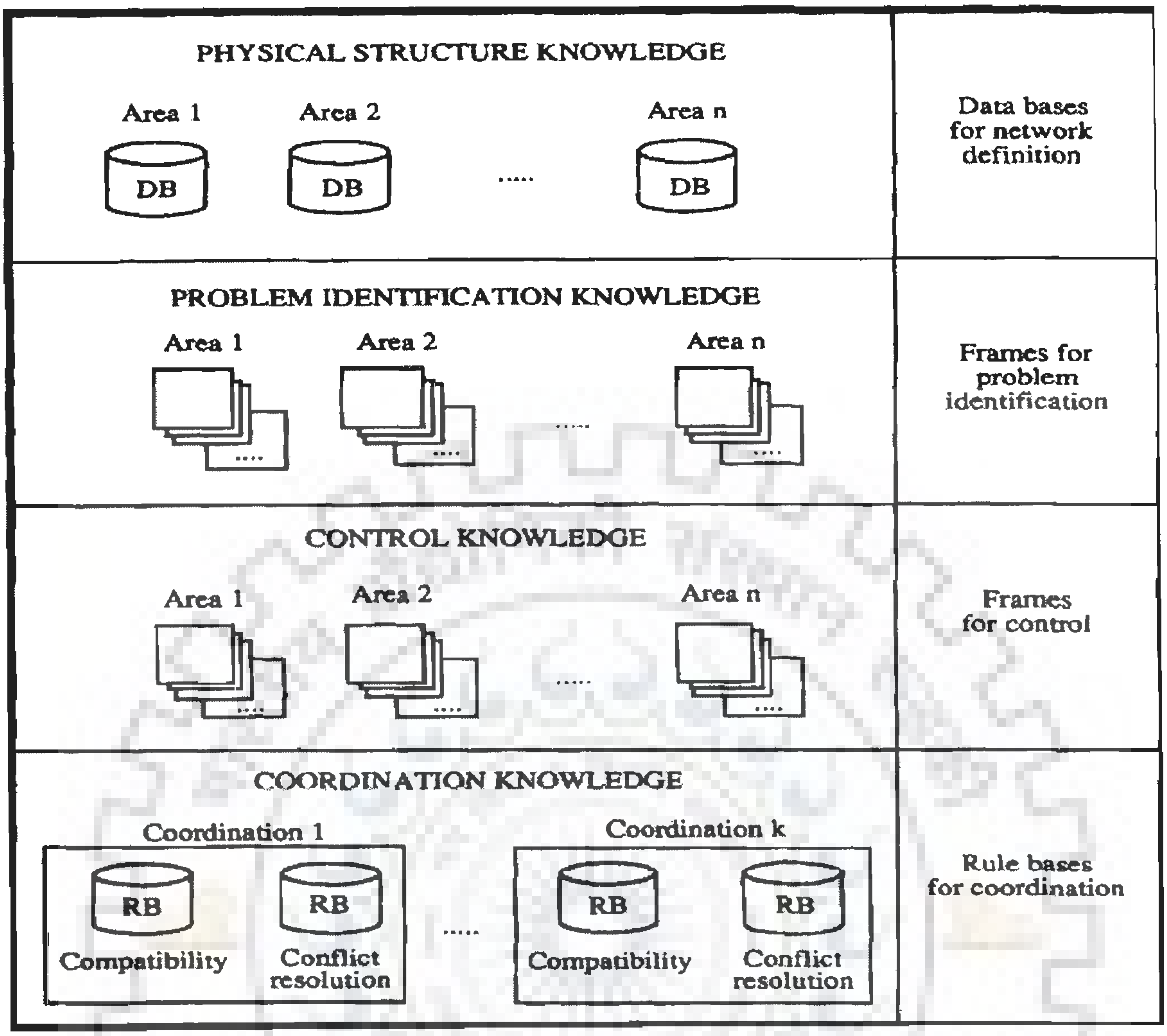


Figure 3.12: Structure of TRYS model

Source: Cuena *et al.*, 1995

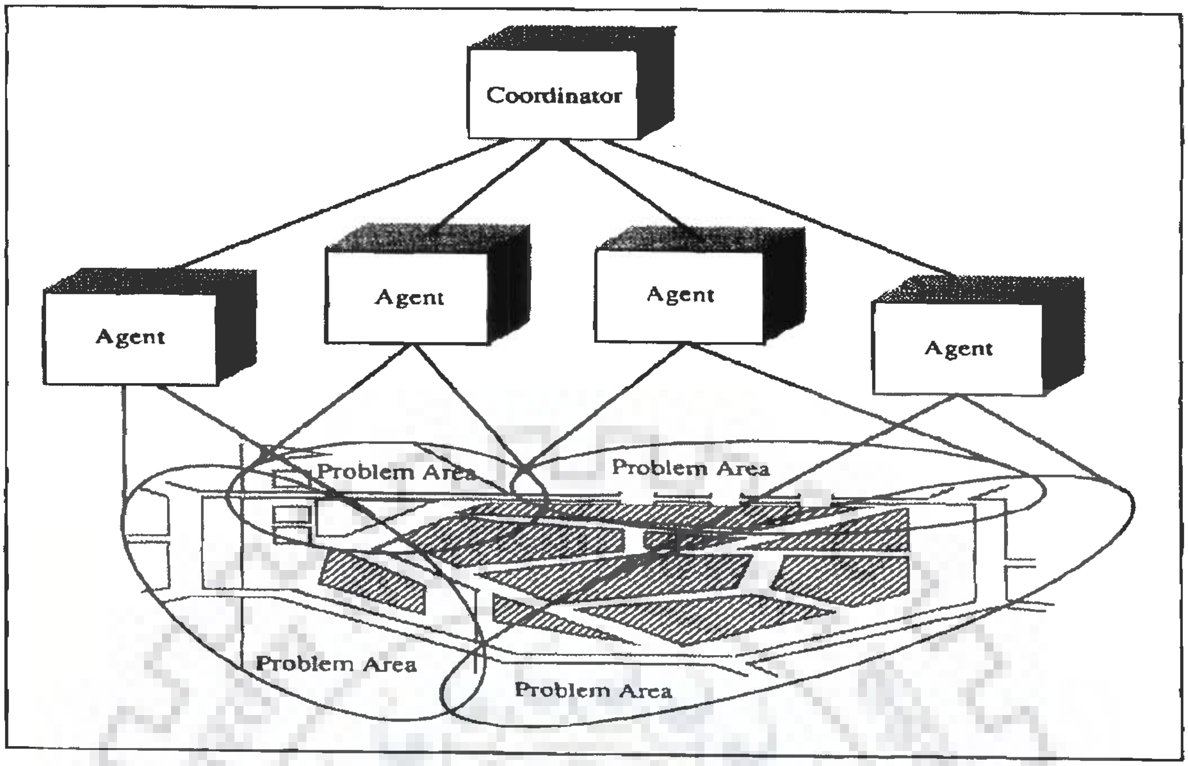


Figure 3.13: Basis Structure of Control Model

3.7.4 FLUIDS approach

This system was developed in the period 1996-1999 under the EC research programme. This is also a knowledge based modelling environment of intelligent interfaces for decision support. Basically this system develops from the experience in projects like KITS and TRYS. The main objective of FLUIDS approach is to support the development of intelligent interpreters capable to bridge the gap between the conceptual models of the users and the systems. FLUIDS approach (Figure 3.14, Cuena *et al.,* 1995) consists of three main components-

- Presentation manager: specialized in the input-output activities of the system
- Problem solving medium: this restrains a knowledge model consisting of a structured collection of automatic tools implementing the problem solving functionalities of the system usable to generate the answers
- Conversation manager: it plays the role of an intelligent interpreter between the user needs and the system capabilities.

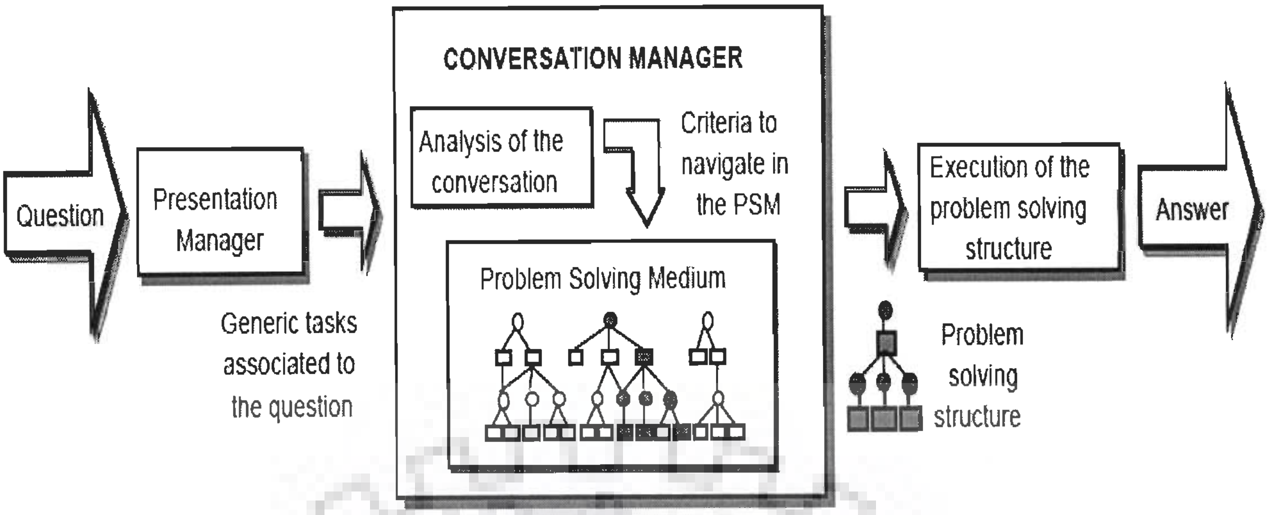


Figure 3.14: A Simple View of FLUIDS Approach

Source: Cuena *et al.*, 1995

In this approach the Conversation Manager applies a meta level knowledge model in two stages:

Analysis of the conversation: Foremost, taking into account the current question, the latest dialogue and possibly interaction preference specified by the user through the user interface the set of criteria that should guide the selection of the problem solvers is established. These criteria take into account not only considerations about the information context where a method has to be applied but also peculiarities of the methods related to conversation requirements as level of abstraction of output, level of assistance, precision degree, possibility of providing explanations etc.

Design of the inference structure: In this a routine design method is applied to configure, in a top-down fashion, the reasoning strategy to be followed selecting the problem solvers that satisfy as much as possible the criteria established in the first step. Once the inference structure has been determined, the corresponding tools in the Problem Solving Medium are applied to get answers with their associated explanations.

From above discussed models, it is clear that KM practices are applied in bits and pieces. In some models, data base management system, knowledge based decision support system are also applied. However no model has come out with the applications of KM practices in comprehensive approach. This study makes an attempt to develop noise and air pollution control model and traffic management model with specifically representing impact of KM practices for minimizing noise and air pollution along with traffic congestion.

3.8 Summary

This chapter consists of different models discussion applied in traffic noise estimation and metro rail noise prediction. These models are FHWA, CORTN, French, FTA etc. Likewise, a number of deterministic, stochastic and numerical models of air pollution are covered in this chapter. Some of the important models like GFLSM, CALINE, HIGWAY are broadly discussed in this chapter. Along with model discussion, available software application in noise and air pollution has been covered by this chapter. Discussion on Knowledge based models like SCOOT, TRYS, KITS etc. are the key modules of this section.

Chapter 4

MONITORING AND DATA COLLECTION

4.1 General

Delhi has primarily road based transportation network. Due to lack of road space, there is hardly any space for further expansion of road network and yet motorization is increasing continuously day by day in Delhi. The result is alarmingly high noise levels at sensitive locations of the capital city. Traffic noise becomes a major cause for irritation and concern for communities living in the vicinity of major road corridors. In view of the rapid vehicular growth in urban areas, it is necessary to study traffic noise with respect to causative factors. From the research point of view, two corridors i.e. MRTS and BRTS have been selected for the data collection related to traffic noise as well as metro rail noise. . The concept of a metro for Delhi was first formalized in the Delhi Master Plan of 1960. The idea of MRTS was approved in 1998, with an aim to improve the traffic condition and mobility of commuters. Delhi Metro is operating around 90 trains and carrying approximately 8 million passengers per day. Phase I of the metro network comprises 65.11 km of route length with 13.01 km underground corridor and 52.10 km surface/elevated corridor. Phase II of the network comprises 128 km of route length and 79 stations and is presently under construction, with the first section opened in June 2008 and a target completion date of 2010. Phase III (112 km) and IV (108.5 km) are planned to be completed by 2015 and 2020 respectively.

Along with this Bus Rapid Transit (BRT) Systems have came out as one of the primary modes of public transport. The objective of this system is to provide dedicated right of way to buses and simultaneously safeguarding cyclists and pedestrians by encouraging lane driving on engineered road spaces and connect them to metros and other colony roads for easy access. Besides giving priority to buses, the system also provides seperate lanes for pedestrians and non-motorized vehicles like cycles and rickshaws etc. Now a days, in highly urbanized capital city like Delhi, the increased number of vehicles on the road has not only reduced the mobility of a large section of people but also increased the pollution level, journey time and average per km fuel consumption. In present days people are very much worried about the traffic noise pollution problem, metro rail noise and vibration problem and traffic air pollution problem. The present study is focused towards the collection of various noise data as well as air pollution data. Along with this the study also covers the analysis of the existing problem on the basis of primary and secondary data.

4.2 Reconnaissance and Description of Study Corridor

Reconnaissance survey has been conducted to finalize the locations for the study. This survey has been carried out along the Line 1 corridor of Metro Line and BRTS corridor. The Line 1 corridor of metro operates between Dilshad Garden and Rithala (Figure 4.1). It covers a distance of 25.15 km. There are 21 stations between these two destinations. This corridor is partly elevated and partly at grade and crosses the Yamuna River between Kasmirigate and Shastri Park. The different criteria have been decided to select the locations along the corridor. First of all, only operational corridor has been selected. Secondly, it was also necessary that those locations should present different kind of land use pattern. In addition to this, only such kinds of locations have been selected where the elevated metro corridor passes through the high rise buildings. The basic reason behind this is to study the combined effect of traffic noise and metro noise on the people living near by areas and in high rise buildings. Four locations i.e. Rithala, Pitampura, Jhilmil and Dilshad Garden have been chosen along Line 1 of Metro where the problem of noise is found much more in comparison to other locations. At these four locations traffic noise as well as metro noise study has been conducted to understand the current scenario of traffic noise. On the other hand air pollution study has also been conducted at the identified locations i.e. Rithala, Pitampura, Kashmiri Gate and Jhilmil along MRTS corridor. Along with this BRTS is also operating in Delhi (Figure 4.2). BRT system is part of the Multi Modal Transport Policy of GNCTD (Government of National Capital Territory of India). Delhi has introduced a new concept of public transport system i.e. Bus Rapid Transit System (BRTS), promoting segregated lane for movement of buses. Total 7 BRT corridors are proposed to be built in the first phase while another 26 corridors covering a total length of 310 km are proposed to be built by the year 2020. One location has also been selected at this corridor for the traffic noise study as well as vehicular pollution study. Overall six locations i.e. Rithala, Pitampura, Kashmiri Gate, Jhilmil, Dilshad garden and Panchsheel Enclave are chosen to perform the noise and air pollution research. The Google earth map of all the selected locations are depicted in Figure 4.3, 4.4, 4.6, 4.7, 4.8 and 4.9 correspondingly. Table 4.1 presents the list of identified locations at different public transport corridors.

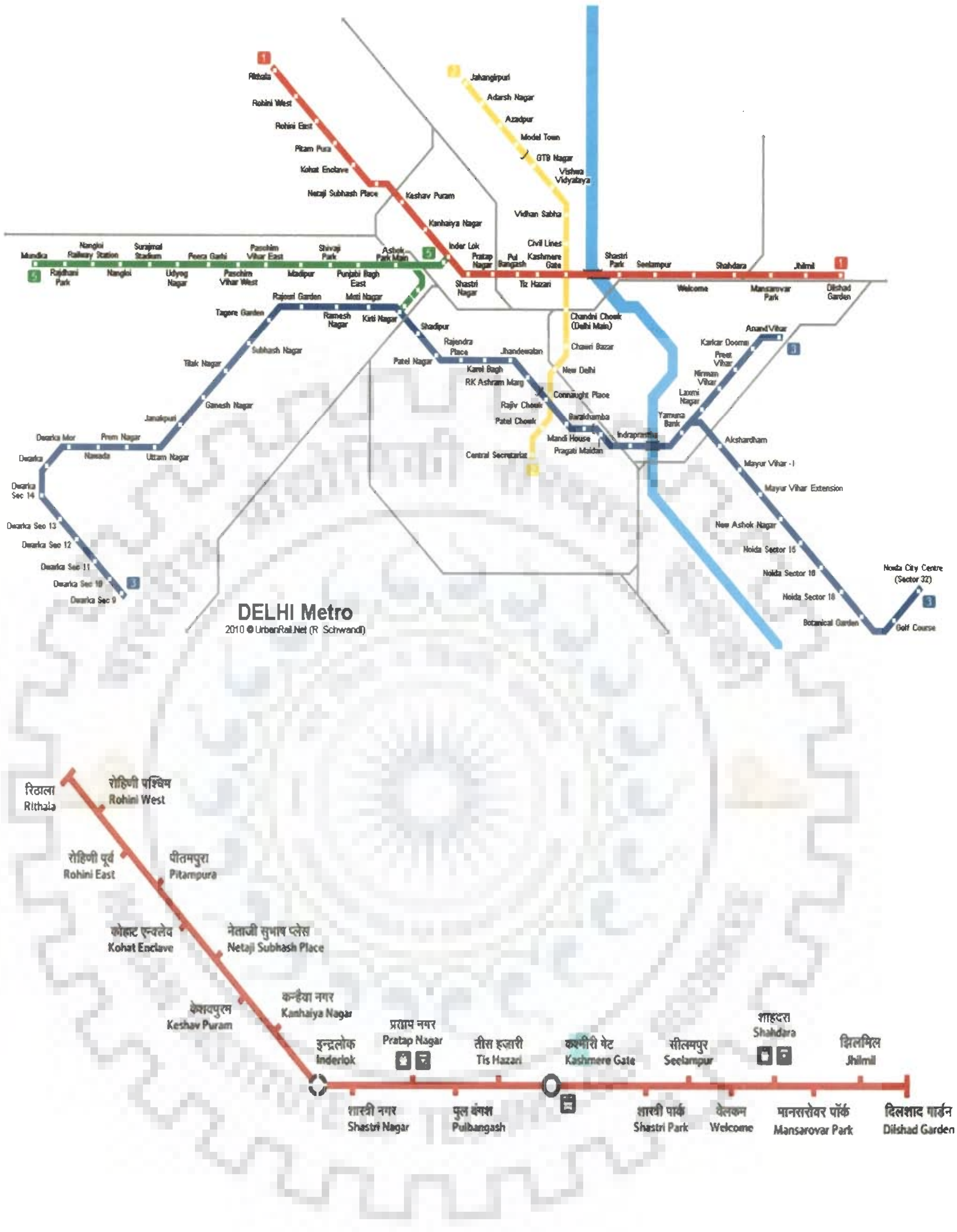


Figure 4.1: MRTS Network of Delhi with Red Line

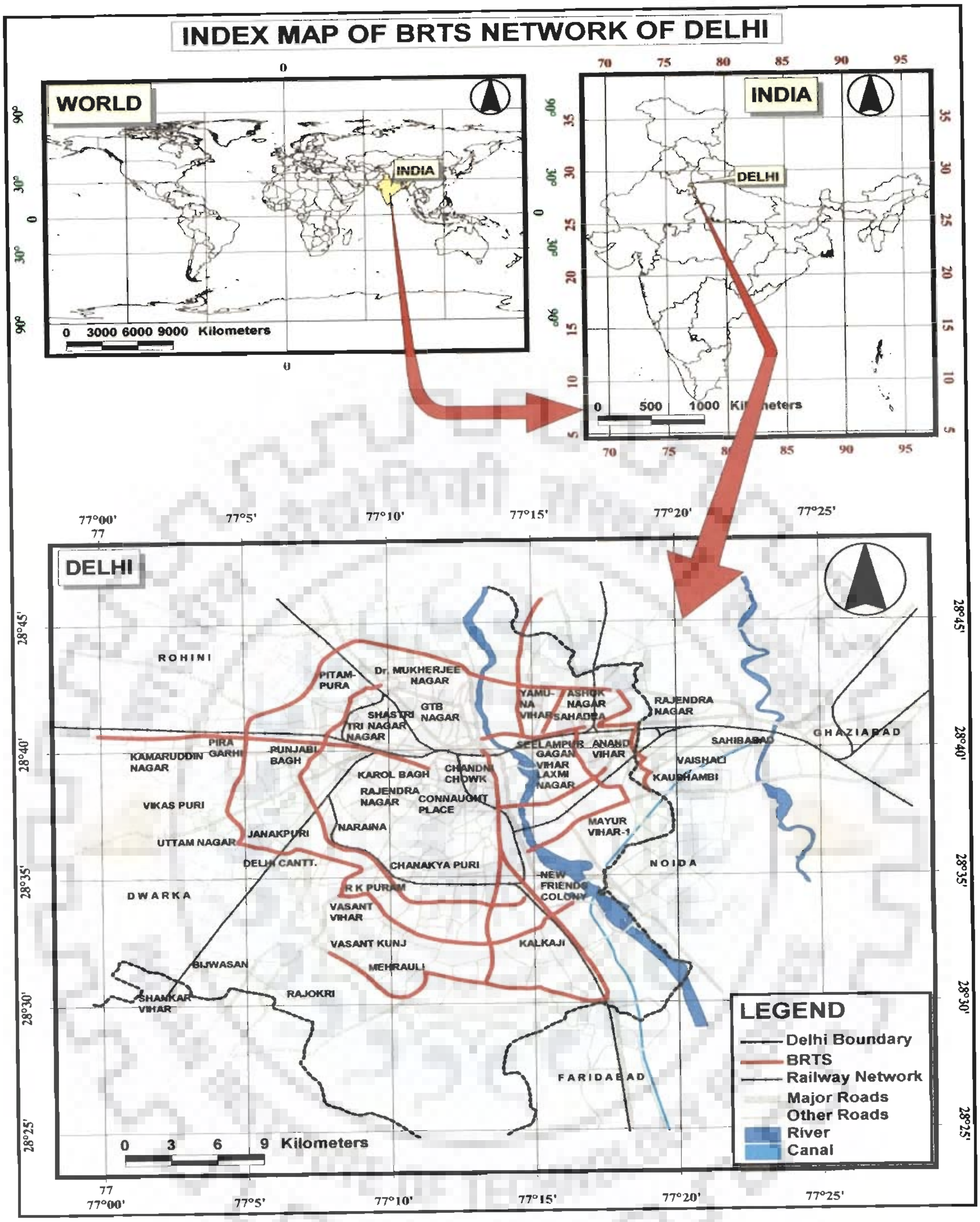


Figure 4.2: BRTS Network of Delhi

Table 4.1: List of Selected Locations for Traffic and Metro Noise Study

No.	Name of Locations	Land Use	Name of Corridor
1	Rithala	Commercial and Residential	MRTS Corridor
2	Pitampura	Commercial and Residential	MRTS Corridor
3	Kashmiri Gate	Commercial	MRTS Corridor
3	Jhilmil	Commercial and Residential	MRTS Corridor
4	Dilshad Garden	Residential	MRTS Corridor
5	Panchsheel Enclave	Commercial and Residential	BRTS Corridor

Figure 4.3: Google Earth Map of Rithala

Figure 4.4: Google Earth Map of Pitampura

Figure 4.5: Google Earth Map of Kashmiri Gate

Figure 4.6: Google Earth Map of Jhilmil

Figure 4.7: Google Earth Map of Dilshad Garden

Figure 4.8: Google Earth Map of Panchsheel Enclave

4.2 Classified Traffic Volume Study

The traffic volume has been collected at all the selected locations of the different corridors. The counting has been done manually for a period of 12 hours from 8:00 am to 20:00 pm. Due to heterogeneous traffic condition in Delhi, the vehicles have been categorized into eight categories i.e. car, mini bus, bus, two wheelers, mini truck, truck, tractor/trailer and auto-rickshaw. Each category of vehicle has been counted on both sides of the identified locations for noise assessment and air pollution assessment. Each classified traffic volume data in both the direction of Rithala, Pitampura, kashmiri Gate, Jhilmil, Dishad Garden and Panchsheel Enclave are presented in Figure 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19 and 4.20 respectively. These figures indicate the hourly variation of different categories of vehicle at selected locations along major public transport corridor.

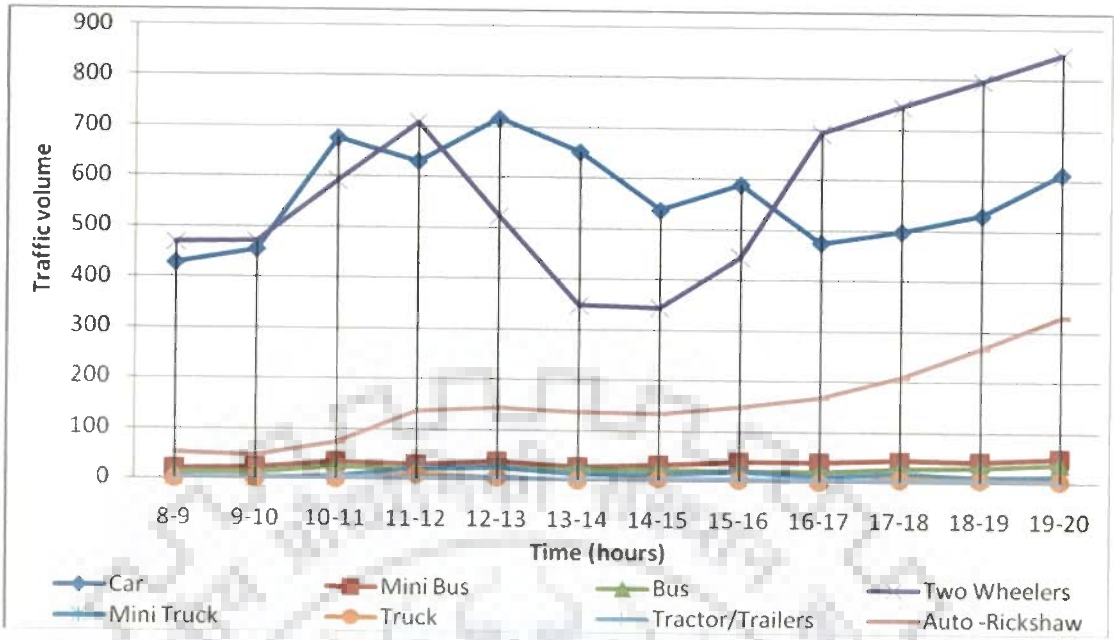


Figure 4.9: Temporal Variation of Traffic Volume at Rithala (Towards Rithala)

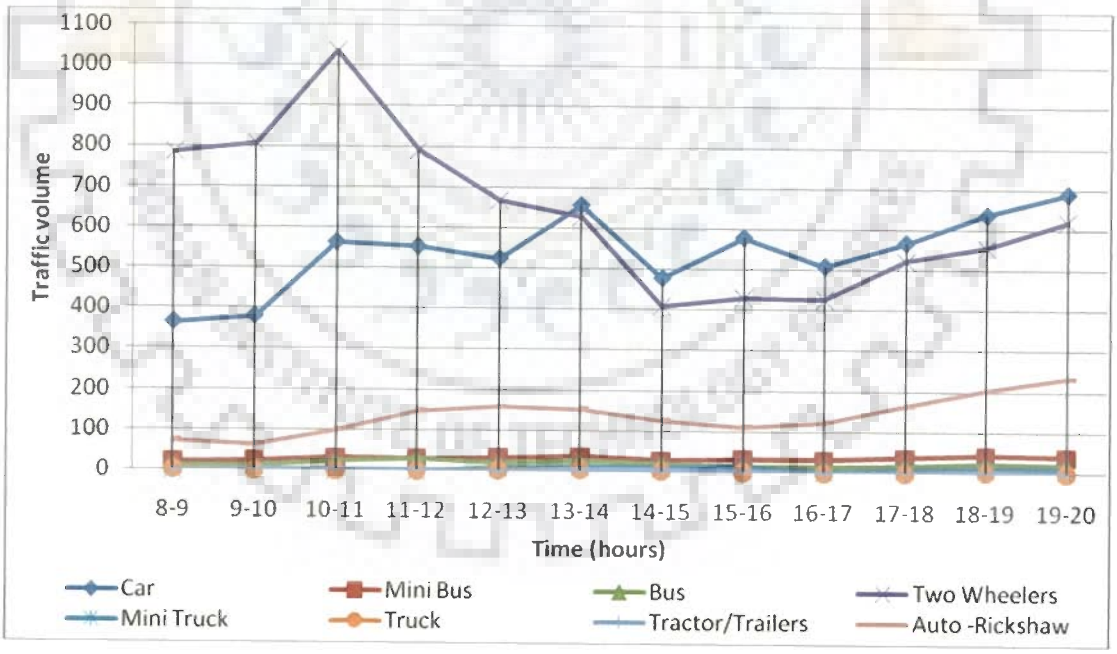


Figure 4.10: Temporal Variation of Traffic Volume at Rithala (Towards Rohini East)

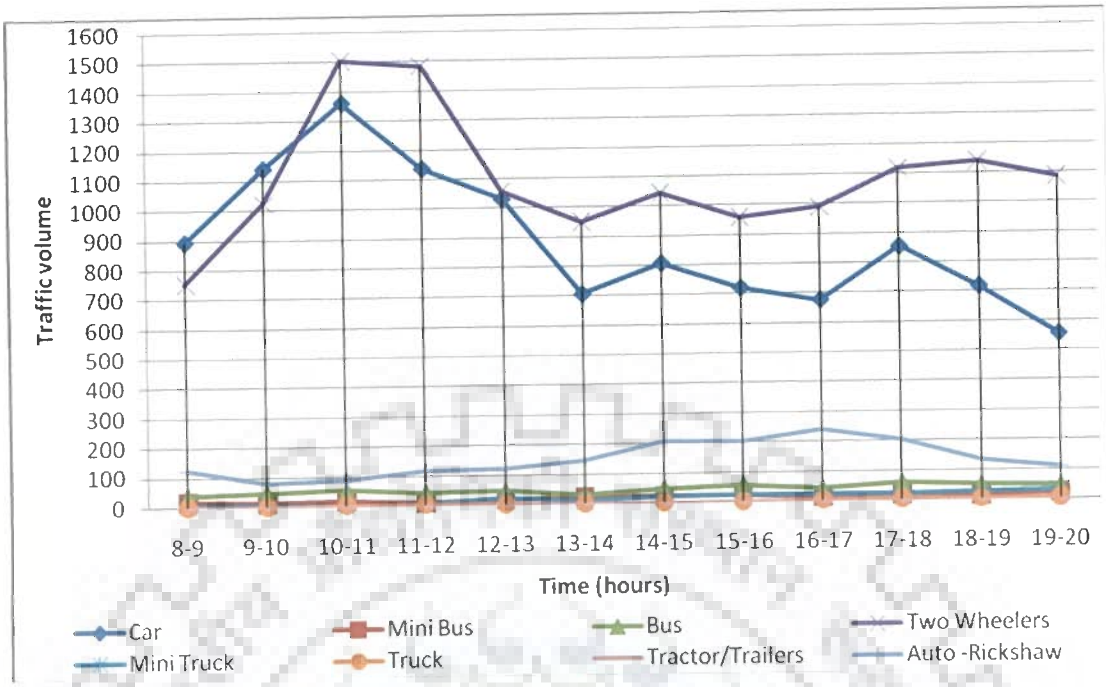


Figure 4.11: Hourly Variation of Traffic Volume at Pitampura (Towards Pitampura)

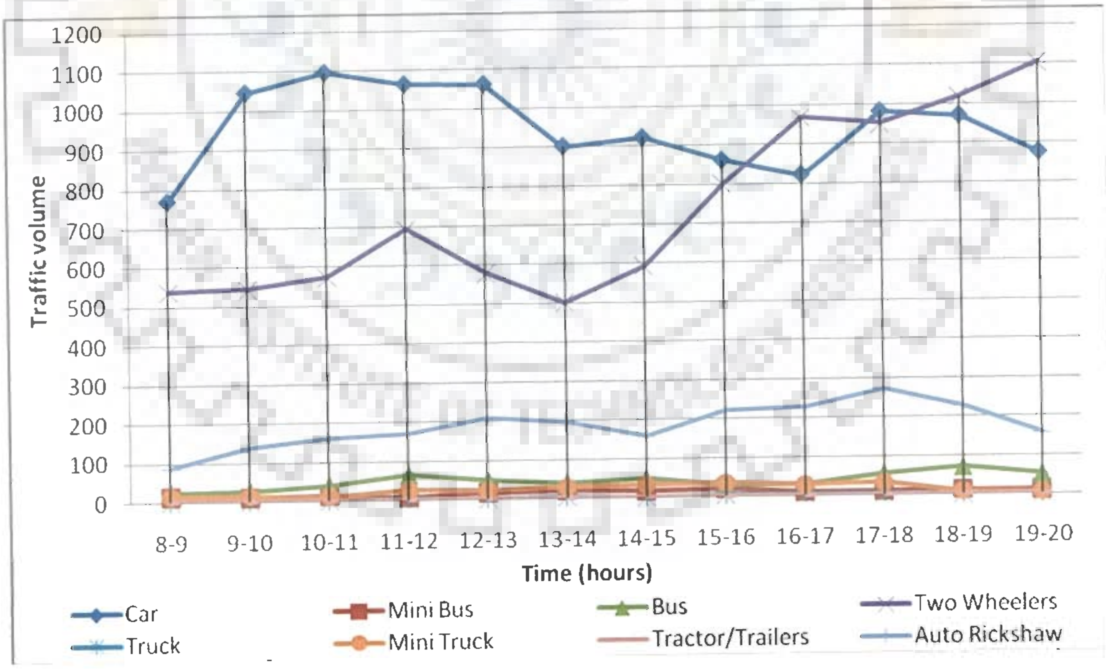


Figure 4.12: Hourly Variation of Traffic Volume at Pitampura (Towards Rohini)

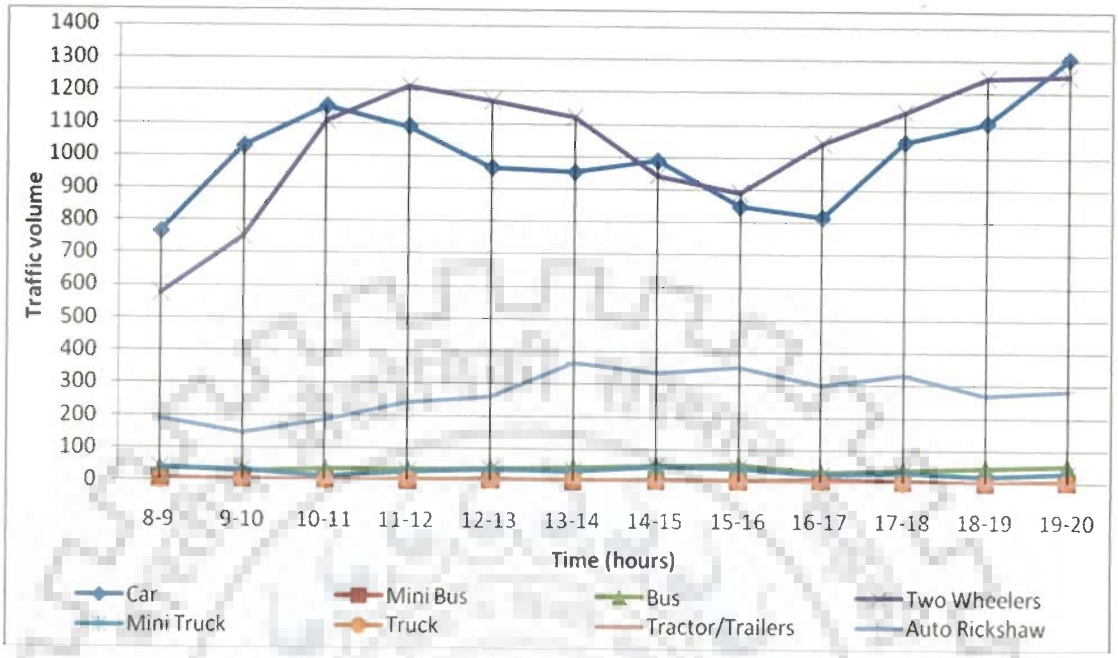


Figure 4.13: Hourly Variation of Traffic Volume at Kashmiri Gate (Towards Lal Kila)

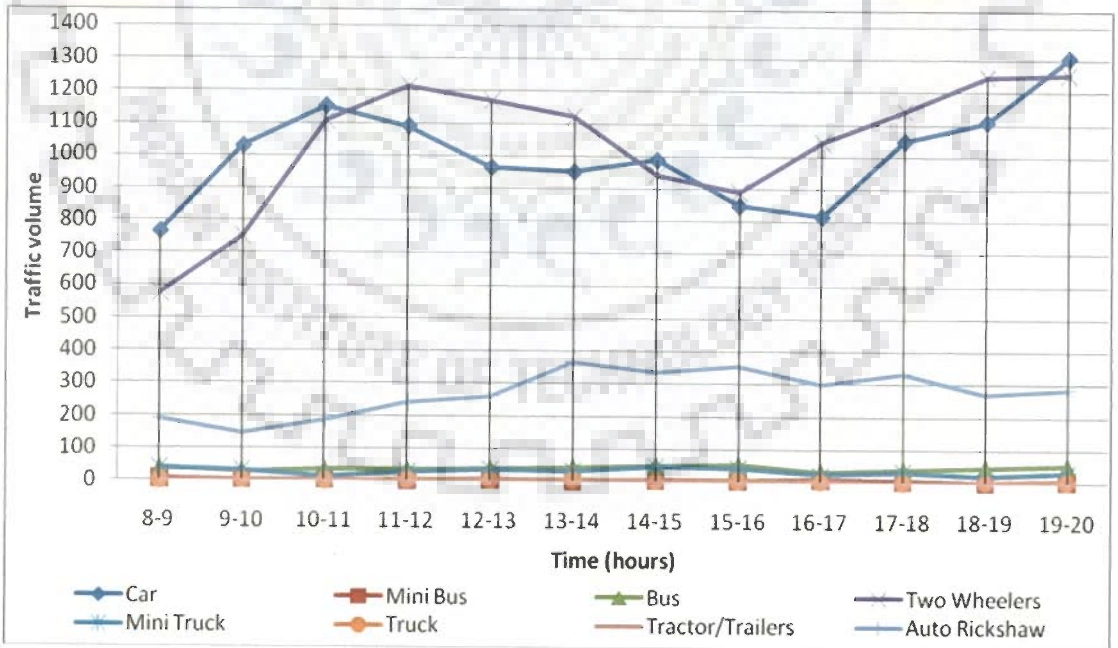


Figure 4.14: Hourly Variation of Traffic Volume at Kashmiri Gate (Towards Ring Road)

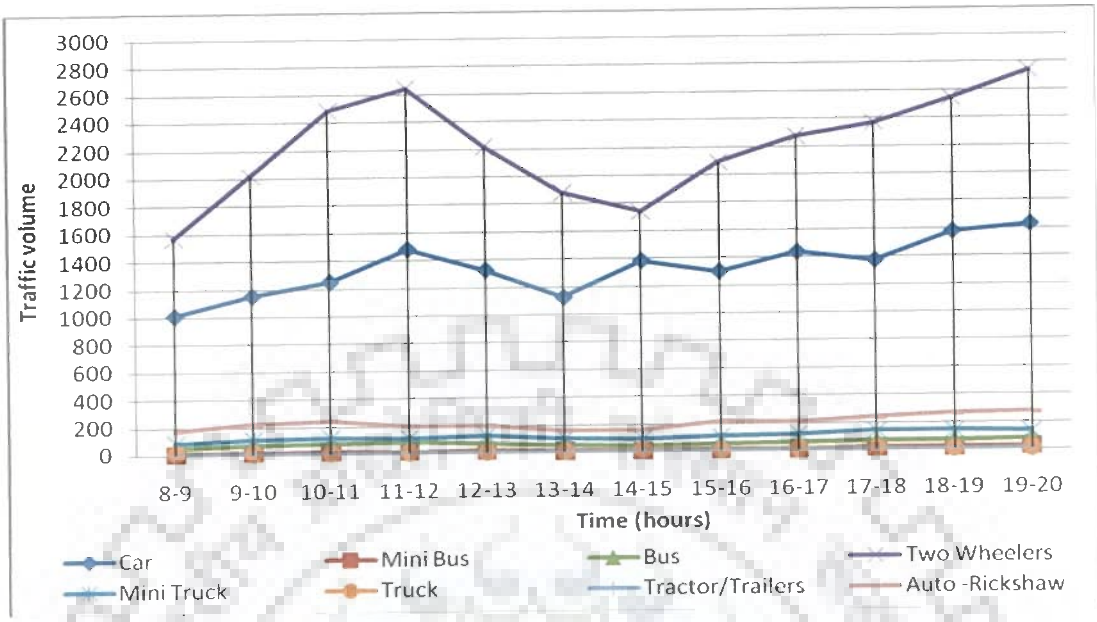


Figure 4.15: Temporal Variation of Traffic Volume at Jhilmil (Towards Mansarovar Park)

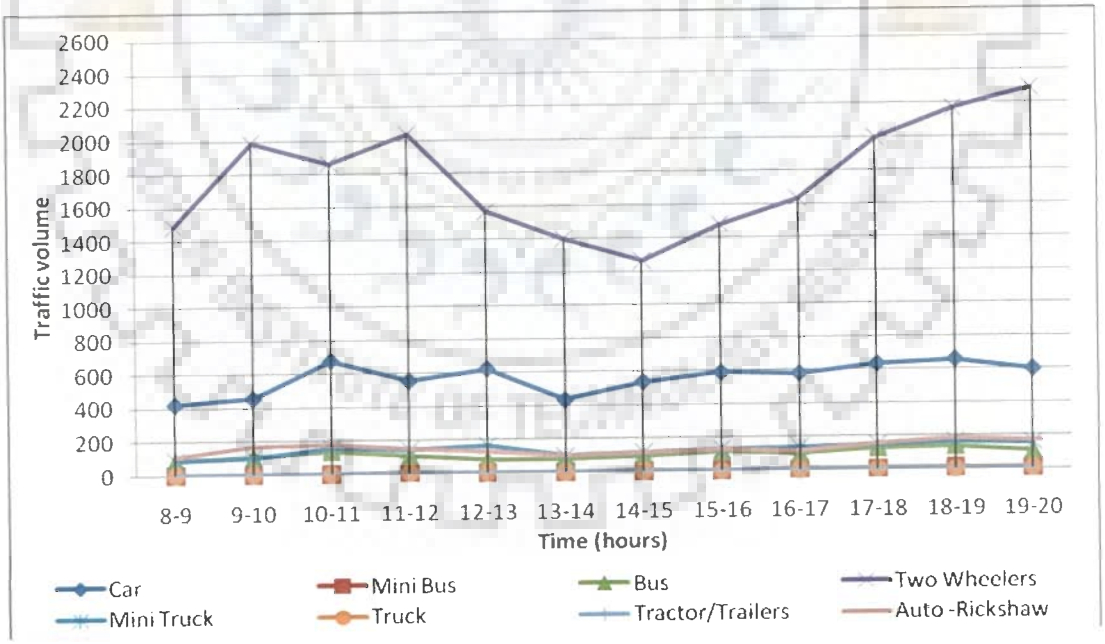


Figure 4.16: Temporal Variation of Traffic Volume at Jhilmil (Towards Dilshad Garden)

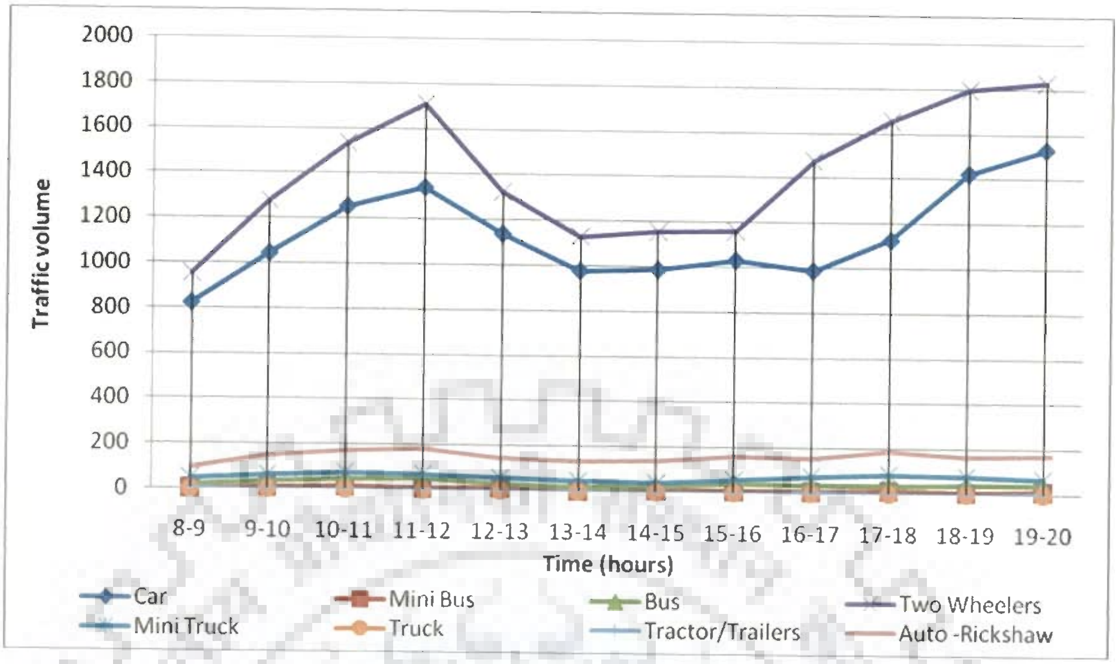


Figure 4.17: Temporal Variation of Traffic Volume at Dilshad Garden (Towards Jhilmil)

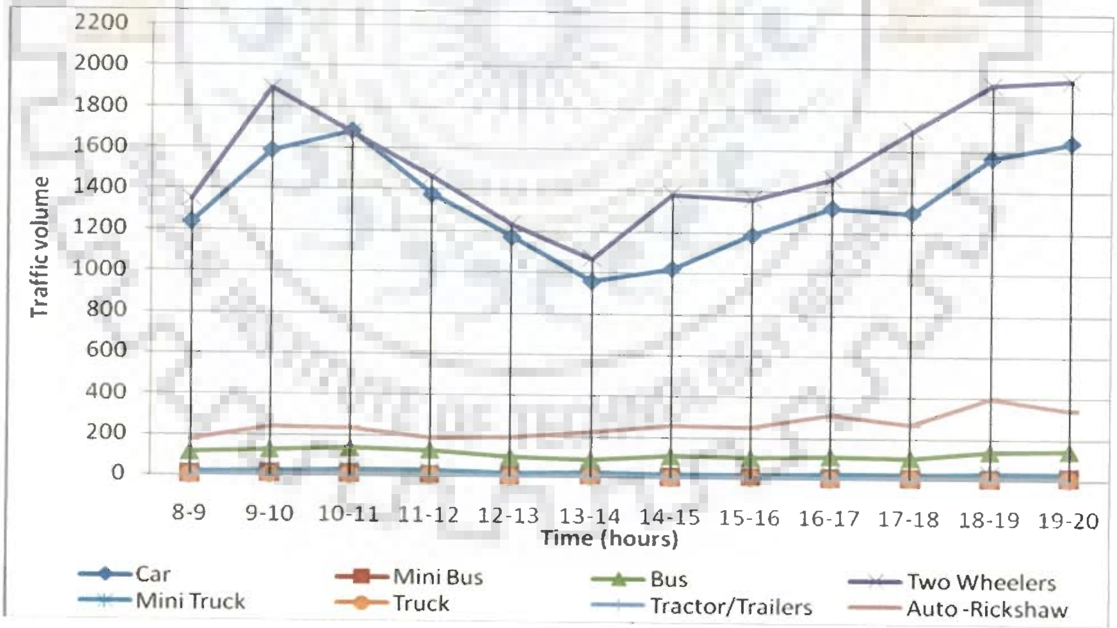


Figure 4.18: Temporal Variation of Traffic Volume at Dilshad Garden (Towards Gaziabad)

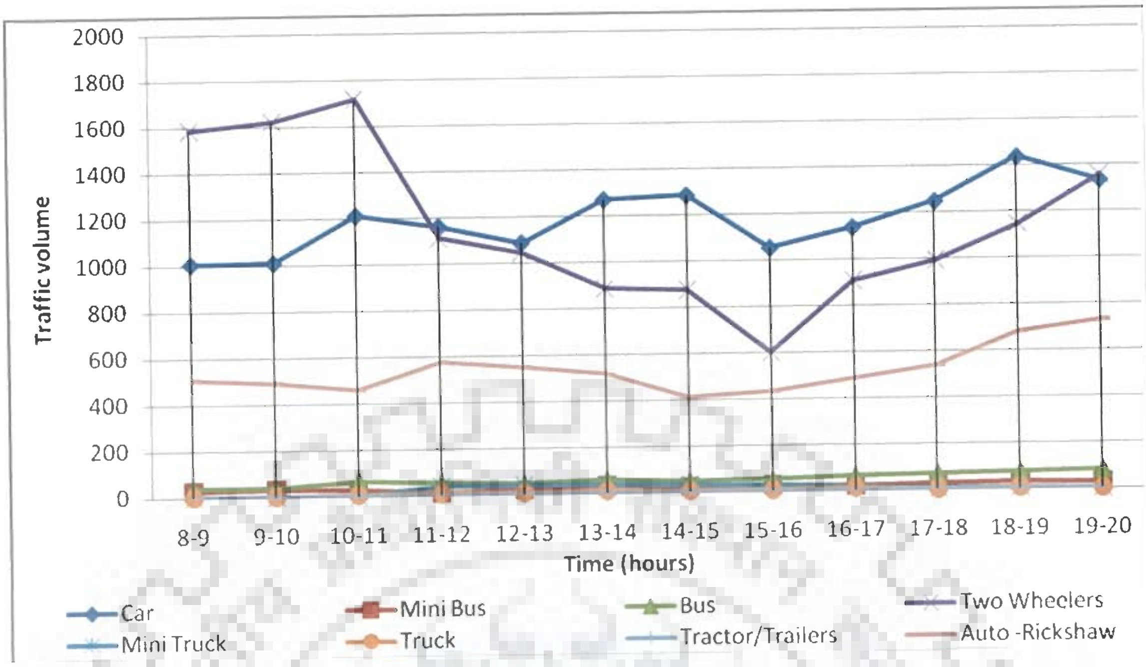


Figure 4.19: Temporal Variation of Traffic Volume at Panchsheel Enclave (Towards Moolchand)

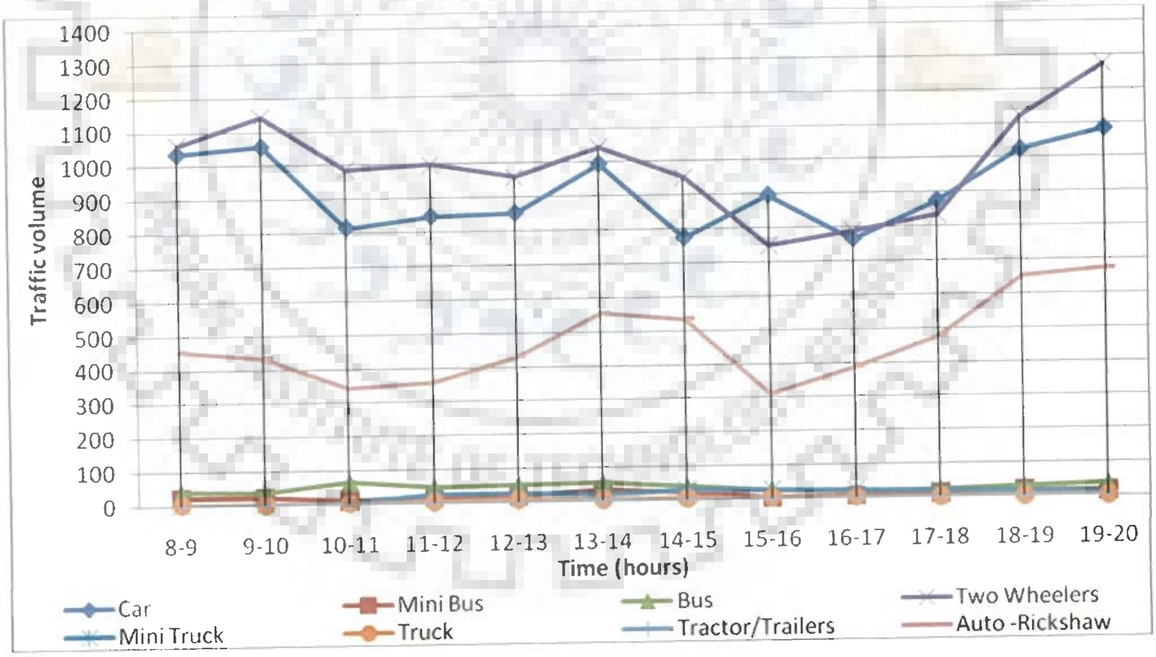


Figure 4.20: Temporal Variation of Traffic Volume at Panchsheel Enclave (Towards Ambedkar Nagar)

4.3 Spot Speed Study

The Radar Gun has been used to measure the vehicle speed at different locations. This study has been conducted for 12 hours at all the selected locations. The ongoing spot speed study at different locations is presented in Figure 4.21. The classified average spot speed data of selected locations are illustrated in Table

Figure 4.21: Spot Speed Study along Public Transport Corridor

Table 4.2: Classified Average Speed at Rithala and Pitampura

Vehicle	Spot Speed(km/h)			
	Rithala		Pitampura	
	Near (Towards Rithala)	Far (Towards Rohini East)	Near (Towards Kohat Enclave)	Far (Towards Rohini East)
Car	53.61	50.71	53.52	51.12
Minibus	36.83	33.37	35.78	32.43
Bus	40.18	34.79	39.56	33.84
Two Wheelers	51.46	51.46	52.34	52.12
Mini Truck	39.87	38.76	39.47	37.86
Truck	40.41	36.43	38.78	35.64
Auto	30.77	30.55	31.21	30.43

Table 4.3: Classified Average Speed at Jhilmil and Dilshad Garden

Vehicle	Spot Speed(km/h)			
	Jhilmil		Dilshad Garden	
	Near (Towards Dilshad Garden)	Far (Towards Mansarovar Park)	Near (Towards Gaziabad)	Far (Towards Jhilmil)
Car	56.45	53.32	53.34	51.52
Minibus	38.32	35.64	34.44	33.68
Bus	41.86	35.76	36.76	35.36
Two Wheelers	55.68	53.46	52.78	51.64
Mini Truck	40.98	38.79	40.74	37.64
Truck	39.88	37.48	37.96	35.65
Auto	33.78	32.82	32.89	32.24
Tractor/Trailer	25.42	22.21	23.74	21.82

Table 4.4: Classified Average Speed at Panchsheel Enclave (BRTS Corridor)

Vehicle	Spot Speed(km/h)	
	Panchsheel Enclave (BRTS Corridor)	
	Near (Towards Moolchand)	Far (Towards Ambedkar Nagar)
Car	52.01	33.31
Minibus	37.27	34.66
Bus	38.48	38.19
Two Wheelers	53.59	39.81
Mini Truck	37.54	36.32
Truck	35.57	28.85
Auto	38.65	29.51

4.4 Geometrical Prameters

Various geometrical parameters have been collected related to road traffic noise analysis, metro rail noise analysis and vehicular pollution analysis at all the selected locations. These parameters includes lane width, number of lanes, shoulder width, median width, gradient if any, type of pavement, barrier height, thickness of existing barrier, distance from barrier to receiver, distance from barrier to source, height of source noise from ground, height of buildings, number of floors, height of elevated corridor from the ground level. In addition to this a number of parameters related air pollutant concentration have also been collected.

4.5Ambient Noise Level Study

The noise level meter has been used to measure the ambient noise level at different locations. The noise levels are recorded in dB (A) using noise level meters. Measurements are recorded every 15 seconds for a period of 15 minutes per hour. This is considered to represent the variations in noise levels of the entire hour. This study has been carried out at all the selected sites for a period of 12 hours. Hourly variation of L10, L50, L90 and Leq in both the direction of Rithala, Pitampura, Jhilmil, Dilshad Garden and Panchsheel Enclave are presented by Figure 4.22, 4.23, 4.24, 4.25, 4.26, 4.27, 4.28, 4.29, 4.30 and 4.31 respectively.

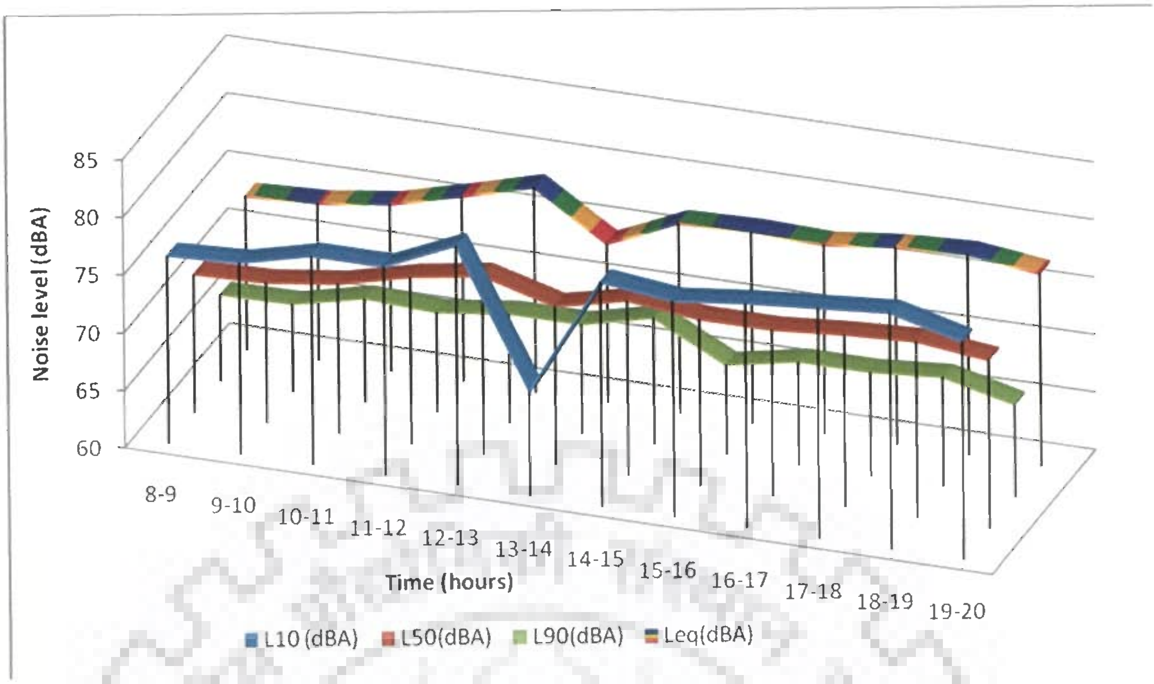


Figure 4.22: Temporal Variation of Noise at Rithala (Towards Rithala)

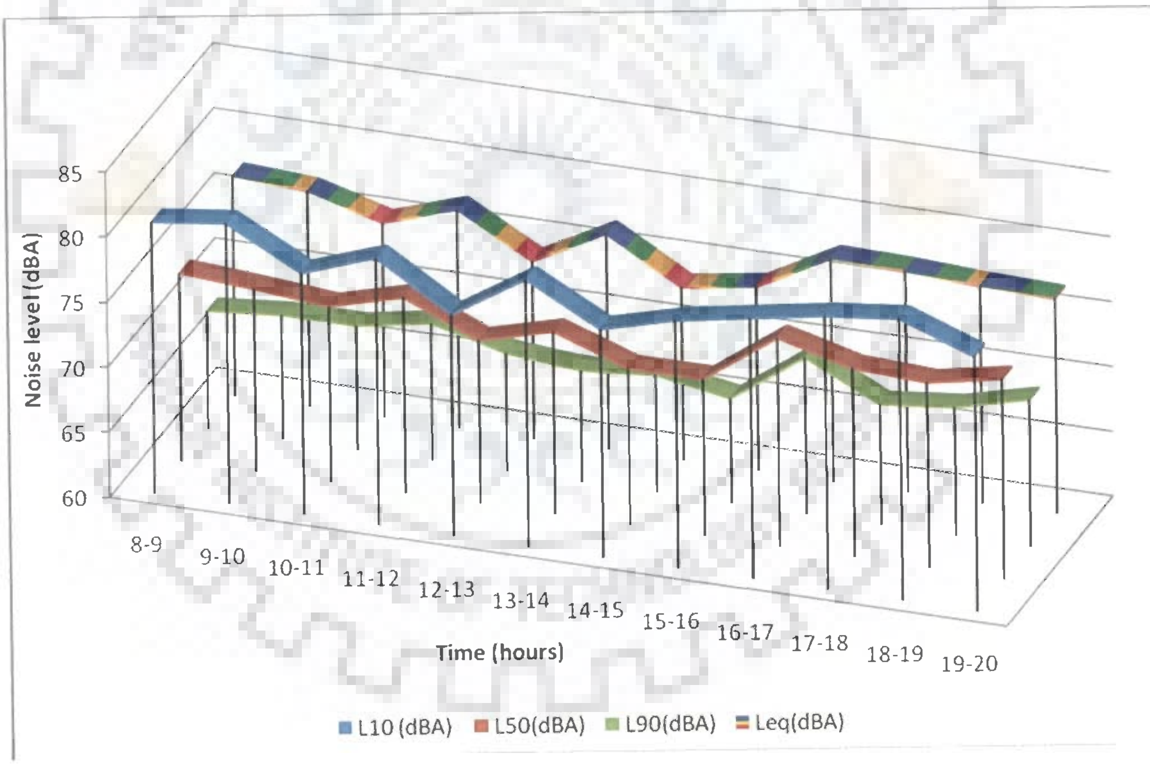


Figure 4.23: Temporal Variation of Noise at Rithala (Towards Rohini East)

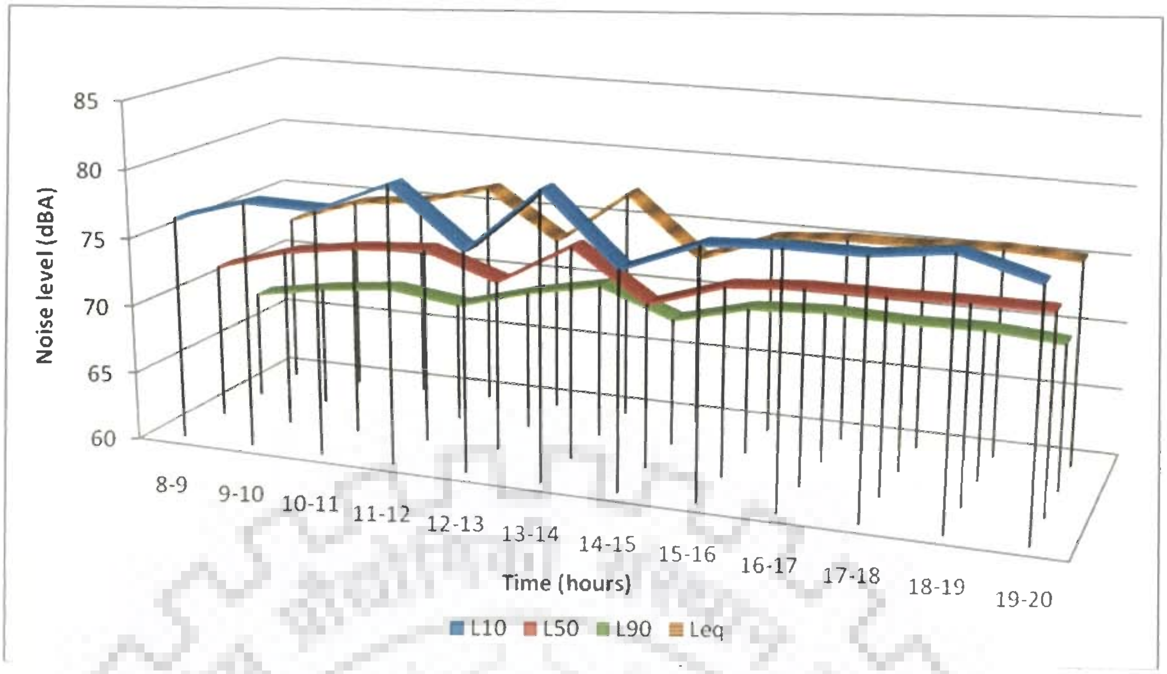


Figure 4.24: Temporal Variation of Noise at Pitampura (Towards Kohat Enclave)

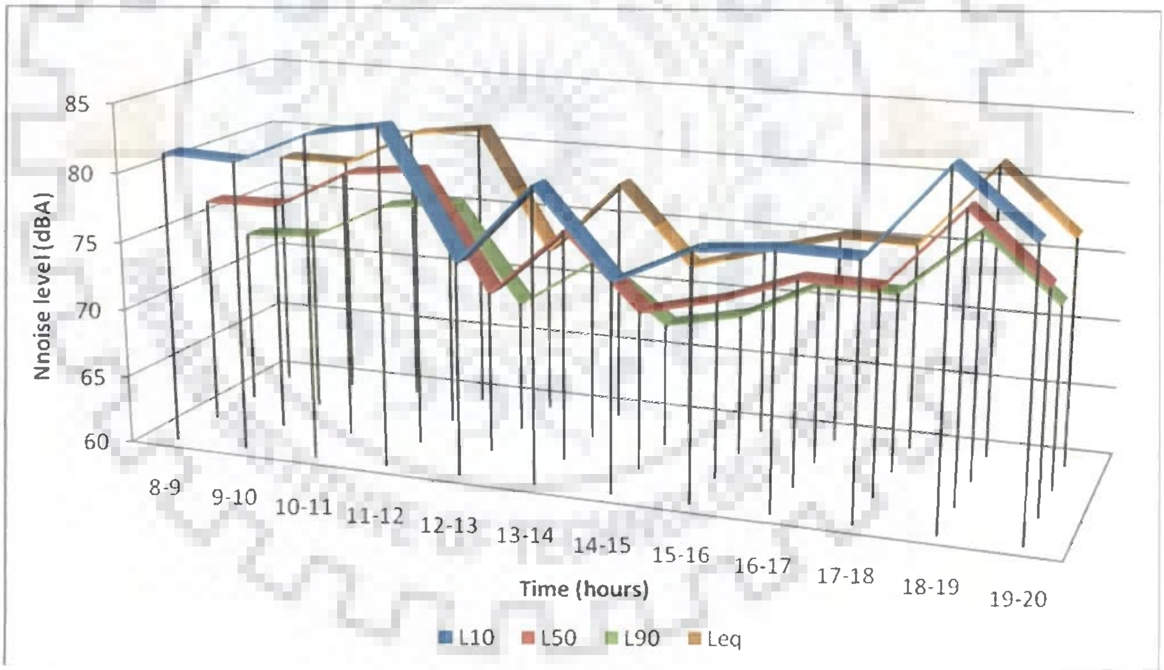


Figure 4.25: Temporal Variation of Noise at Pitampura (Towards Rohini East)

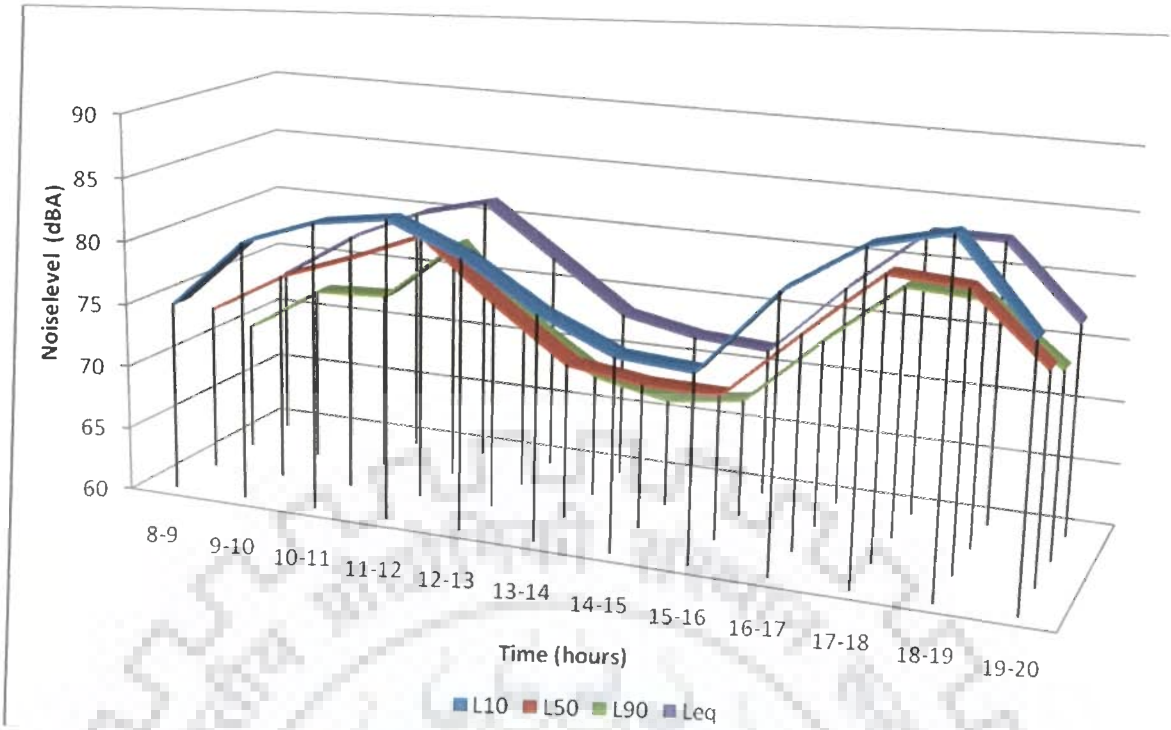


Figure 4.26: Temporal Variation of Noise at Jhilmil (Towards Mansarovar Park)

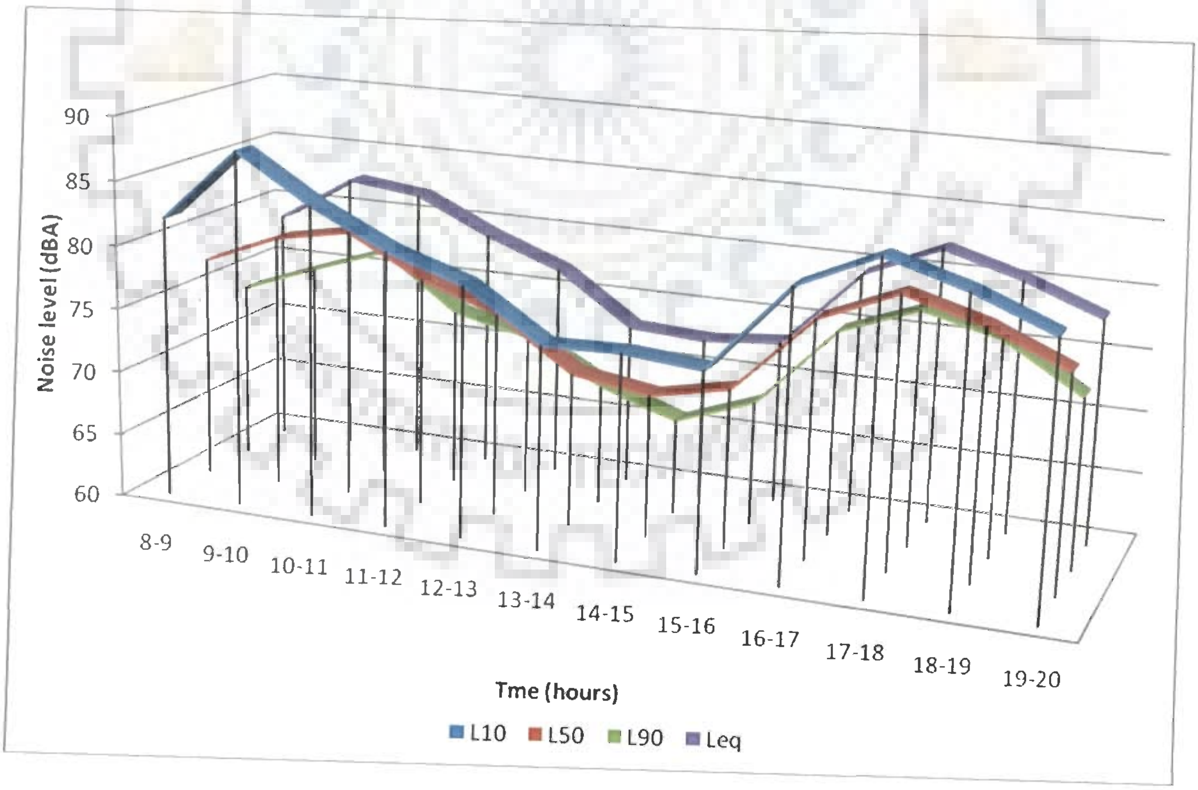


Figure 4.27: Temporal Variation of Noise at Jhilmil (Towards Dilshad Garden)

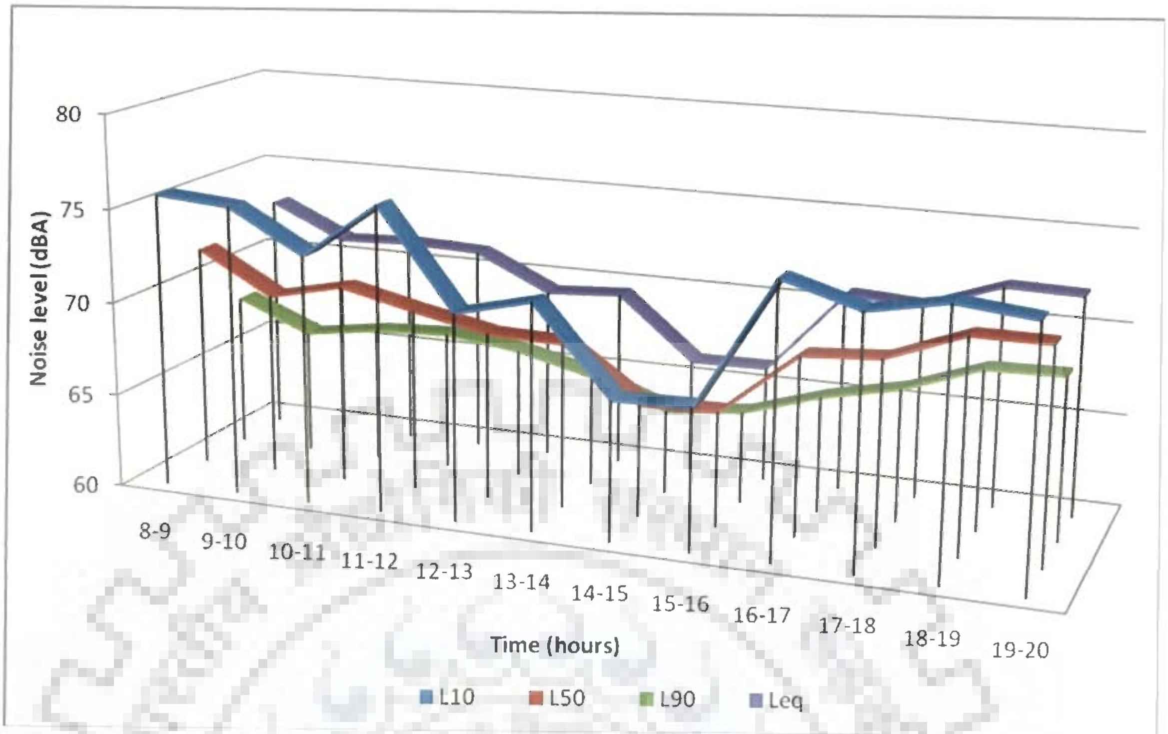


Figure 4.28: Temporal Variation of Noise at Dilshad Garden (Towards Jhilmil)

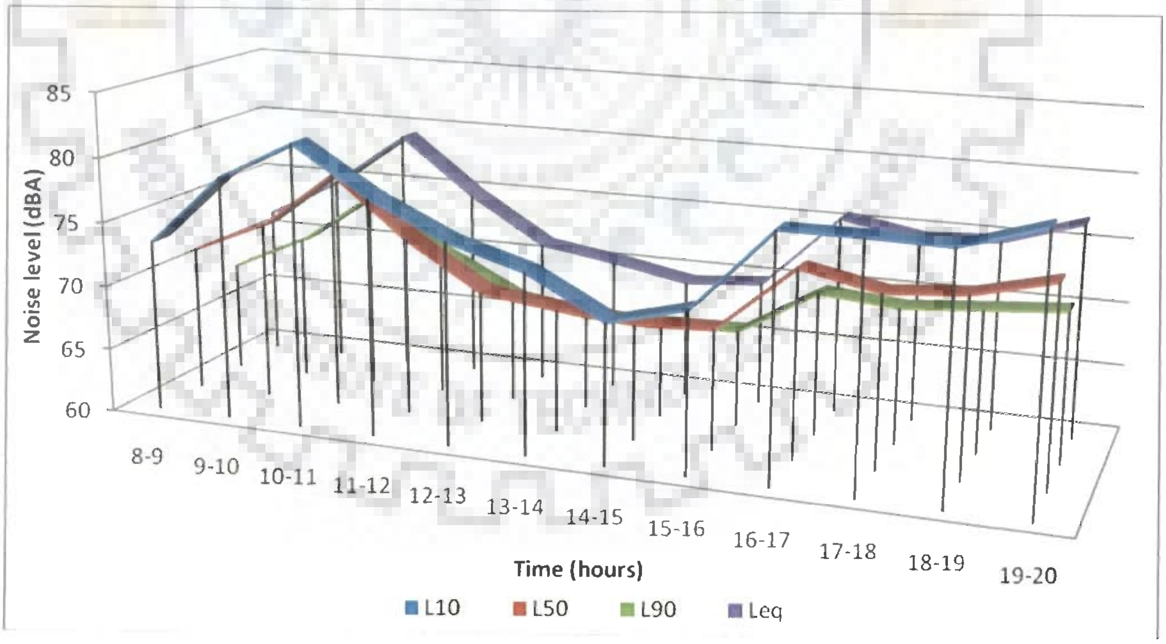


Figure 4.29: Temporal Variation of Noise at Dilshad Garden (Towards Gaziabad)

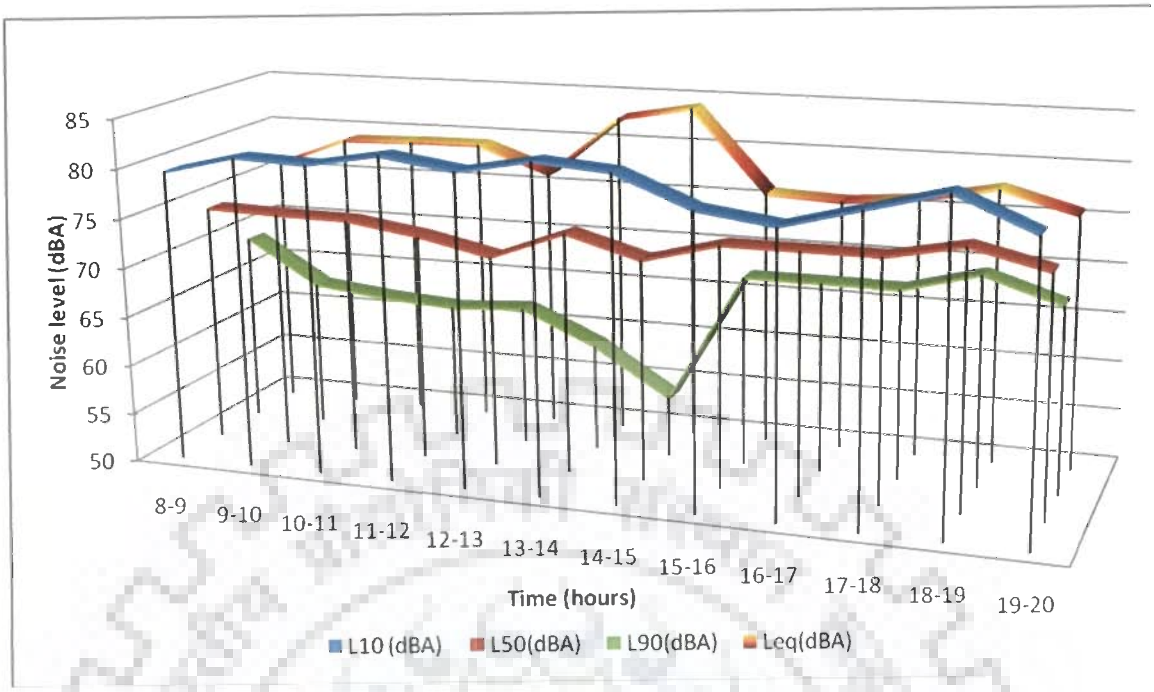


Figure 4.30: Temporal Variation of Noise at Panchsheel Enclave (Towards Moolchand)

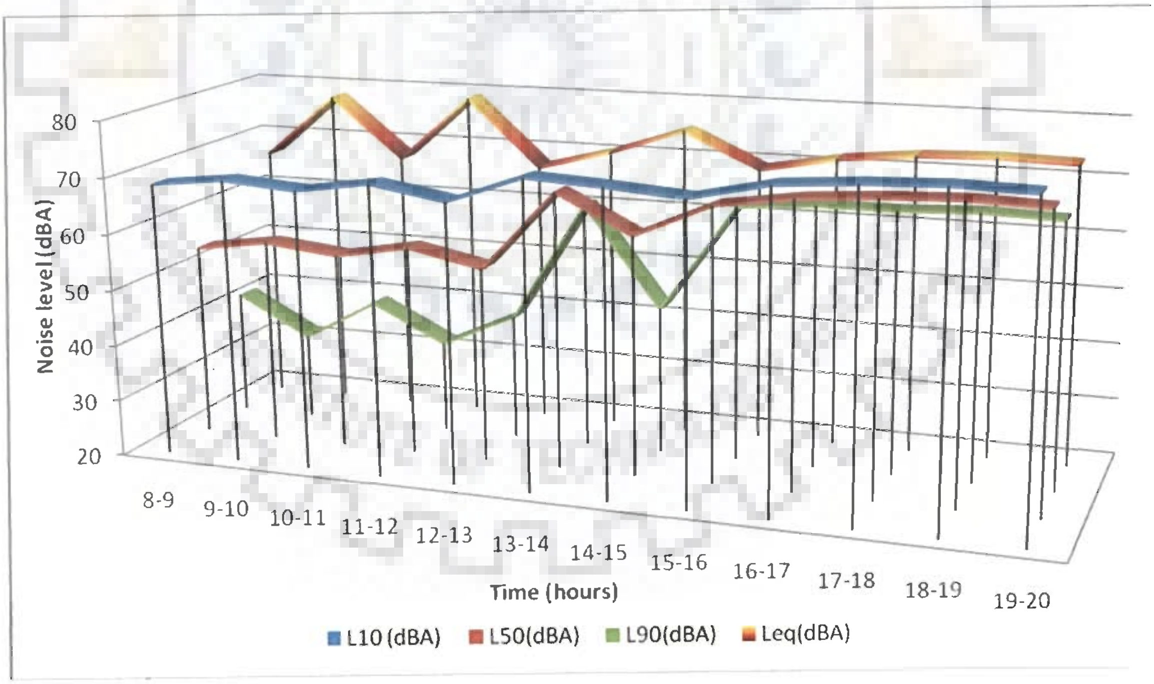


Figure 4.31: Temporal Variation of Noise at Panchsheel Enclave (Towards Ambedkar Nagar)

4.5 Air Pollution Monitoring

To monitor the ambient air pollution concentration, high volume sampler has been used for 12 hours along the selected major public transport corriodor. The prime gases which has been measured along the corriodrs are carbon monoxides (CO), sulphur dioxide (SO_2) oxides of nitrogen (NOx), suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM). Hourly variation of CO, SO_2, NOx, SPM and RSPM concentration at different selected locations of public transport corridors are depicted from from Figure 4.32, 4.33, 4.34, 4.35 and 4.36 respectively. From the figure 4.32, the maximum average concentration of carbon monooxide is found at Jhilmil location (2039.25 $\mu g/m^3$) followed by Rithala (1396.06 $\mu g/m^3$) , Pitampura (1243.17 $\mu g/m^3$), Kashmiri Gate (1231.08 $\mu g/m^3$) and Panchsheel Enclave of BRTS Corridor (1058.25 $\mu g/m^3$). In case of sulphure dioxide (Figure 4.33), the highest observed average concentration is also found at Jhilmil location with the concentration of 49.42 $\mu g/m^3$ and the minimum is found at Panchsheel Enclave (32.72 $\mu g/m^3$). The same situation is also found with oxides of nitrogen at Jhilmil location. The maximum NOx concentration is found at Jhilmil and minimum is found at Rithala location with the average concentration of 166.42 $\mu g/m^3$ and 83.13 $\mu g/m^3$ respectively (Figure 4.34). Figure 4.35 shows the maximum average concentration of suspeneded particulate matter at Jhilmil location (670.28 $\mu g/m^3$) followed by Kashmiri Gate (608.94 $\mu g/m^3$), Pitampura (555.66 $\mu g/m^3$), Panchsheel Enclave (540.69 $\mu g/m^3$) and Rithala (519.66 $\mu g/m^3$). On the other hand, the average highest concentration of respirable suspended particulate matter is obtained at Kashmiri Gate (469.71 $\mu g/m^3$) followed by Jhilmil (369.37 $\mu g/m^3$), Rithala (336.56 $\mu g/m^3$), Panchsheel Enclave (330.54 $\mu g/m^3$) and Pitampura (329.38 $\mu g/m^3$) (Figure 4.36).

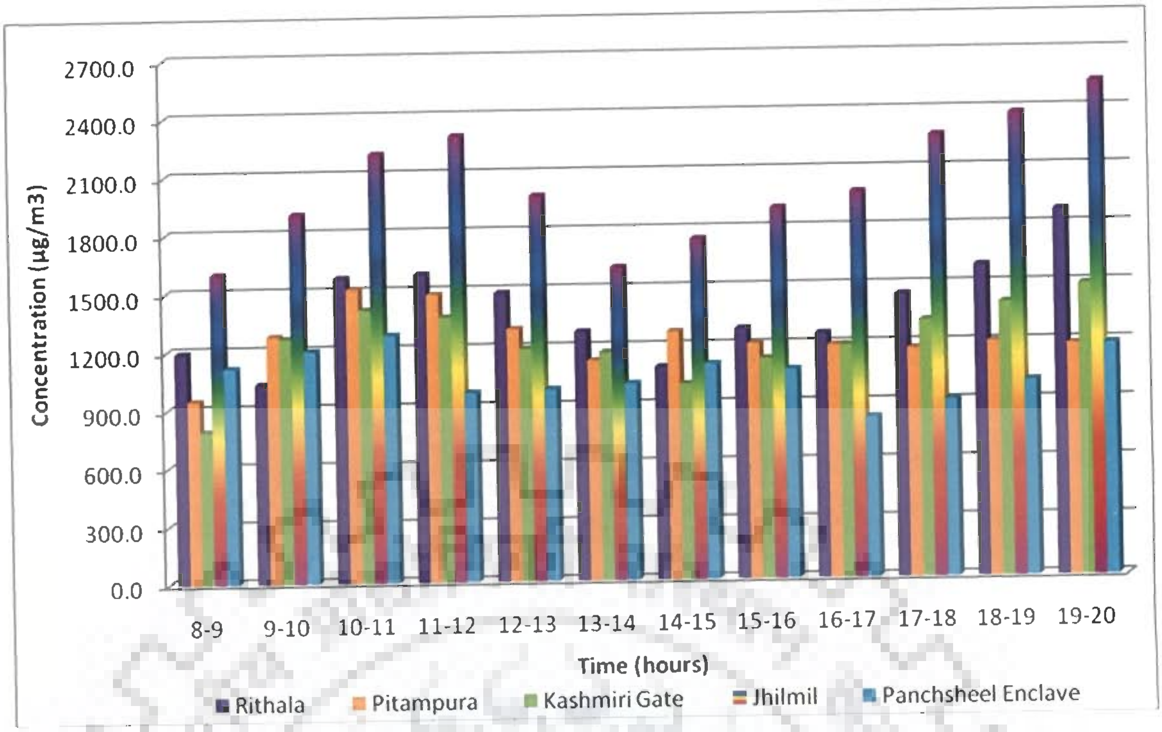


Figure 4.32: Hourly Variation of CO at Selected Locations Along Major Public Transport Corridor

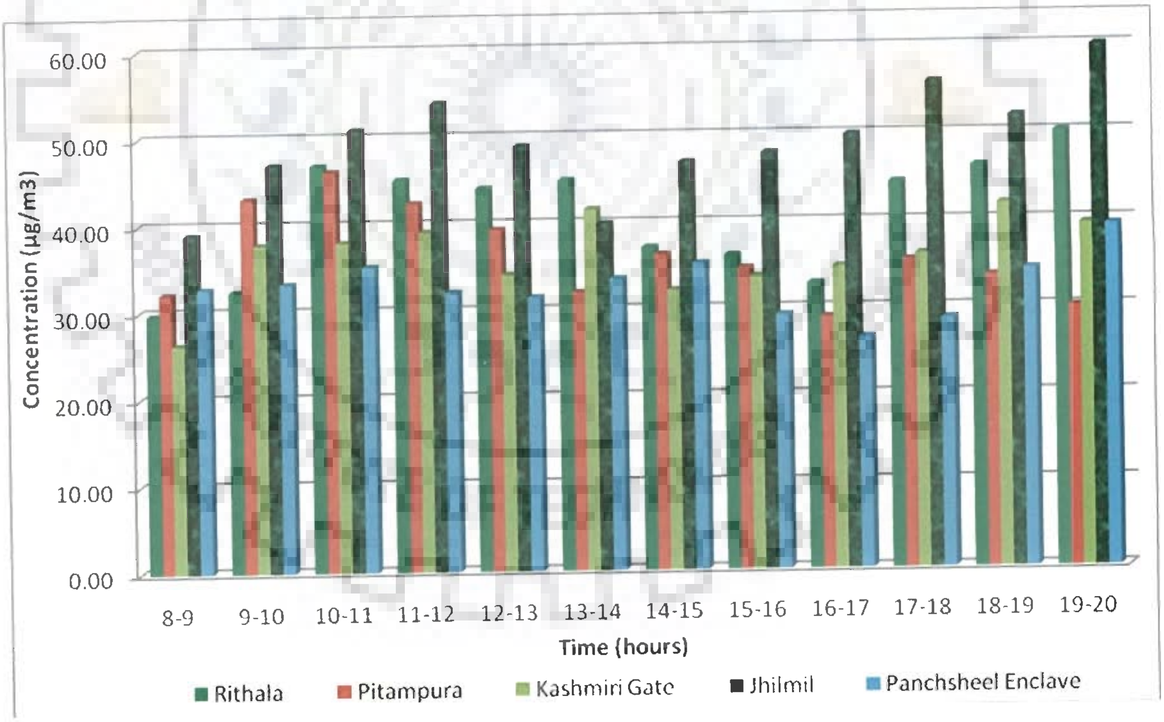


Figure 4.33: Hourly Variation of SO_2 at Selected Locations Along Major Public Transport Corridor

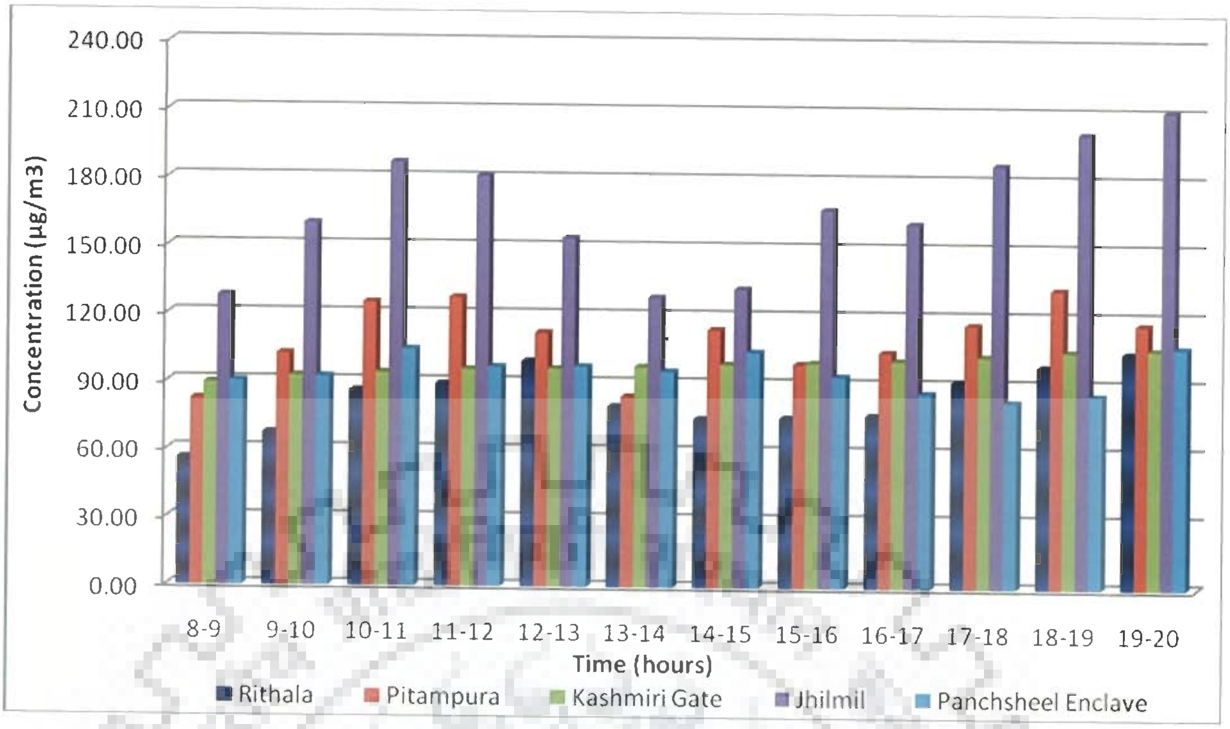


Figure 4.34: Hourly Variation of Nox at Selected Locations Along Major Public Transport Corridor

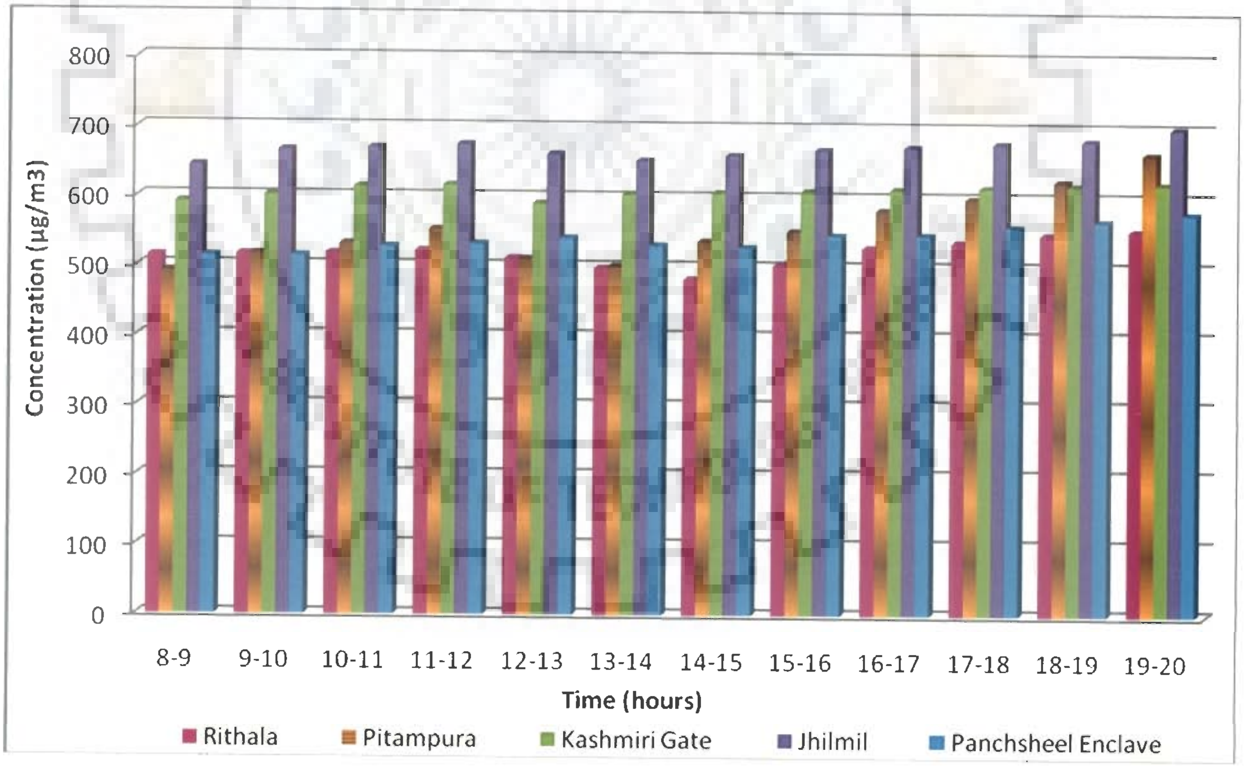


Figure 4.35: Hourly Variation of SPM at Selected Locations Along Major Public Transport Corridor

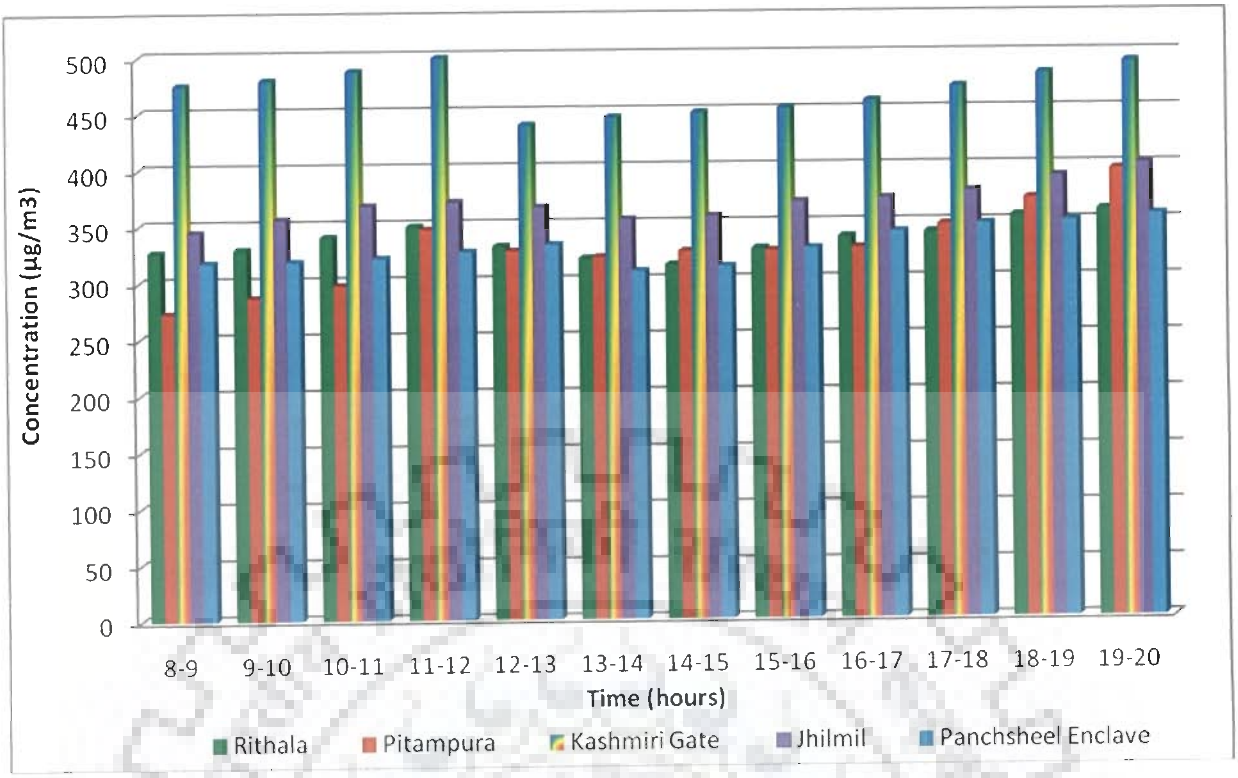


Figure 4.36: Hourly Variation of RSPM at Selected Locations Along Major Public Transport Corridor

4.6 Summary

This chapter presents a brief introduction about the study area i.e. Delhi, and the selected locations i.e. Rithala, Pitampura, Kashmiri Gate, Jhilmil, Dilshad Garden and Panchsheel Enclave along major public transport corridor i.e. MRTS and BRTS. A detailed discussion on primary and secondary data like traffic volume, ambient noise level, spot speed of different category of vehicles, geomatrical parameters, air pollutant concentration and its analysis are given in this chapter. Temporal varitaion of ambient noise level as well as vehicular pollutants like CO,NOx, SO_2, SPM and RSPM are exposed in present chapter.

Chapter 5

MODELLING OF SURFACE TRANSPORT NOISE

5.1 General

A number of data related to road traffic noise and metro rail noise have been collected at different selected locations along major public transport corridor. On the basis of analysis of these data knowledge based tool has been developed in MS Excel worksheet system to predict the noise generated due to road traffic and due to metro rail at identified locations. These are mini knowledge management tools to enhance transparency and easy application for transport environment interaction studies. This model is also found free from mathematical complexities and user friendly to academician, engineers and general people. This chapter includes the description about the developed model, validation of model and application of model.

5.2 KM – Based Model Development to Predict Road Traffic Noise

5.2.1 Description about model

The developed model is based on FHWA procedure (Annexure I). To avoid the mathematical complexities, MS EXCEL worksheet system has been used to formulate this model. This model can be used to predict noise levels (L_{eq}) due to road traffic. Methodology to predict noise level has been given in Figure 5.1. In this model, the user can get the noise level by putting the inputs i.e. characteristics of site, category wise traffic volume, speed of vehicles, segment angle, height of source etc. Various adjustments i.e. flow adjustment, distance adjustment, finite segment adjustment, shielding adjustment and grade adjustment also to be made to basic noise levels to arrive at final noise levels. The value of final L_{Aeq} is determined from the following equation:

$$L_{Aeq} = L_0 + \sum L_i \qquad \text{- - - - (5.1)}$$

Where, L_{Aeq} is continuous steady noise level on A-weighted scale, L_0 is basic noise level for a stream of vehicle and L_i is adjustments for each vehicle category.

5.2.1.1 Basic noise level equations

Final equivalent noise level has been predicted on the basis of reference energy mean emission levels of different category of vehicles. According to Indian traffic condition, the vehicles are divided into seven categories in this model and consequently seven equations have been incorporated into model. The reference energy mean emission levels equations are mentioned in Table 5.1.

Table 5.1 Reference Mean Emission Levels for FHWA

Category	Equation
Car/Jeep/Van	Y = 32.372*log S+15.891
Minibus	Y = 31.212*log S+23.26
Truck	Y = 43.248*log S+6.597
Bus	Y= 41.378*log S+8.873
Motorcycle	Y = 35.871*log S+8.979
Auto	Y= 0.2202*log S+61.51
Tractor trailer	Y= 6.411*log S+73.065

5.2.1.2 Adjustments applied

The developed mini KM tool predicts noise level through a number of adjustments to a reference sound level. The reference sound level may be defined as energy mean emission level, determined through field measurement. During the calculation of equivalent noise level, the adjustments which have been incorporated are flow/speed adjustment, distance adjustment and finite segment adjustment. No grade and shielding adjustments are found at selected locations. These adjustments have already been discussed in Chapter 2.

5.2.1.3 Computation of hourly Leq through developed model

One hour equivalent sound level from a given class of vehicle is calculated by summing up the various adjustments to the energy mean emission level

$$L_{eq\,H} = L_0 + \Delta_{traffic} + \Delta_{distance} + \Delta_{shielding} + \Delta_{grade} + \Delta_{segment} + \Delta_{barrier} \quad ---- (5.2)$$

where, L_0 is the contribution of a given vehicle class, $\Delta_{traffic}$ is traffic flow adjustment for a given class of vehicles, $\Delta_{distance}$ is distance adjustment for a given class of vehicles, $\Delta_{shielding}$ is shielding adjustment for a given class of vehicles, Δ_{grade} is grade adjustment for a given class of vehicles, $\Delta_{segment}$ is segment adjustment for a given class of vehicles and $\Delta_{barrier}$ is barrier adjustment for a given class of vehicles.

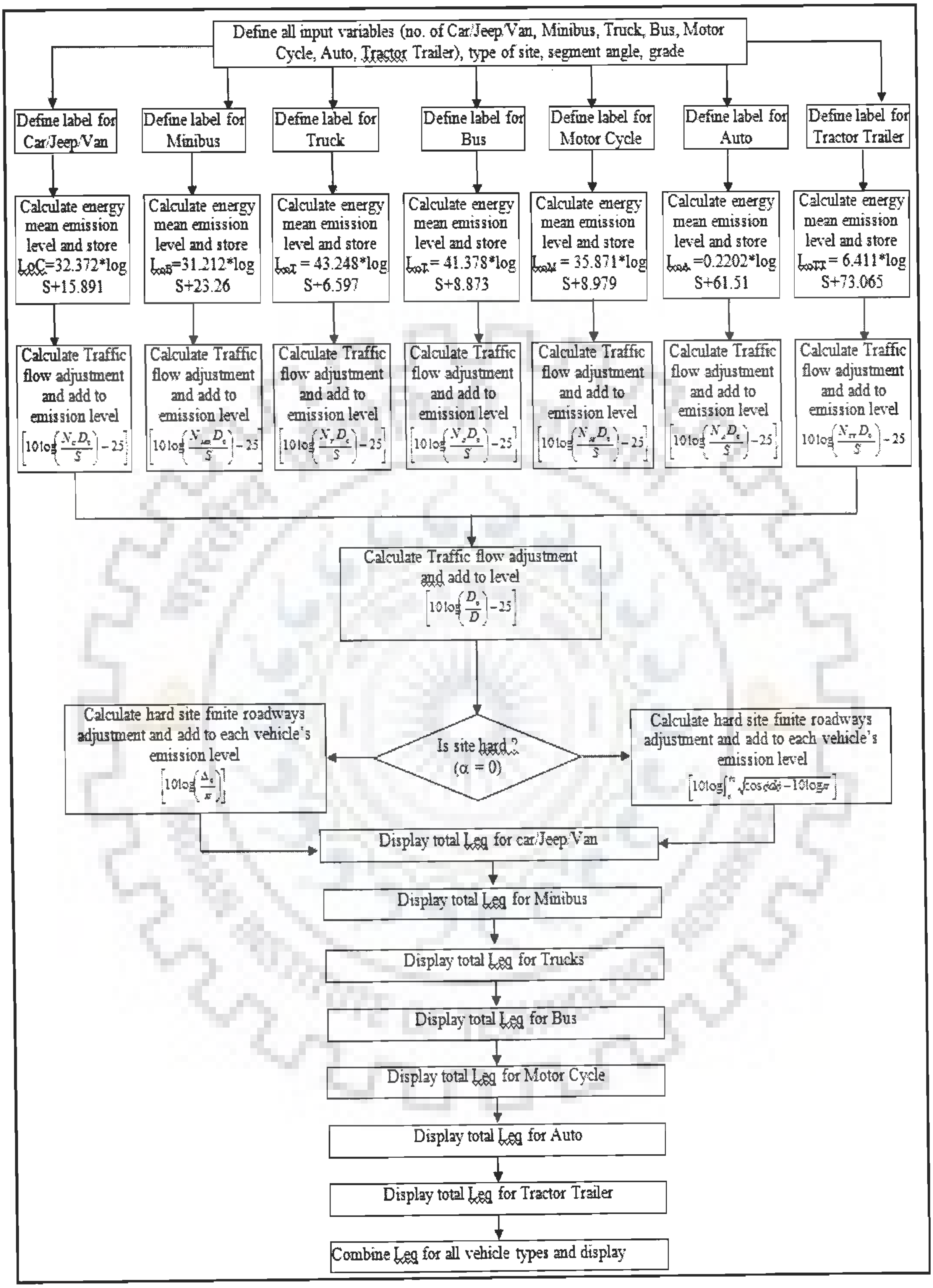


Figure 5.1: Noise Prediction Methodology

5.2.2 Validation of model and discussion of results

The developed model has been validated through the comparative analysis of predicted and observed noise level with percentage error of every selected location along major public transport corridor.

5.2.2.1. Comparative analysis of observed and predicted noise level at Rithala

The comparative study between predicted and observed equivalent noise level has been presented in Figure 5.2 (a) and 5.2 (b). From the model analysis, the maximum and minimum observed and predicted equivalent noise level in the direction of Rithala has been found 77.96, 70.86 dBA (19-20 hour) and 72.95, 68.12 dBA during 8-9 hour of the study respectively. On the other hand, the highest and lowest observed and predicted value of noise level in the direction of Rohini East are obtained 78.48 dBA, 70.87 dBA and 73.29 dBA, 66.49 dBA correspondingly. The maximum and minimum percentage error between observed and predicted values are found -9.93 and -6.11 (Table 5.2). It is found that the modified FHWA model predicts the noise with an average percentage error of -9 which indicates the suitability of this model at Rithala location.

Table 5.2: Observed and Predicted Noise Level at Rithala Location

Direction: Rohini East to Rithala			
Time	Observed (Leq)	Predicted (Leq)	% Error
8-9	72.95	68.12	-6.62
9-10	73.65	68.51	-6.98
10-11	74.48	69.93	-6.11
11-12	76.08	69.84	-8.20
12-13	77.78	70.63	-9.19
13-14	75.44	69.22	-8.25
14-15	76.49	69.58	-9.03
15-16	76.66	69.10	-9.86
16-17	76.47	68.88	-9.93
17-18	76.98	69.65	-9.522
18-19	77.84	70.54	-9.378
19-20	77.96	70.86	-9.107

Direction: Rithala to Rohini East			
Time	Observed (Leq)	Predicted (Leq)	% Error
8-9	75.85	69.21	-8.75
9-10	76.57	70.60	-7.80
10-11	74.95	67.92	-9.39
11-12	76.79	69.66	-9.29
12-13	73.64	67.40	-8.47
13-14	76.57	69.33	-9.46
14-15	73.29	66.49	-9.28
15-16	74.16	66.92	-9.77
16-17	77.14	69.64	-9.72
17-18	77.69	70.74	-8.95
18-19	77.97	71.32	-8.53
19-20	78.48	70.87	-9.70

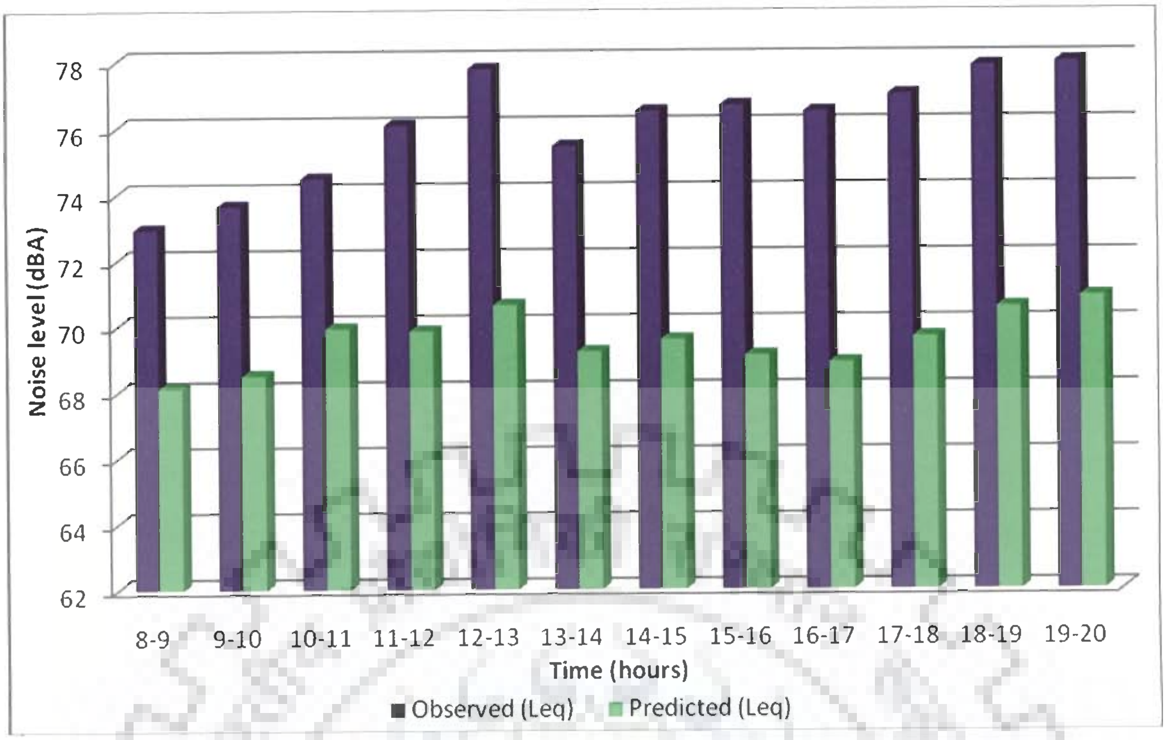


Figure 5.2 (a): Temporal Variation of Observed and Predicted Noise Level at Rithala (Towards Rithala)

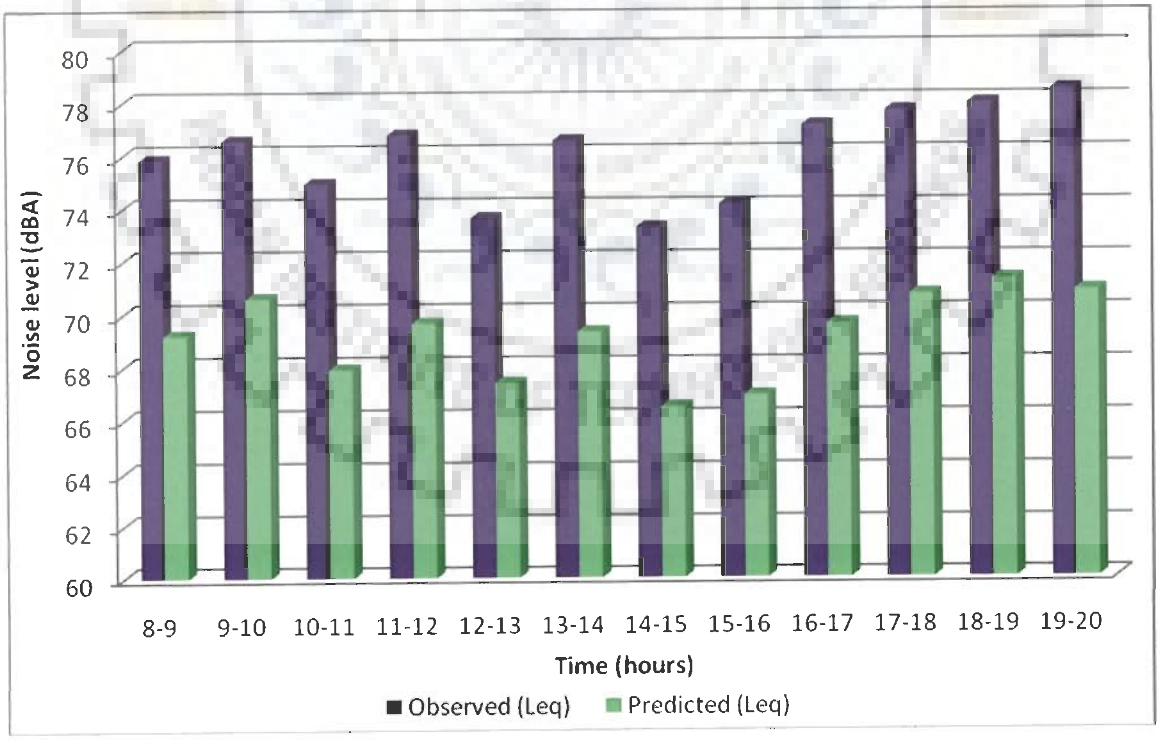


Figure 5.2 (b): Temporal Variation of Observed and Predicted Noise Level at Rithala (Towards Rohini east)

5.2.2.2 Comparative analysis of observed and predicted noise level at Pitampura

Figure 5.3 (a) and (b) depicts the comparison between measured and modelled equivalent noise level. It is clear from the figures that hour 13-14 and 10-11 shows maximum observed (77.2 dBA) and predicted value (76.11 dBA) in the direction of Kohat Enclave. On the other hand minimum observed and predicted value is found 72.7 and 74.26 dBA. Towards Rohini East direction, the maximum and minimum observed and predicted noise levels are obtained 81.4, 76.7 dBA and 72.1, 74.9 dBA correspondingly. Table 5.3 presents the percentage error found between predicted and observed noise. The range between the maximum and minimum percentage error are found 5.06 to -0.18. It is obvious from this percentage error that the proposed modified model can be used to predict noise level successfully.

Table 5.3: Observed and Predicted Noise Level at Pitampura Location

Direction: Towards Kohat Enclave				Direction: Towards Rohini East			
Time	**Observed (Leq)**	**Predicted (Leq)**	**% Error**	**Time**	**Observed (Leq)**	**Predicted (Leq)**	**% Error**
8-9	72.8	74.26	2.06	8-9	77.9	74.9	-3.83
9-10	74.6	75.3	0.97	9-10	77.9	76.0	-2.47
10-11	75.2	76.11	1.26	10-11	80.6	76.7	-4.85
11-12	76.6	75.91	-0.93	11-12	81.2	76.6	-5.75
12-13	73.1	75.33	3.08	12-13	72.4	76.0	5.06
13-14	77.2	74.42	-3.57	13-14	77.9	75.2	-3.51
14-15	72.7	74.91	3.00	14-15	72.1	75.6	4.86
15-16	74.7	74.85	0.17	15-16	73.8	75.6	2.55
16-17	75.1	74.83	-0.39	16-17	75.3	75.7	0.53
17-18	75.2	75.49	0.42	17-18	75.1	76.3	1.51
18-19	75.4	75.31	-0.18	18-19	81.4	76.2	-6.45
19-20	75.2	74.97	-0.24	19-20	76.6	75.9	-1.01

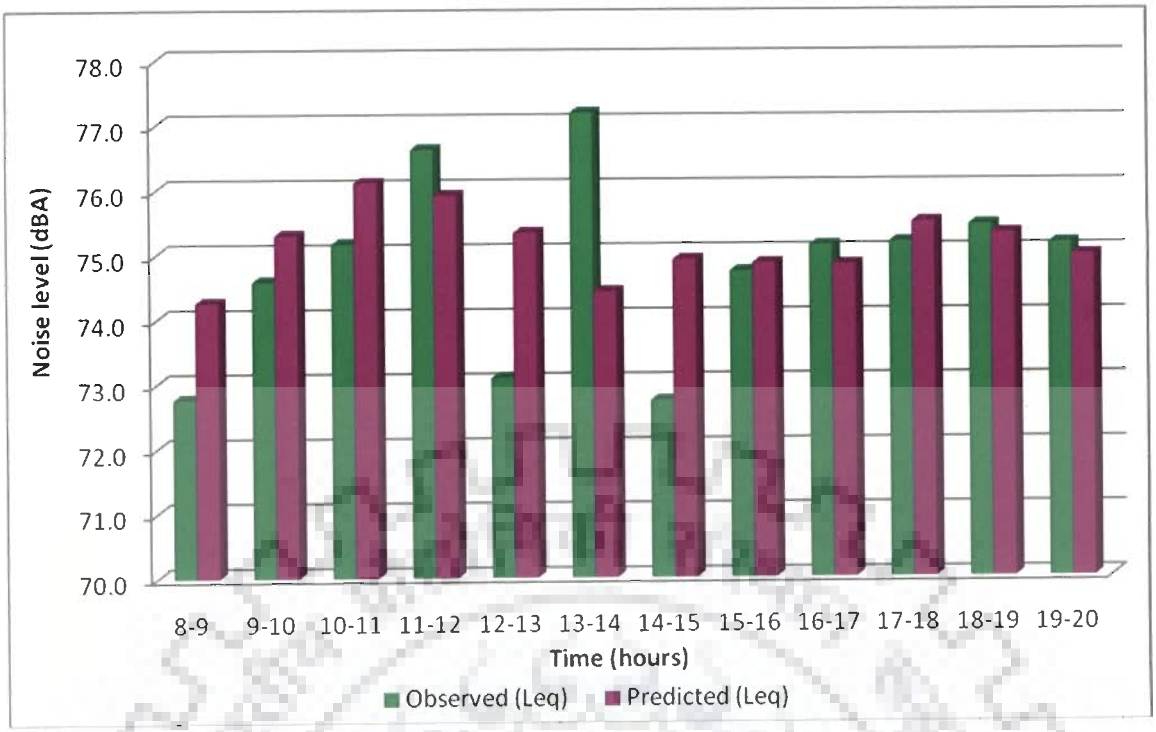


Figure 5.3 (a): Hourly Variation of Observed and Predicted Noise Level at Pitampura (Towards Kohat Enclave)

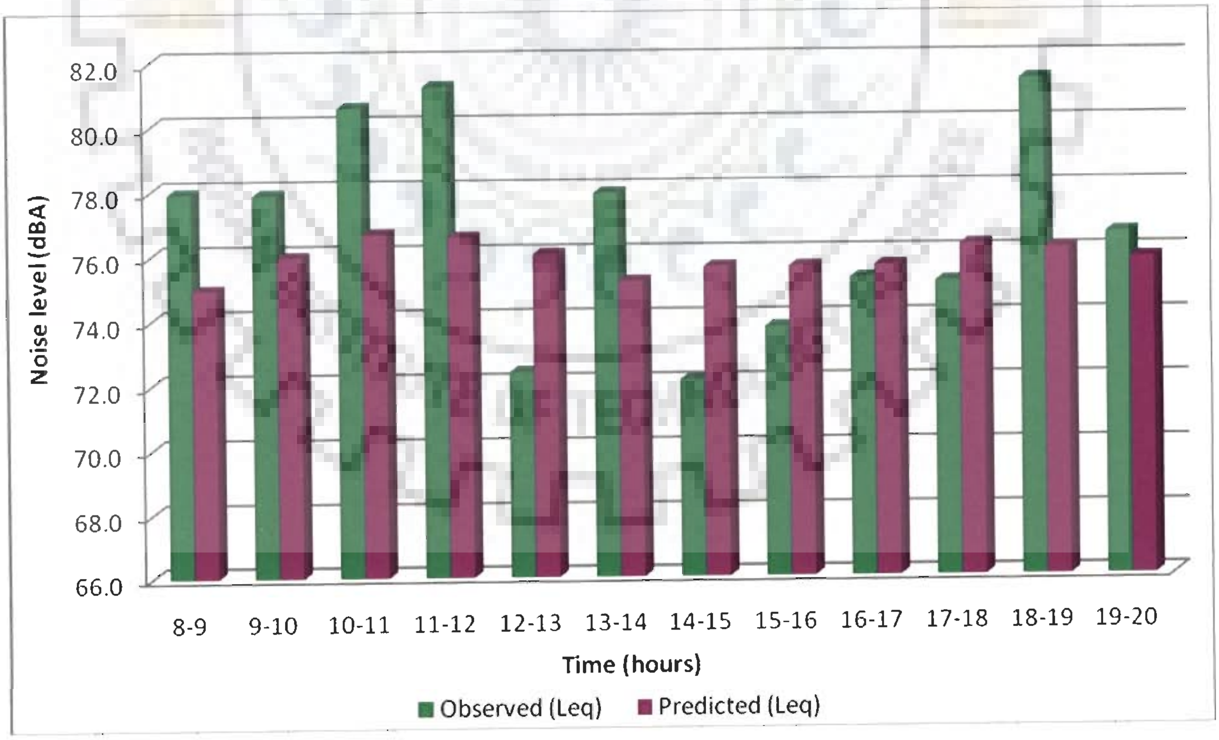


Figure 5.3 (b): Hourly Variation of Observed and Predicted Noise Level at Pitampura (Towards Rohini East)

5.2.2.3 Comparative analysis of observed and predicted noise level at Jhilmil

Hourly variation of observed and predicted equivalent noise levels are shown in Figure 5.4 (a) and 5.4 (b). From the traffic noise data analysis at this corridor, the maximum predicted noise level is found 79.3 dBA during 18-19 hour and 19-20 hour towards Dishad Garden direction, whereas the minimum predicted equivalent noise is found 76.9 dBA in other direction (towards Manasarovar Park). The maximum and minimum average percentage error between measured and modelled noise level is found 1.4 and 0.6 (Table 5.4) for developed modified FHWA model, which indicates the applicability of this model at this location. Similarly the highest observed noise level is obtained 82.6 dBA during 17-18 hour and 18-19 hour in the direction of Mansarovar Park, whereas the lowest is obtained 71.8 dBA during 15-16 hour.

Table 5.4: Observed and Predicted Noise Level at Jhilmil Location

Direction: Towards Mansarovar Park			
Time	**Observed (Leq)**	**Predicted (Leq)**	**% Error**
8-9	73.6	76.9	4.55
9-10	77.3	77.9	0.76
10-11	79.9	78.5	-1.73
11-12	81.3	78.7	-3.27
12-13	77.4	78.3	1.16
13-14	73.3	77.3	5.38
14-15	72.2	77.4	7.25
15-16	71.8	77.8	8.38
16-17	77.6	78.1	0.73
17-18	82.6	78.5	-4.90
18-19	82.6	78.9	-4.47
19-20	76.8	79.0	2.83

Direction: Towards Dilshad Garden			
Time	**Observed (Leq)**	**Predicted (Leq)**	**% Error**
8-9	78.8	77.3	-1.88
9-10	82.4	78.3	-5.08
10-11	81.7	78.9	-3.54
11-12	79.0	79.0	-0.01
12-13	76.9	78.3	1.94
13-14	72.8	77.6	6.51
14-15	72.5	77.7	7.19
15-16	73.1	78.2	6.94
16-17	79.3	78.4	-1.08
17-18	82.0	78.9	-3.78
18-19	80.2	79.3	-1.20
19-20	77.9	79.3	1.76

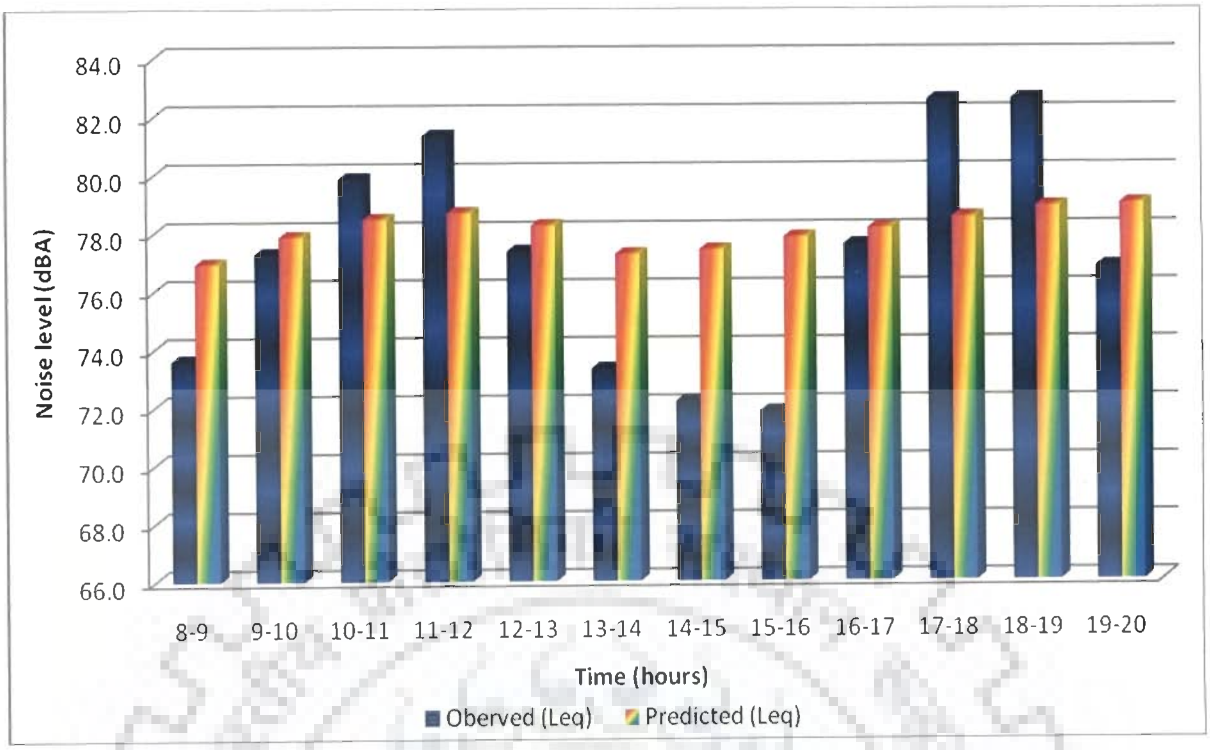


Figure 5.4 (a): Temporal Variation of Observed and Predicted Noise Level at Jhilmil (Toards Mansarovar Park)

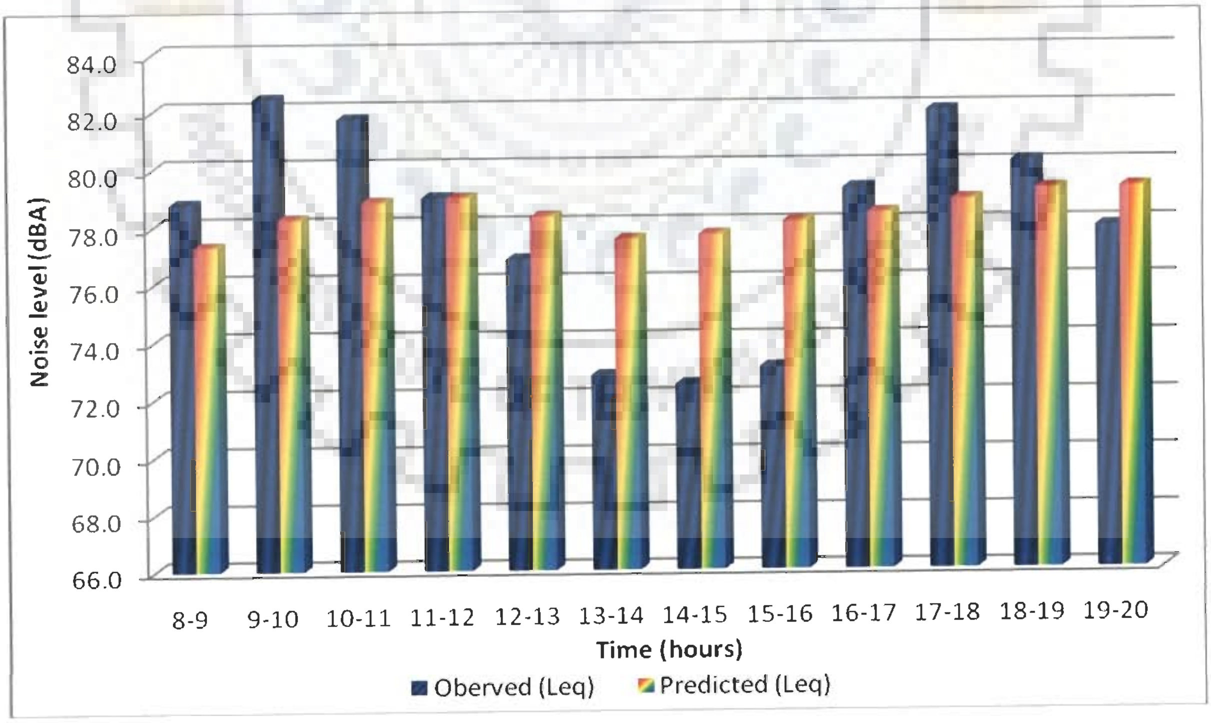


Figure 5.4 (b): Temporal Variation of Observed and Predicted Noise Level at Jhilmil (Towards Dilshad Garden)

5.2.2.4 Comparative analysis of observed and predicted noise level at Dilshad Garden

The graphical comparison between observed and predicted equivalent noise level has been exposed in Figure 5.5 (a) and 5.5 (b). From both the figures, it is established that the maximum and minimum predicted and observed noise level ranges between 76.8 – 72.3 dBA and 72.9 – 66.2 dBA respectively (towards Jhilmil). In the other direction of the location the highest and lowest predicted noise level is found 78.3 and 75.5 dBA correspondingly. The percentage difference has also been calculated to valid the model and at this location, the modified FHWA model predicts the noise with the maximum and minimum percentage difference of 9.9 and -1.58 (Table 5.5). This range of percentage error proves the suitability and applicability of the model to predict the traffic noise level.

Table 5.5: Observed and Predicted Noise Level at Dilshad Garden Location

Direction: Towards Jhilmil				Direction: Towards Gaziabad			
Time	Observed (Leq)	Predicted (Leq)	% Error	Time	Observed (Leq)	Predicted (Leq)	% Error
8-9	72.9	74.8	2.53	8-9	71.8	76.4	6.39
9-10	71.5	75.9	6.28	9-10	74.9	77.6	3.56
10-11	71.2	76.3	7.03	10-11	79.2	77.9	-1.58
11-12	71.1	76.1	7.02	11-12	74.7	77.6	3.85
12-13	69.2	75.2	8.71	12-13	71.2	76.8	7.90
13-14	69.5	74.5	7.26	13-14	70.3	76.1	8.28
14-15	66.2	72.7	9.90	14-15	69.2	75.5	9.09
15-16	66.2	72.3	9.18	15-16	69.7	76.5	9.71
16-17	70.7	75.6	6.93	16-17	75.5	77.2	2.24
17-18	70.5	75.9	7.75	17-18	74.5	77.5	4.07
18-19	71.9	76.6	6.47	18-19	74.8	78.1	4.41
19-20	71.8	76.8	6.86	19-20	76.7	78.3	2.07

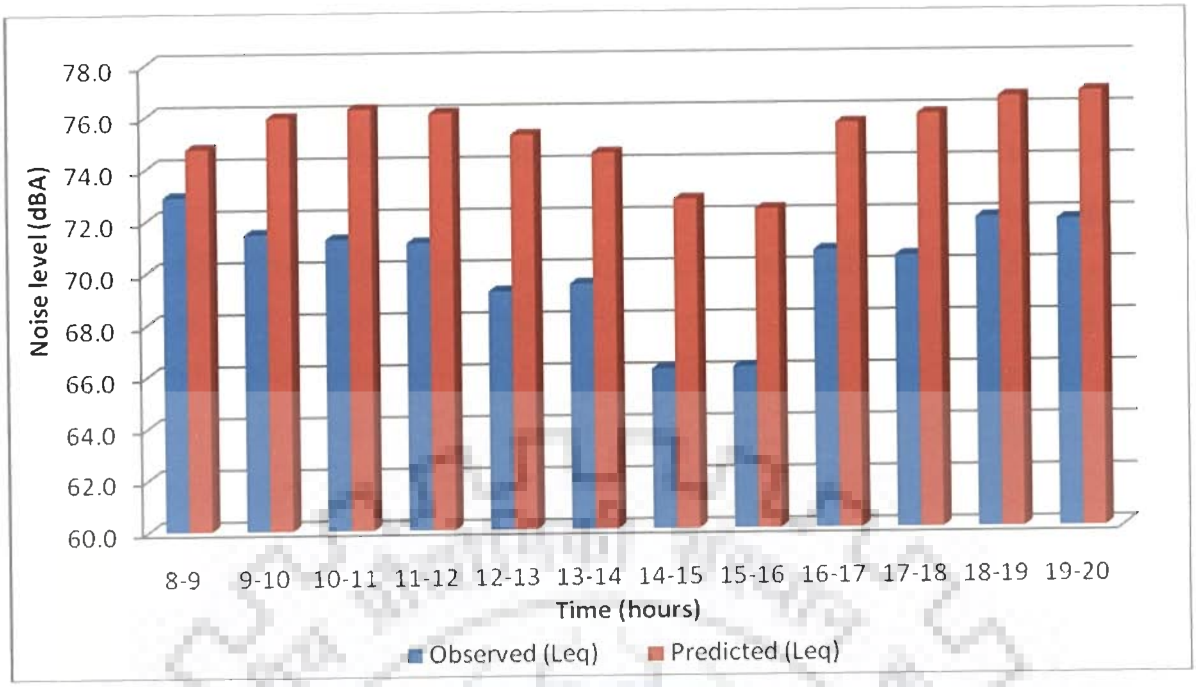


Figure 5.5 (a): Hourly Variation of Observed and Predicted Noise Level at Dilshad Garden (Towards Jhilmil)

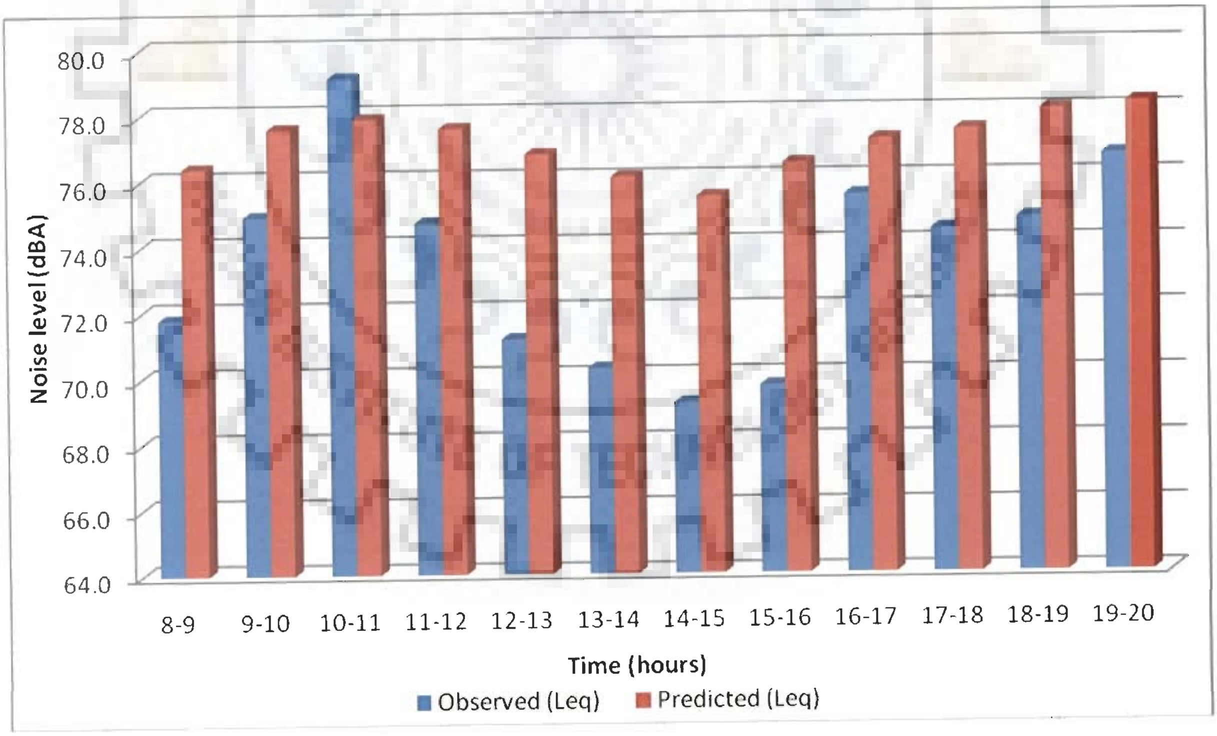


Figure 5.5 (b): Hourly Variation of Observed and Predicted Noise Level at Dilshad Garden (Towards Gaziabad)

5.2.2.5 Comparative analysis of observed and predicted noise level at Panchsheel Enclave

After analyzing the ambient noise level data of BRTS corridor, the highest predicted and observed equivalent noise level has been found during the same hour 14:00 to 15:00 i.e. 73.26 dBA and 84.07 dBA respectively, whereas lowest predicted and observed noise value is found during 8:00 to 9:00 hour (70.85 dBA) and 16:00 to 17:00 hour (75.45 dBA) respectively along one side (towards Moolchand). While on the other side of corridor (towards Ambedkar Nagar), the lowest modeled (63.72 dBA) and monitored (66.64 dBA) value is found during 15:00 to 16:00 hour and 8:00 to 9:00 hour respectively (Figure 5.6 a and 5.6 b). From the results of both side of the corridor, it is found that the observed value is always higher than the predicted value during monitoring hours. It is found that the average percentage error between observed and predicted noise levels varies between -9.4 to -7.8 (Table 5.6) for modified FHWA model, which specified the appropriateness of this model.

Table 5.6: Observed and Predicted Noise Level at Panchsheel Enclave

Direction: Towards Moolchand				**Direction: Towards Ambedkar Nagar**			
Time	**Observed (Leq)**	**Predicted (Leq)**	**% Error**	**Time**	**Observed (Leq)**	**Predicted (Leq)**	**% Error**
8-9	76.06	70.85	-6.85	8-9	66.64	64.42	-3.33
9-10	78.86	72.46	-8.12	9-10	77.88	65.87	-15.42
10-11	79.06	72.84	-7.87	10-11	67.14	65.25	-2.82
11-12	79.11	72.16	-8.79	11-12	78.88	66.78	-15.33
12-13	76.48	71.96	-5.91	12-13	66.94	64.66	-3.40
13-14	82.66	72.16	-12.71	13-14	70.46	64.95	-7.82
14-15	84.07	73.26	-12.86	14-15	75.02	65.45	-12.75
15-16	75.79	71.06	-6.24	15-16	68.88	63.72	-7.48
16-17	75.45	71.65	-5.03	16-17	71.45	64.1	-10.28
17-18	76.16	71.26	-6.43	17-18	72.79	64.54	-11.33
18-19	77.66	72.12	-7.13	18-19	73.25	64.66	-11.73
19-20	75.56	71.02	-6.01	19-20	72.89	64.64	-11.31

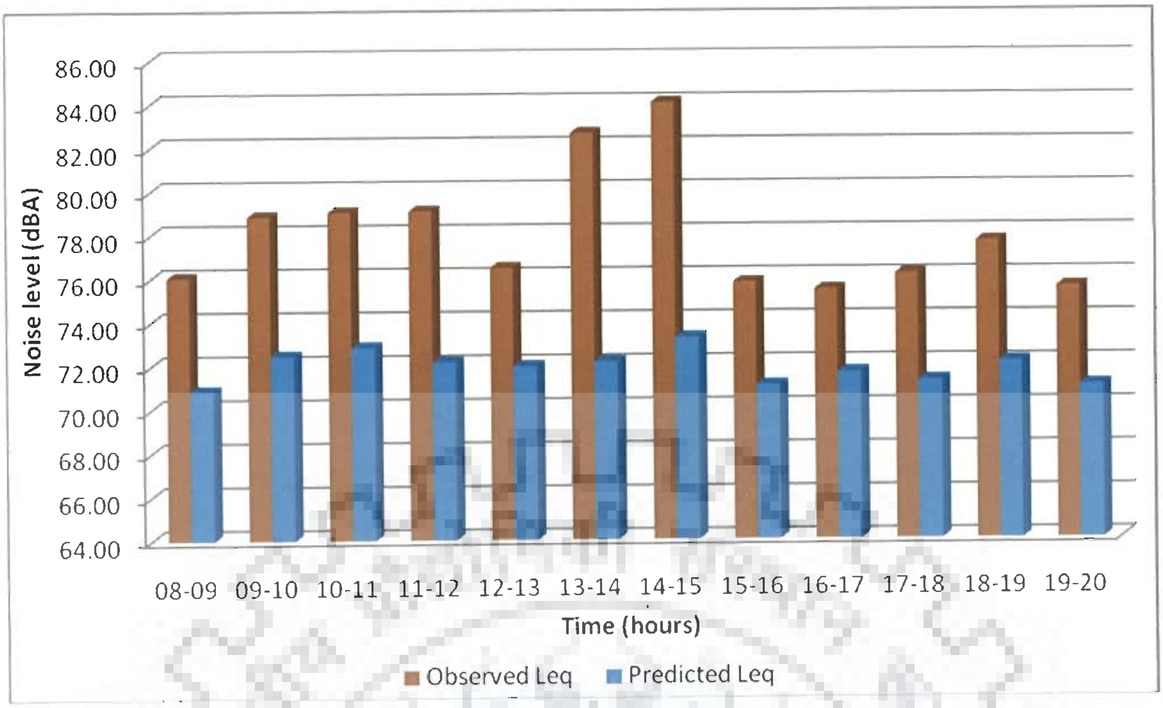


Figure 5.6 (a): Temporal Variation of Observed and Predicted Noise Level at Panchsheel Enclave (Towards Moolchand)

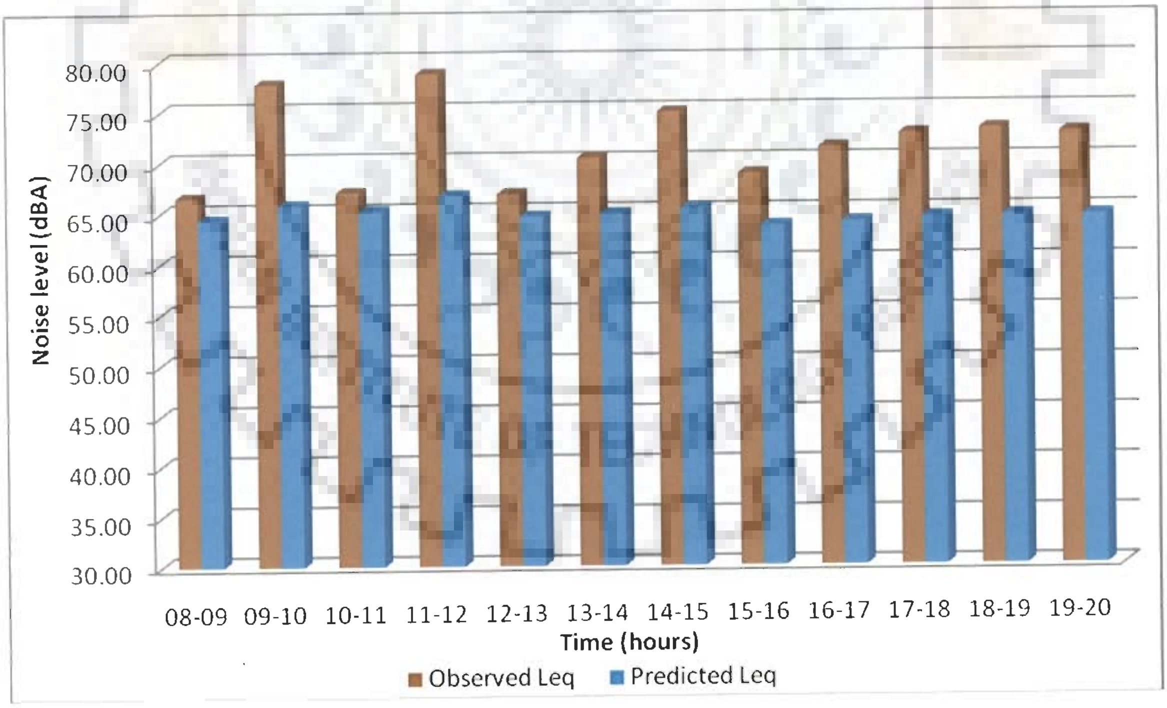


Figure 5.6 (b): Temporal Variation of Observed and Predicted Noise Level at Panchsheel Enclave (Towards Ambedkar Nagar)

5.2.3 Features and application of model

The EXCEL based developed model can be applied in field condition for the prediction of traffic noise due to vehicles. It is easy to use by people due its user friendly feature. The developed model basically calculates Leq of noise level. By feeding all necessary inputs i.e. traffic volume, spot speed, height of noise source etc. in this model, traffic noise level can be predicted within no time. Due to free from mathematical complexity, it is applicable to academician, engineers as well as students.

5.3 Model Development for Metro Rail Noise and Barrier Design

5.3.1 Description of model

Federal Transit Administration (FTA) methodology has been used to develop this KM based model in MS EXCEL worksheet system to predict the metro rail noise level (Annexure II). In addition to this by using this worksheet system it is possible to calculate the required height of barrier along elevated corridor of metro line to overcome the problem of metro rail noise. The model requires inputs such as maximum noise levels at 50 feet for each type of noise source (e.g., rapid transit and commuter rail passbys, wheel squeal) expected to occur. For modelling purposes, the affected rail lines have been divided into segments based on various operations data and terrain features (i.e., cuts and fills, existing noise barriers). Different inputs such as vehicle volumes, train consist sizes and speeds have been combined with terrain features (which affect the noise propagation path) to determine noise levels at identified receptors within each segment. Other inputs such as track type (i.e., jointed or continuously welded), the presence of an intervening noise barrier, ground attenuation effects and shielding from rows of houses or trees will also be used to refine the modelling assessment. Each of the applicable noise metrics and criteria has been used to evaluate project-related noise impacts at receptor locations identified.

This model has been applied to predict train noise levels at sensitive receptor locations. This process can be completed in following stages:

5.3.1.1: Hourly equivalent sound level @ 15.24 metre (50 feet)

The following equation has been used to compute the hourly L_{eq} at 50 feet.

$$L_{eq@\,50feet} = SEL_{ref} + 10log(Ncars) + 20log(S/50) + 10log(V) + C_{adj} - 10log(3600) \text{.......(5.3)}$$

where:

$L_{eq}50(h)$ = hourly L_{eq} noise level at 15.24 mt (50 feet) (in dBA),

SEL_{ref} = reference SEL noise level at 15.24 mt (50 feet) (in dBA),

N_{cars} = average consist size (i.e., number of locomotives or rail cars per train);

S = train speed (in mph);

V = average hourly train volumes as follows (in trains/hour):

$$V_D = \left[\frac{\sum_{7AM}^{10PM} no\ of\ trains}{15}\right] \quad [Average\ hourly\ day\ time\ volume]$$

$$V_N = \left[\frac{\sum_{10PM}^{7AM} no\ of\ trains}{9}\right] \quad [Average\ hourly\ night\ time\ volume]$$

$$V_{PK} = \left[\sum_{PK-HR} number\ of\ trains\right] \quad [Average\ hourly\ peak\ hour\ volume]$$

C_{adj} = adjustment factor applied to track type as follows (in dBA):

= +5 for jointed rail track;

= +4 for aerial structure with slab track; and,

= +3 for embedded track on grade.

10 log (3600) = L_{eq} (h) adjustment factor based on the number of seconds in one hour (in dBA).

5.3.1.2: Hourly equivalent sound level @ distance d feet

This equation can be used to predict hourly equivalent sound level at d distance.

$$L_{eq\ @\ D\ feet} = [L_{eq\ @50feet}]-[15\log^{(D/50)}] \quad \text{...... (5.4)}$$

where d is the distance between receiver and the track center line in feet

5.3.1.3: Barrier shielding

Barrier shielding is computed using equation 5.5. Shielding provided by a barrier is based on the path length difference between the noise path over the barrier and the direct line-of-sight path in the absence of a barrier.

$$A_{BARRIER} = min\left\{20\ or \left[20\log\left[\frac{3.54\sqrt{p}}{\tanh[6.27\sqrt{p}]}\right] + 5\right]\right\} \quad \text{......(5.5)}$$

where:

$A_{barrier}$ = barrier shielding (in dBA),

P= barrier path length difference: P = A + B - C (in feet).

$$P = A+B-C \qquad \text{..... (5.6)}$$

$$A = \sqrt{D_{SB}^2 + (H_B - H_S)^2} \qquad \text{.....(5.7)}$$

$$B = \sqrt{D_{BR}^2 + (H_B - H_R)^2} \qquad \text{......(5.8)}$$

$$C = \sqrt{(D_{SB} + D_{BR})^2 + (H_S - H_R)^2} \qquad \text{...... (5.9)}$$

5.3.1.4: Barrier insertion loss

The barrier insertion loss is determined using the FTA equation 5.10. The overall reduction in noise at a receptor behind a barrier is based on the combination of the barrier shielding effects and the difference between the ground attenuation with and without a barrier.

$$IL_{Bar} = A_{barrier} - 10(G_{NB}-G_B) \log (ds/50) \qquad \text{...... (5.10)}$$

where:

IL_{Bar} = barrier insertion loss (in dBA);

$A_{barrier}$ = barrier shielding (in dBA);

G_{NB} = ground factor computed without a barrier;

G_B = ground factor computed with a barrier; and,

dS = closest distance between the receptor and the source (in feet)

5.3.1.5 Ground attenuation: effective height:

The effective height between the source and the receptor has been calculated according to the following equation.

$$H_{eff} = \frac{H_S +_2 H_B + H_R}{2} \qquad \text{...... (5.11)}$$

where:

H_{eff} = effective height (in feet),

H_{Source} = height of noise source with the following acoustical heights (in feet),

H_{Bar} = height of intervening barrier (in feet) and

H_{Rec} = height of receptor (in feet)

5.3.1.6 Ground attenuation: ground factor

On the basis of effective height, an appropriate ground attenuation factor may be estimated according to following equation:

$$G = \begin{cases} 0.66 & H_{eff} < 5 \\ 0.75 \times \left(1 - \frac{H_{eff}}{42}\right) & 5 < H_{eff} < 42 \\ 0 & 42 < H_{eff} \end{cases} \qquad \text{...... (5.12)}$$

where:

G = ground factor (dimensionless) and

H_{eff} = computed effective height (in feet)

5.3.1.7: Building shielding

In addition to barrier shielding effects, dense residential neighbourhoods may also provide shielding due to intervening rows of buildings. Depending on the density of the rows of buildings, shielding due to rows of buildings is computed using the equation given below.

$$A_{Bldg} = \{\text{Min } 10 \textit{ or } [\, 1.5 \text{ X } (N_{Row} - 1) + C_{Gap} \,]\} \qquad \text{......(5.13)}$$

where:

A_{Bldg} = building shielding (in dBA),

N_{Row} = number of rows of buildings that intervene between the source and receptor and

C_{Gap} = building shielding adjustment factor as follows (in dBA):

= 5 dBA if gap between row of buildings is less than 35 percent of the row length;

= 3 dBA if gaps between row of buildings is between 35 and 65 percent of the row length and

A_{Bldg} = 0, if gaps between row of buildings is greater than 65 percent of the row length.

5.3.1.8: Maximum allowable shielding

The developed FTA based model limits the total shielding allowed according to the equation shown below.

$$A_{Shld} = Max\ \{IL_{Bar} \text{ or } A_{Bar} \text{ or } A_{Bldg}\} \qquad \text{...... (5.14)}$$

where:

A_{Shld} = total shielding allowed (in dBA),

IL_{Bar} = barrier insertion loss (in dBA),

A_{Bar} = barrier shielding (in dBA) and

A_{Bldg} = building shielding (in dBA)

5.3.1.9: Final L^{1}_{eq} after insertion of barrier

Final L^{1}_{eq} after barrier insertion can be obtained by the following relation:

$$\text{Final } L^{1}_{eq} = L_{eq} \text{ @ distance d} - IL_{Bar} \quad \text{..... (5.15)}$$

This L^{1}_{eq} should be within the standards of CPCB and FHWA.

5.3.2 Model calibration

To calibrate the model, noise levels are predicted at various points using developed KM based tool in MS EXCEL worksheet system. The results are presented in Figure 5.7 and 5.8. Figure 5.7 depicts the variation of noise level with distance at same height of source, whereas Figure 5.8 illustrates the variation of noise level with height at certain distance.

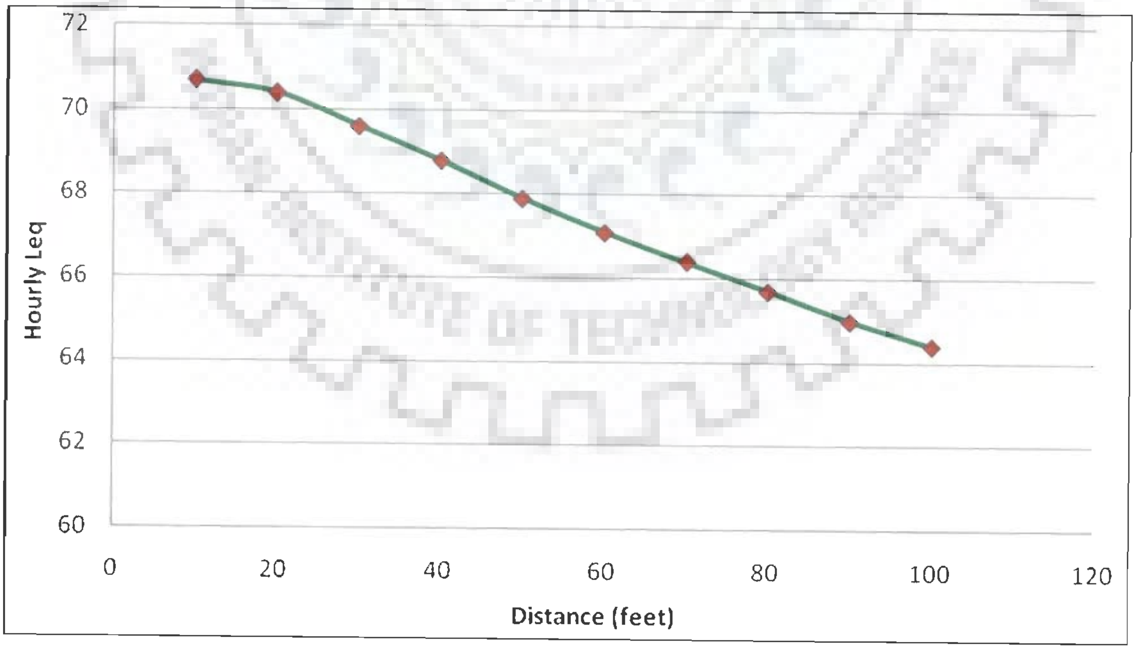


Figure 5.7: Variation of Noise Level with Distance

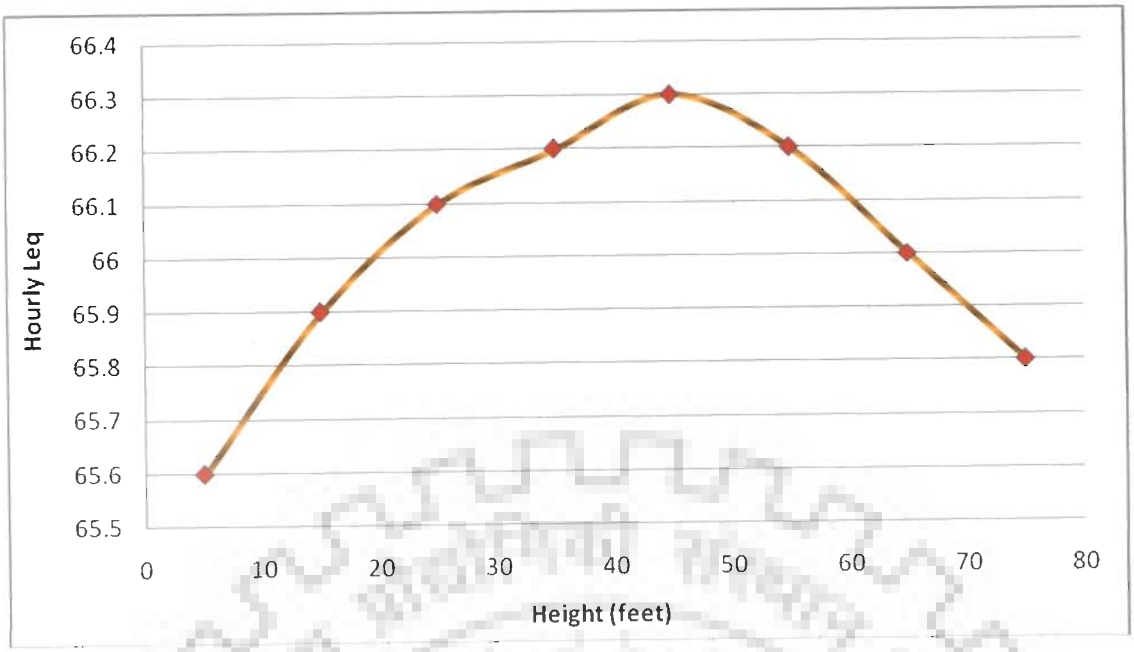


Figure 5.8: Variation of Noise Level Height

5.3.3 Validation of model and discussion of results

For the validation of developed model, different studies have been conducted at different selected locations along the major public transport corridor.

5.3.3.1: Rithala metro station

To validate the model, noise level has been measured using the Sound Level Meter by standing at 1.8 mt (6 feet) away from the centre of track. The observed and predicted noise levels are found 74.7 and 71.2 dBA with the percentage error of -4.68, which indicates the suitability of this model. Table 5.7 presents the predicted and observed value with percentage error.

Table 5.7: Observed vs. Predicted Noise at Rithala Metro Station

Observed L_{eq} in dB	Predicted L_{eq} in dB	Percentage Error
74.7	71.2	-4.68

5.3.3.2: Residential apartments of selected locations

At Ritahal, Pitampura, Jhilmil and Dilshad Garden metro station, the noise levels have been measured on the third floor of residential apartment at the distance of 24.59 mt (80.7 feet), 20.87 mt (68.2 feet), 15.88 mt. (52.12 feet) and 21.4 mt (70.24 feet) from the centre line of track respectively. With the help of developed spread sheet based model, the noise level has been predicted and -14.2, -13.7, -12.3 and -13.6 percentage error has been found between the predicted and observed noise level measured at Ritahal, Pitampura, Jhilmil and Dilshad Garden correspondingly. The reason behind the higher percentage error between measured and modelled values are incorporation of road traffic noise by the vehicles moving beside the track at the ground level, to metro rail noise, which results into the overall increment of metro noise. Table 5.8 indicates the measured and modelled noise levels of all the selected locations.

Table 5.8: Observed Value vs. Predicted Values at Selected Metro Stations

Location	Observed (Leq)	Predicted (Leq)	% Error
Rithala	77.3	66.3	-14.2
Pitampura	78.1	67.4	-13.7
Jhilmil	78.8	69.1	-12.3
Dilshad Garden	77.8	67.2	-13.6

5.3.3.3: Elevated track moving from Kashmere Gate to Shasthri Park

To validate the developed model the study is conducted at this location which was free from road traffic. During this study, noise levels are observed at three different points. In first identified point, the noise is measured at 2.7 mt (9 feet) height above the ground level and at a distance of 13.7 mt (45 feet) from the outer face of viaduct. The percentage error between measured and modelled noise level has been obtained -4.08. In other case, the noise level is measured at a height of 1.2 mt (4 feet) and distance of 6.1 mt (20 feet) from the outer face of viaduct. In this situation, the computed percentage error is found +1.4. In addition to this, the same process has been repeated at a distance of 3.04 mt (10 feet) and height of 1.2 mt (4 feet) and again +2.7 percentage errors has been found between observed and predicted values (Figure 5.9).

Table 5.9: Comparative Study of Observed and Predicted Noise Level

Identified points	Height (feet)	Distance (feet)	Observed L_{eq} in dB	Predicted L_{eq} in dB	Percentage error
1.	9	45	71	68.1	-4.08
2.	4	20	68.8	69.8	+1.4
3.	4	10	68.6	70.5	+2.7

From the study at identified locations, it is found that the percentage error varies from -4.08 to +2.7 which is considerable range and this shows that the proposed model for the noise prediction is validated and can be used to design the noise barrier for elevated section of Delhi metro.

5.3.4 Features and application of model

Along with road traffic noise, metro rail noise is also creating undesirable health impact problems to the people living in high rise buildings along corridor because of its noise and vibration generation. To predict the noise level at different floors of buildings situated along corridor, this model has been formulated. To avoid its long mathematical calculation in the prediction of metro rail noise, the help of MS EXCEL has been taken. This model is developed in spread sheet. The MS EXCEL is very easy to use and understandable to people. Along with the prediction of metro rail noise, the same model can also be applied for the calculation of required barrier height at sensitive location to curb the noise. This model is very helpful and applicable for the megacity like Delhi to control the metro rail noise and to analyse the adverse health impact on people residing in high residential buildings along corridor.

5.4 Summary

In this chapter, modelling of surface transport noise has been discussed. The discussion part also includes the formulation of MS EXCELL mini KM tool to predict the noise level due to road and rail. The present chapter covers the validation of both the developed model through the comparative study of observed and predicted road traffic noise and metro rail noise at all the identified locations along major public transport corridor.

Chapter 6

MODELLING CONCENTRATION OF AIR POLLUTANTS

6.1 General

Keeping in view the research objective, a field study has been conducted to collect data related to air pollutant at identified locations along major public transport corridor in Delhi. Along with this secondary data has also collected to develop the model framework. With the help of the analysis of this primary and secondary data, a knowledge based model has been formulated in MS EXCEL worksheet system. Due to user friendly property of this worksheet system, it is very easy to model the concentration of gaseous pollutants like CO, SO_2 and NOx. This chapter has discussed about the development of model, validation of model through analysis of data and application of model in current scenario.

6.2 KM – Based Model Development to Predict Concentration of Air Pollutants

6.2.1 Description about model

This is General Finite Line Source based model. To overcome the problem of computational complications, this model has been formulated in MS-EXCEL spread sheet (Annexure III). With the application of this model, it is very easy to predict the concentration of gaseous pollutants within no time. This model need not require long mathematical calculations. Only by giving specified inputs like hourly traffic volume, emission factor of different gases for different category of vehicles, temperature, wind direction etc., it will automatically give the concentration of different gaseous pollutants.

6.2.1.1 Inputs of model

This model requires following inputs to calculate the concentration of gaseous pollutant:

(a) Mean ambient wind speed(m/s), u

(b) Wind direction, θ

(c) Temperature(^{o}k), T

(d) Volume(vph), V

(e) Length of the source(m), L

(f) Distance of the receptor from the line source(m), x

(g) Receptor distance from the roadway centre line along the line source(m), y

(h) Stability class

(i) Line source height(m), h_0

(j) Acceleration due to gravity(m/s^2), g

(k) Height of receptor relative to ground(m), Z

6.2.1.2 Calculation of emission rate

The following equation has been used in model to calculate the emission rate:

$$Q = (E_f * V) / 3600 \qquad \ldots\ldots (6.1)$$

where:

Q = emission rate per unit length (gm/mile-second)

Ef = emission factor

V = vehicles per hour

6.2.1.3 Emission factor

Model requires different emission factor for different gases and for different vehicles. Table 6.1 shows the emission factor of different gases and of different vehicles:

Table 6.1 Emission Factor of Different Classes of Indian Vehicles (g/mile-hr)

Pollutants	Car	Two wheeler	Mini Bus	Bus	Mini Truck	Truck	Auto Rickshaw
CO	1.433	1.667	5.890	5.986	5.890	9.656	1.359
NOx	0.489	0.502	3.411	9.994	3.411	14.966	0.555
SO_2	0.085	0.020	0.046	0.241	0.046	0.241	0.020
HC	0.400	0.782	2.173	6.035	2.173	0.595	1.867
PM	0.048	0.034	0.764	NA	0.764	1.996	0.108

Source: The Automotive Research Association (ARAI), 2007

6.2.1.4 Prediction of pollutant concentration

To calculate the concentration of pollutants the following equation has been incorporated in the model:

$$C = \frac{Q}{2\sqrt{2\pi\sigma_z u_e}}\left[\exp\left\{-\frac{1}{2}\left(\frac{z-h_0}{\sigma_z}\right)^2\right\}+\exp\left\{-\frac{1}{2}\left(\frac{z+h_0}{\sigma_z}\right)^2\right\}\right]$$
$$\times\left[erf\left|\frac{\sin\theta\,(L/2-y)-x\cos\theta}{\sqrt{2}\sigma_y}\right|+erf\left|\frac{\sin\theta\,(L/2+y)+x\cos\theta}{\sqrt{2}\sigma_y}\right|\right] \quad (6.2)$$

where:

$\frac{Q}{\sin\theta}$ = emission rate per unit length in line coordinate system,

σ_y = function of downwind distance and

σ_z = function of stability class

6.2.2 Validation of model and discussion of results

To validate the applicability and suitability of the developed model, various studies have been conducted at different locations of major public transport corridor. Through the comparative study between predicted and observed concentration of air pollutants, the model has been validated. In addition to this, percentage difference of every location has also been computed to show the appropriateness of this model.

6.2.2.1 Trend analysis of predicted and observed air concentration at Rithala

6.2.2.1.1 Modelling of CO

The developed model has been applied to predict the concentration of carbon monoxides at selected location. The prediction has been calculated by using equation 6.2 and the results are presented in Figure 6.1. From the figure the maximum and minimum predicted concentration of CO is found 1735.14 μg/m^3 and 1081.48 μg/m^3 respectively during 19-20 hours and 8-9 hours with an average concentration of 1365.22 μg/m^3, whereas the highest and lowest observed concentration of CO is found 1882 μg/m^3 and 1033 μg/m^3 respectively.

6.2.2.1.2 Modelling of NOx

The same model has also been used for the modelling of oxides of nitrogen. The result analysis is presented in Figure 6.2. From the analysis, it is found that level of NOx is higher than the permissible CPCB standard almost throughout the observation period. The maximum predicted concentration of NOx is obtained 100.48 $\mu g/m^3$ during 19-20 hours and minimum (56.03 $\mu g/m^3$) during 8-9 hours with an average of 77.37 $\mu g/m^3$, which is higher than the permissible limit of CPCB. Likewise the highest and lowest observed concentration is found 104.25$\mu g/m^3$ and 56$\mu g/m^3$ correspondingly.

6.2.2.1.3 Modelling of SO_2

The above procedure of prediction has been followed in this case also. The results are shown in Figure 6.3 and it shows the average observed concentration, 40.91$\mu g/m^3$. Along with this highset and lowest modelled concentration is found 49.14 and 29.66 $\mu g/m^3$ with an average of 39.99$\mu g/m^3$. These concentrations are found in limit at Rithala in comparison to CPCB standards.

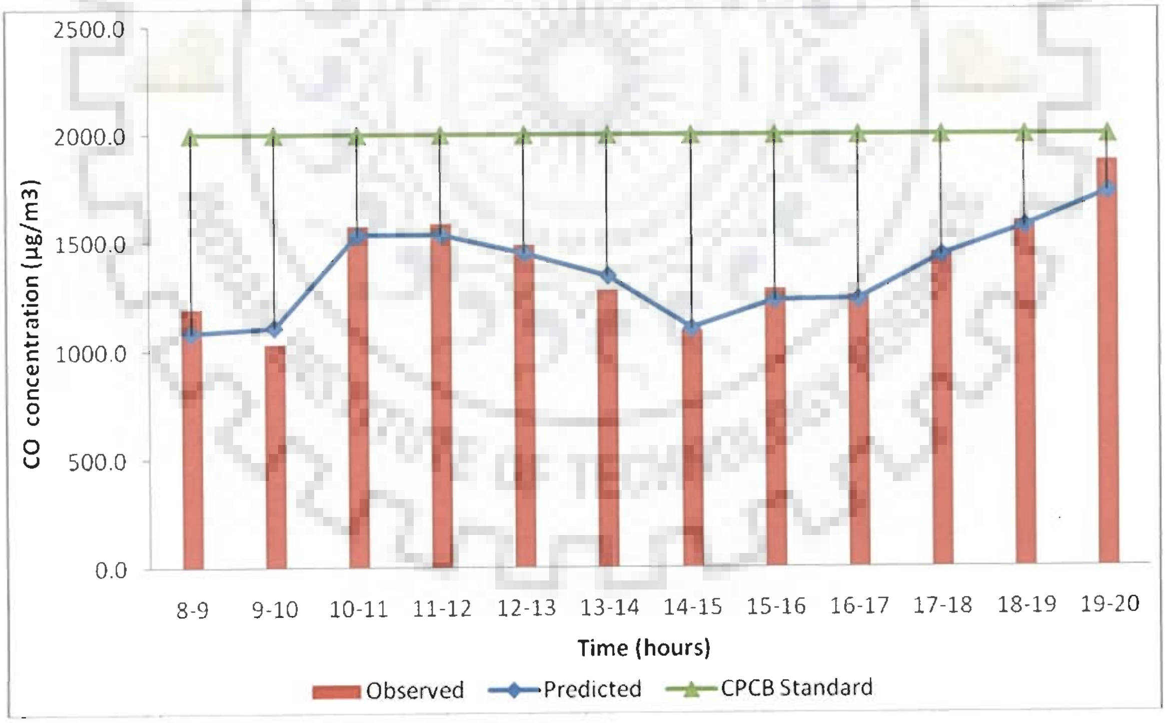


Figure 6.1: Predicted and Observed Concentration of CO at Rithala

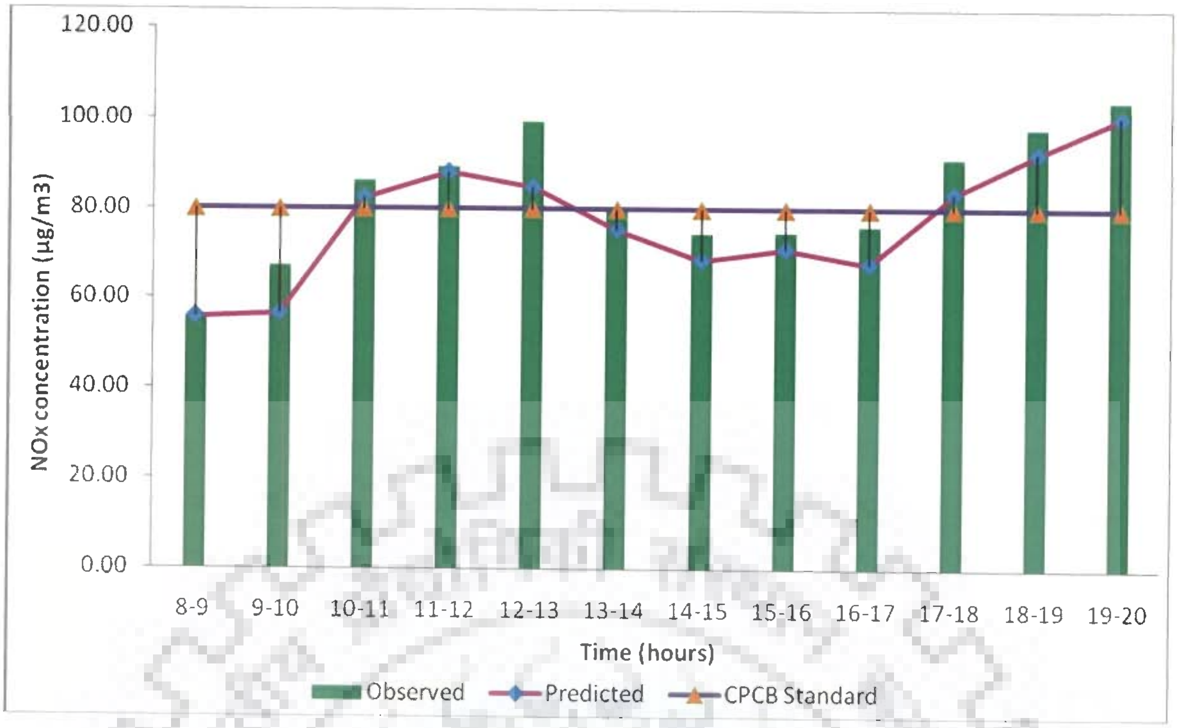


Figure 6.2: Predicted and Observed Concentration of NOx at Rithala

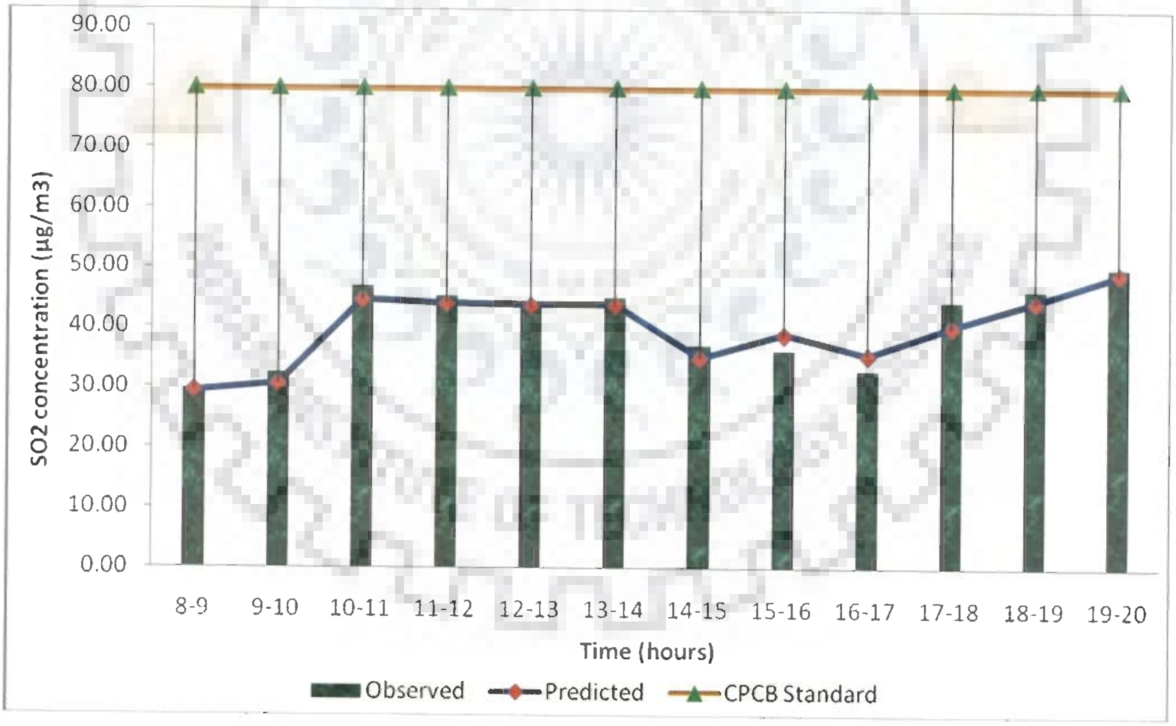


Figure 6.3: Predicted and Observed Concentration of SO_2 at Rithala

6.2.2.1.4 Performance evaluation of KM based GFLS model at Rithala location

Different statistical tests like regression analysis, t-test and index of agreement have been applied on developed model to investigate the performance at particular location. In this regard, different regression equations have been developed to find the correlation between observed and predicted values. Figure 6.4, 6.5 and 6.6 shows the developed regression equation for CO, NOx and SO_2 respectively. Different R^2 vale is found i.e. 0.946, 0.917 and 0.918 for CO, NOx and SO_2 respectvely. This value shows a good correlation between observed and predicted concentration. On the other hand, the index of agreement with 0.9764 (CO), 0.9342 (NOx) and 0.9703 (SO_2) gives very satisfactory results with model performance at particular location. A significance test is also applied to check the consistency of the observed data with predicted data to have confidence in prediction exercise. Significance test between observed and predicted values gives t_{calc}=0.47 for CO, t_{calc}= 1.42 for NOx and t_{calc}= 0.50 for SO_2, which is less than $t_{tabulated}$ =2.179, for degree of freedom = 11 and level of significance = 0.05 (Table 6.2) , which supports the appropriateness of this model for the selected location.

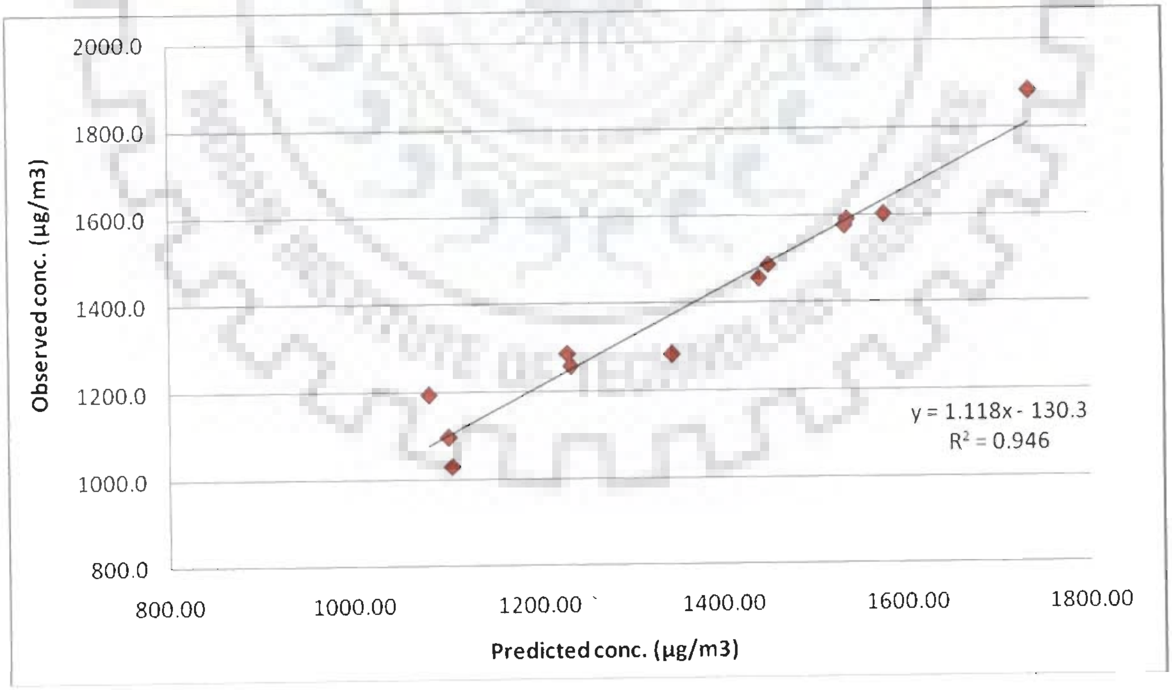


Figure 6.4: Regression Equation Developed for CO at Rithala

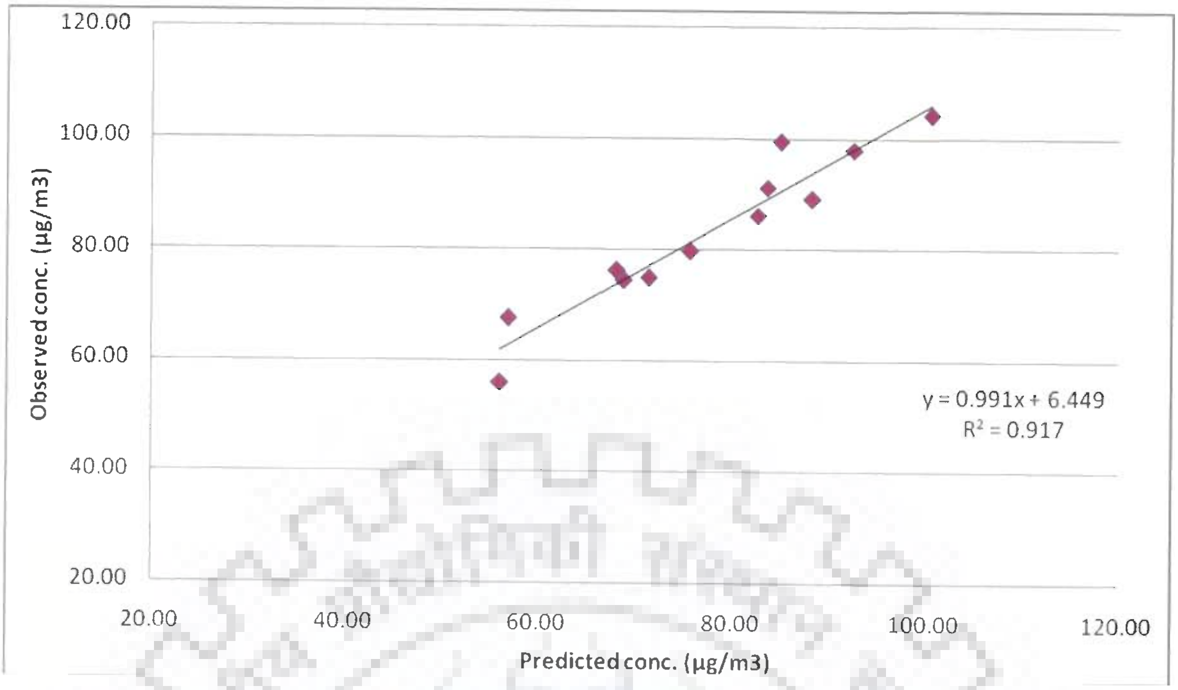


Figure 6.5: Regression Equation Developed for NOx at Rithala

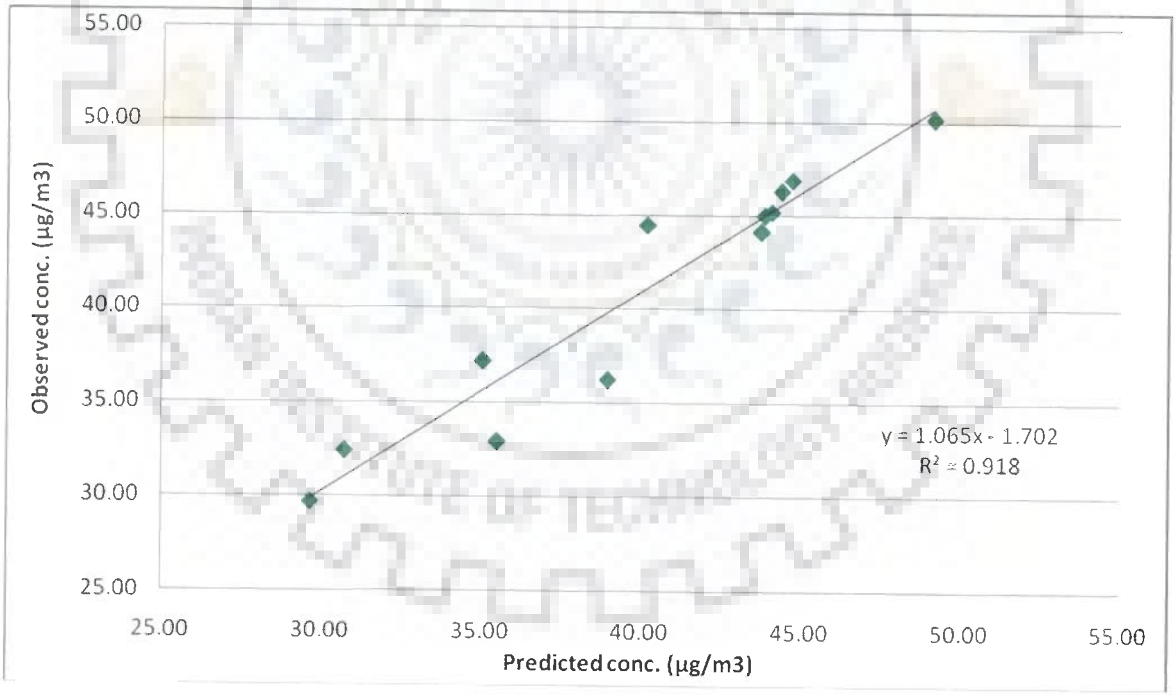


Figure 6.6: Regression Equation Developed for SO_2 at Rithala

Table 6.2: Summarized Results of T-Test at Rithala

	CO	NOx	SO2
$\overline{d}$	30.84	5.75	0.92
Sd	225.88	14	6.32
N	12	12	12
D.O.F	11	11	11
t_{calc}	0.47	1.42	0.50
α	0.05	0.05	0.05
$t_{tabulated}$	2.179	2.179	2.179

6.2.2.2 Trend analysis of predicted and measured air concentration at Pitampura

6.2.2.2.1 Modelling of CO

At Pitampura location, the maximum and minimum predicted concentration is obtained 1487.11μg/m^3 and 899.88μg/m^3 during 10-11 hours and 8-9 hours respectively with an average of 1195.85 μg/m^3 (Figure 6.7). On the other hand, during the entire study at this particular location the average observed concentration is found 1243.17μg/m^3. It is clear from figure that both the values are found lesser than prescribed standard by CPCB.

6.2.2.2.2 Modelling of NOx

Figure 6.8 shows the detailed analysis of data at this location. Predicted concentration is found greater than observed value. In comparison to average observed concentration (109.71 μg/m^3), the average predicted concentration is found 108.32 μg/m^3, which lesser than earlier one. But both the values are found not to compliance CPCB standard. During the analysis of data at this location, frequent deviations are found between observed and predicted concentration during entire study.

6.2.2.2.3 Modelling of SO_2

The maximum and minimum predicted concentration at this location is obtained 45.28μg/m^3 and 29.97μg/m^3. Whereas the highest and lowest measured concentration is found 46.26μg/m^3 and 29.04μg/m^3. The overall average predicted and observed value has been calculated and found 35.54μg/m^3 and 36.26μg/m^3. In both the condition it is concluded that the analysed value comes under limit.

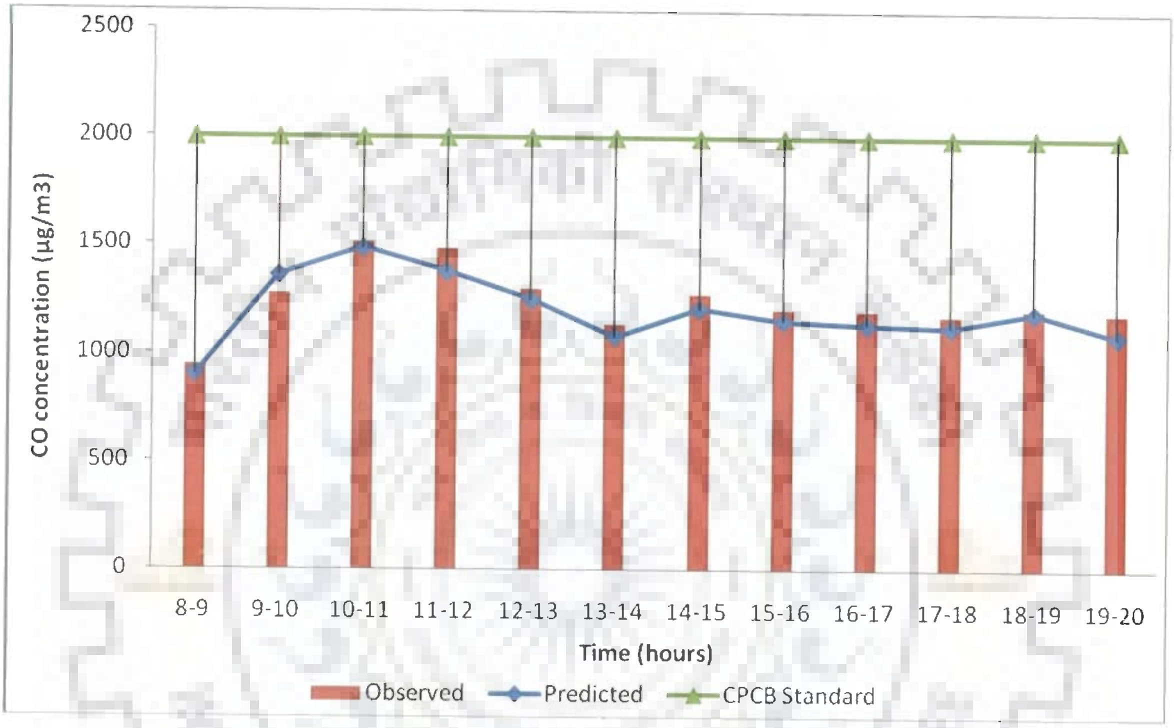


Figure 6.7: Predicted and Observed Concentration of CO at Pitampura

Figure 6.8: Predicted and Observed Concentration of NOx at Pitampura

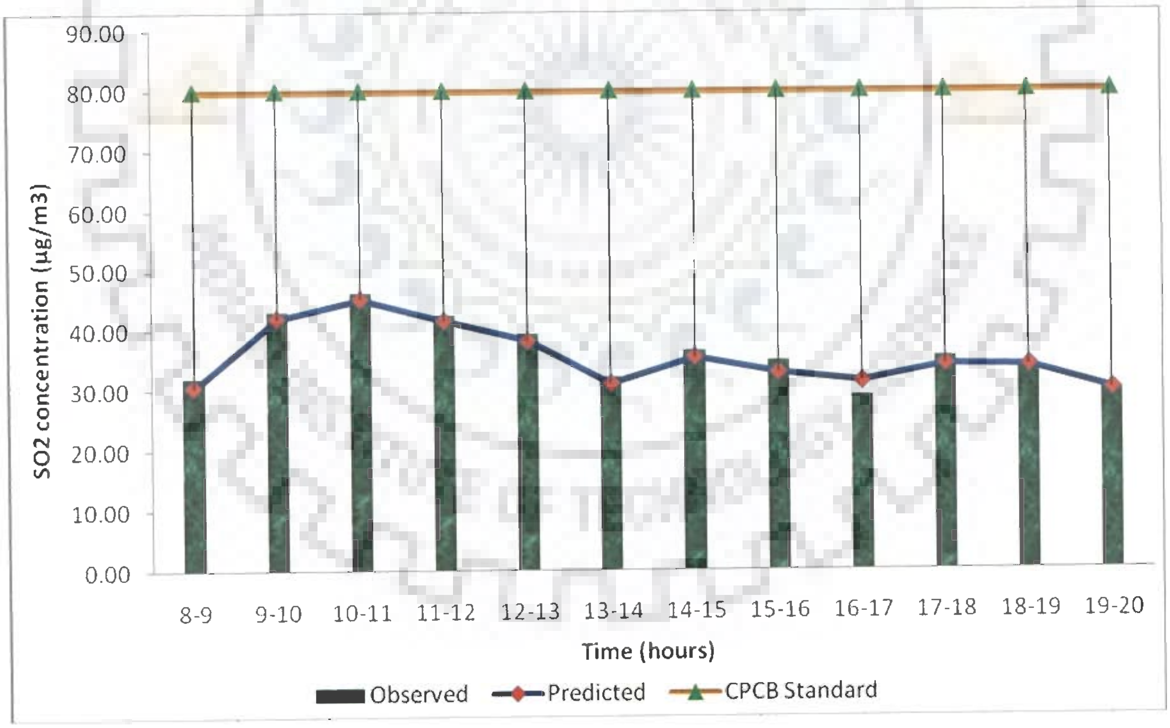


Figure 6.9: Predicted and Observed Concentration of SO_2 at Pitampura

6.2.2.2.4 Performance assessment of KM based GFLS model at Pitampura location

This location comes under semi residential area. It is the combination of residential as well as commercial zone. To ensure the accuracy of applied model regression equations have been developed separately for each gas i.e. CO, NOx and SO_2. Equations are depicted in Figure 6.10, 6.11 and 6.12. Figure 6.10, 6.11 and 6.12 shows the R^2 value 0.902 for CO, 0.821 for NOx and 0.96 for SO_2. All these three figures show a good relationship between observed and predicted concentration of different gases. The index of agreement for these three gases have been computed and found 0.9490 for CO, 0.9399 for NOx and 0.9836 for SO_2, which indicates satisfactory performance of the model. In addition to this significance test between observed and predicted values gives t_{calc}= 1.07 for CO, t_{calc}= 0.34 for NOx and t_{calc}= 0.48 for SO_2, which is less than $t_{tabulated}$ =2.179, for degree of freedom = 11 and level of significance=0.05 (Table 6.3), hence the difference between observed and predicted value is found insignificant. Thus the test describes the better application of this model in Indian condition.

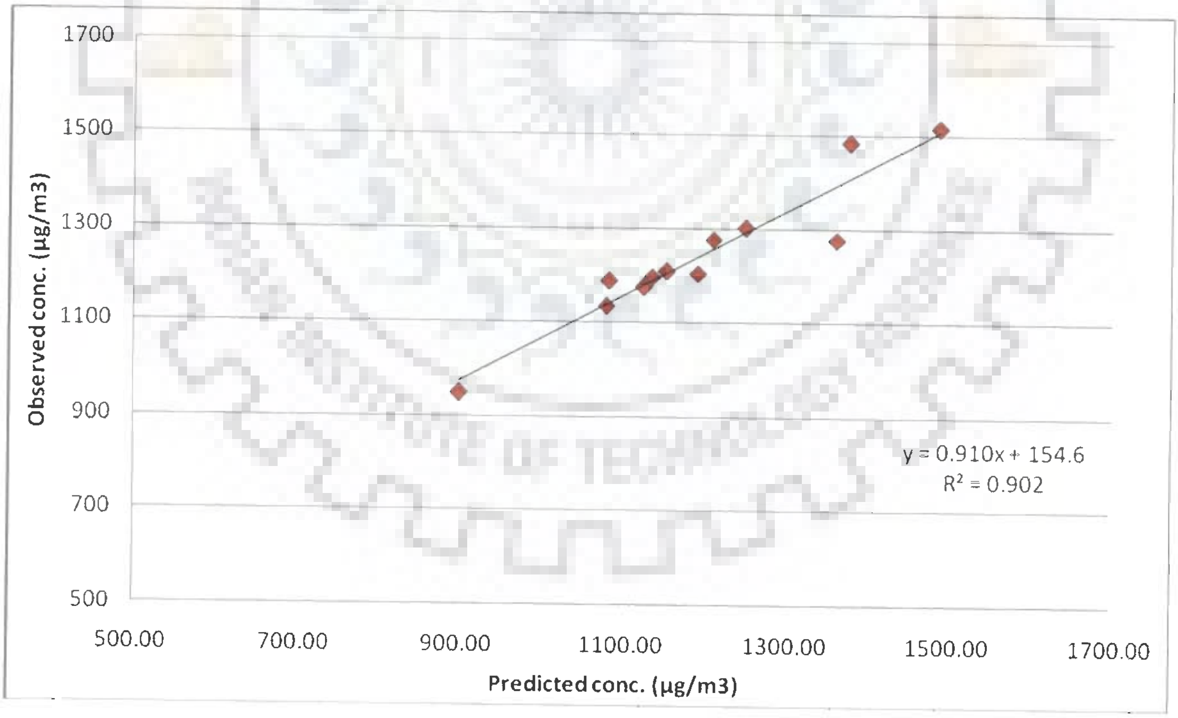


Figure 6.10: Regression Equation Developed for CO at Pitampura

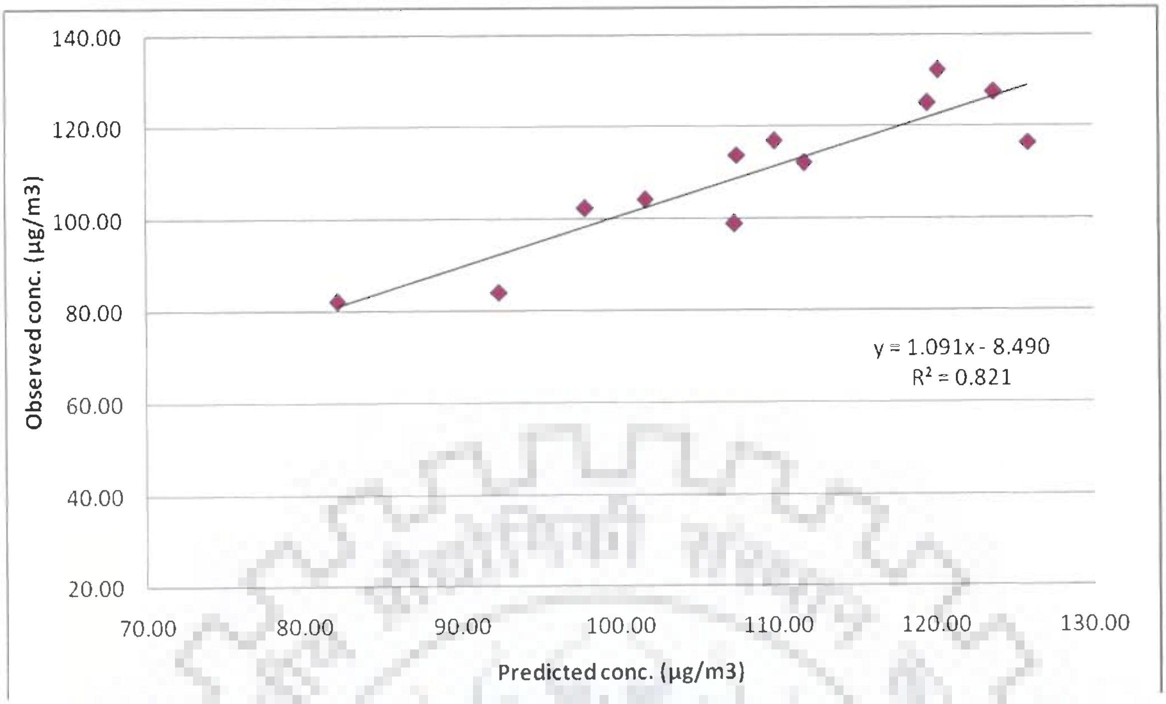


Figure 6.11: Regression Equation Developed for NOx at Pitampura

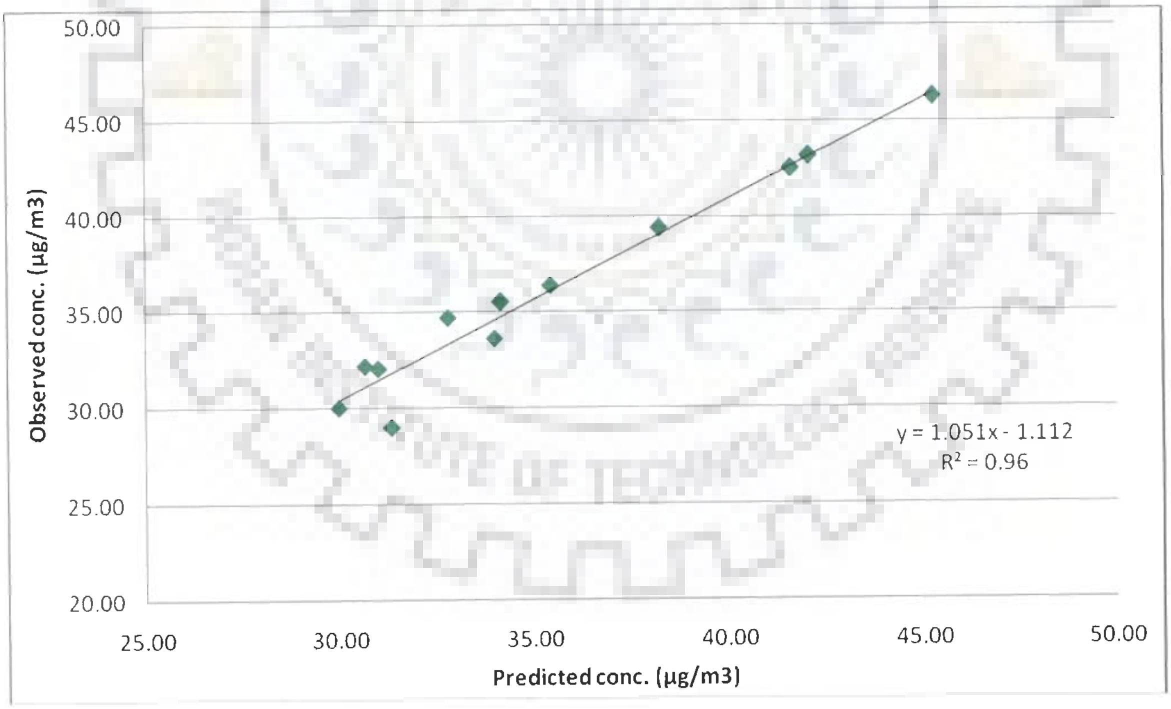


Figure 6.12: Regression Equation Developed for SO_2 at Pitampura

Table 6.3: Summarized Results of T-test at Pitampura

	CO	NOx	SO2
$\bar{d}$	47.31	1.39	0.71
Sd	152.63	14.32	5.1948
N	12	12	12
D.O.F	11	11	11
t_{calc}	1.07	0.34	0.48
α	0.05	0.05	0.05
$t_{tabulated}$	2.179	2.179	2.179

6.2.2.3 Trend analysis of modelled and measured air concentration at Kashmiri Gate

6.2.2.3.1 Modelling of CO

The pattern analysis of carbon monoxide is presented in Figure 6.13 and the highest modelled concentration is found during 1308.43μg/m^3 during 18-19, whereas the lowest is found during 8-9 hours (758.60μg/m^3) of the study. The overall average concentration of entire hour has also been estimated and found 1162.42μg/m^3. On the other side the average concentration of measured value is found 1231.08μg/m^3 with the highest and lowest concentration of 1497μg/m^3 and 790μg/m^3 respectively. Finally, it is found that the predicted and observed maximum, minimum and average concentration of CO is much lower than permissible CPCB limit.

6.2.2.3.2 Modelling of NOx

The selected location is identified as a commercial zone. The comparative study is shown in Figure 6.14. It can be observed from the figure that predicted concentration is higher than observed concentration as well as CPCB standard. The average predicted concentration is found 97.64μg/m^3 and observed is found 98.07μg/m^3. It is concluded from figure that both the concentration are higher than the permissible standard almost throughout the entire study.

6.2.2.3.3 Modelling of SO_2

The 12 hour study at Kashmiri Gate shows that the maximum observed concentration of SO_2 is 41.98μg/m^3 during 18-19 hours and minimum is 26.34μg/m^3 during morning hours (8-9 hours) with an average of 36.33μg/m^3. Similarly, the maximum predicted concentration of SO_2 is found 40.96μg/m^3 and minimum is obtained 24.30μg/m^3 with an average of 34.46μg/m^3. Both the predicted and observed values are found much lower than ambient air quality standard.

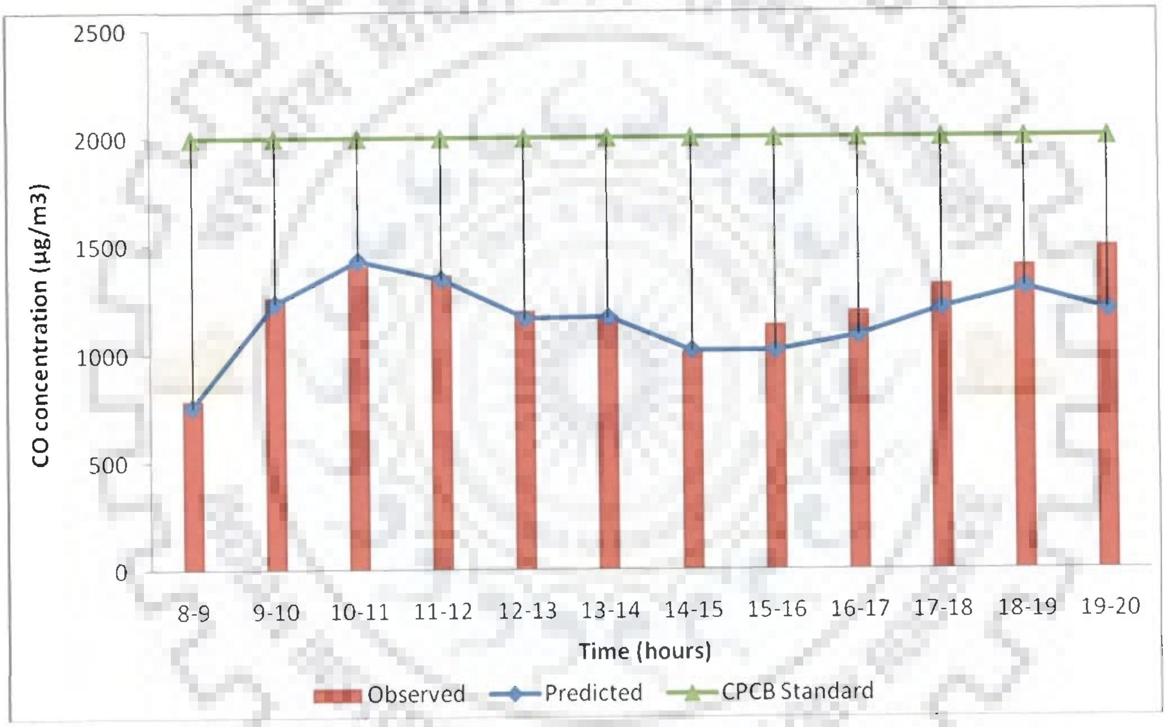


Figure 6.13: Predicted and Observed Concentration of CO at Kashmiri Gate

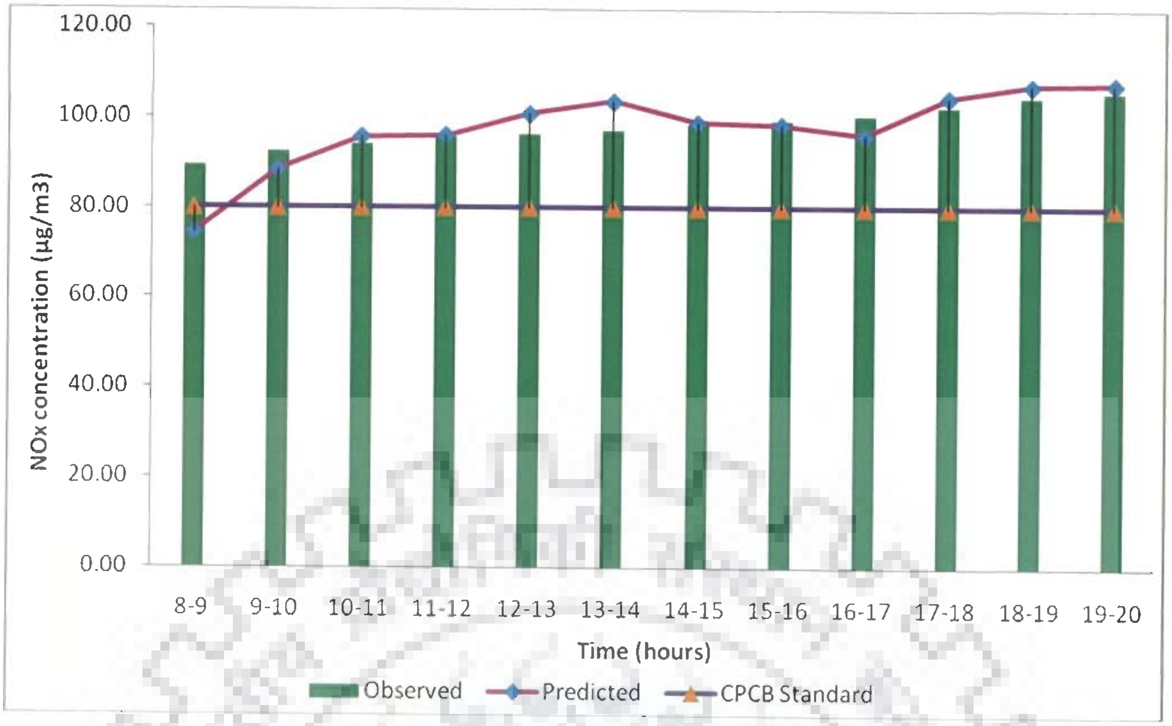


Figure 6.14: Predicted and Observed Concentration of NOx at Kashmiri Gate

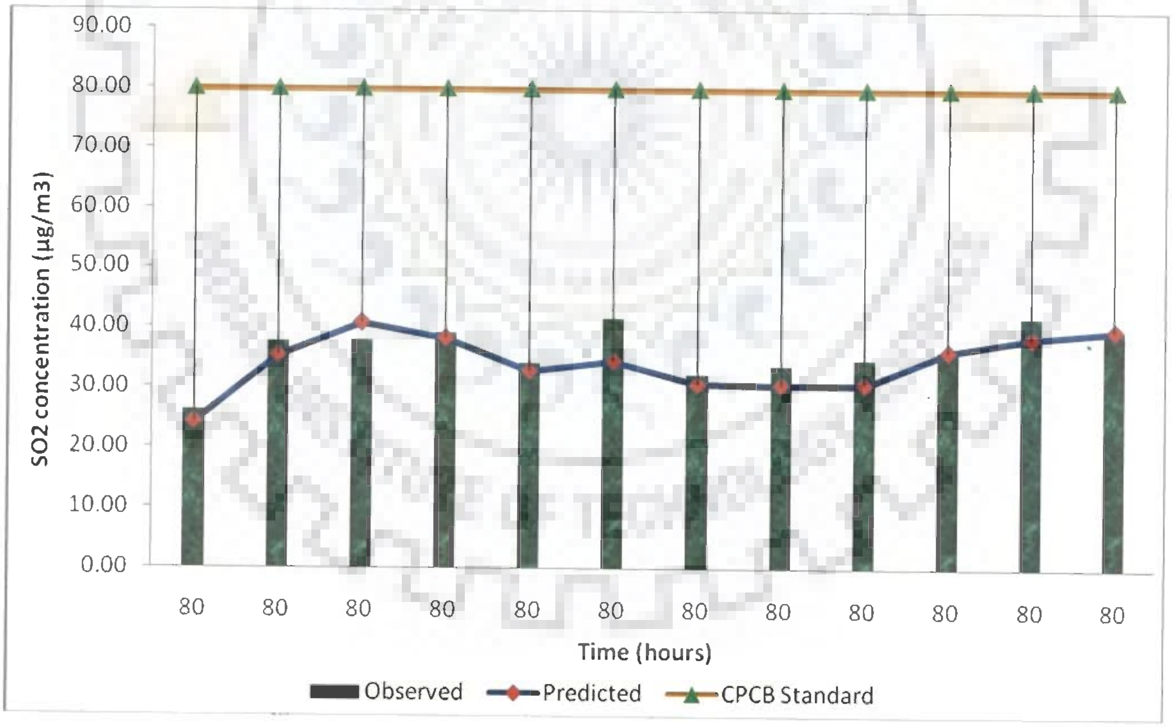


Figure 6.15: Predicted and Observed Concentration of SO_2 at Kashmiri Gate

6.2.2.3.4 Performance evaluation of KM based GFLS model at Kashmiri Gate location

To validate the KM based developed model, regression equations have been generated in Figure 6.16 to 6.18. Different regression coefficient (R^2) value has been calculated. Figure 6.16 discuss about the regression equation i.e. y = 0.978 x+ 93.55, developed for CO with R^2 value of 0.8. In the same way equation y = 0.460 x+ 53.06 has been generated for NOx with R^2 value of 0.739 (Figure 6.17). In case of SO_2, the R^2 value is found 0.731. From these equations there is good relationship is found between observed and predicted concentration. Index of agreement has also been calculated for CO, NOx and SO_2 and found 0.907, 0.8366 and 0.8774 respectively, which indicate satisfactory results with the model performance. Significance test has been tested on this model performance and between observed and predicted values, it gives t_{calc}= 1.28 for CO, t_{calc}= 0.206 for NOx and t_{calc}= 1.41 for SO_2, which is less than $t_{tabulated}$ =2.179, for degree of freedom = 11 and level of significance=0.05 (Table 6.4), hence the test favors the suitability and applicability of this model in currently existing traffic condition in Dehi, India.

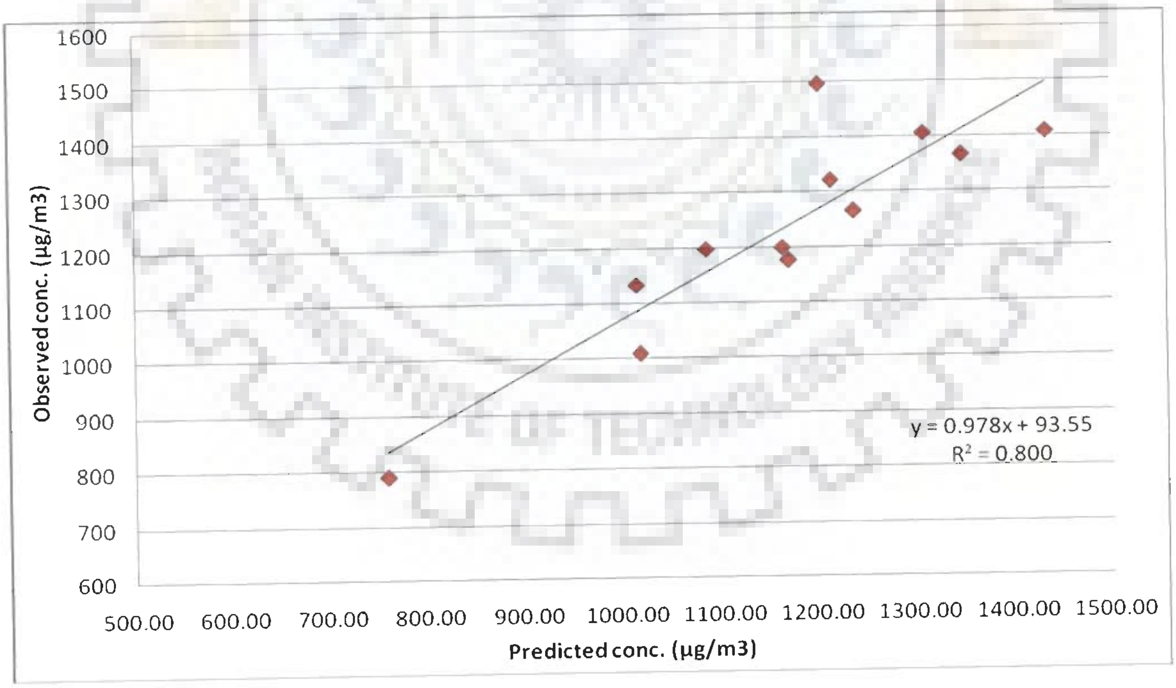


Figure 6.16: Regression Equation Developed for CO at Kashmiri Gate

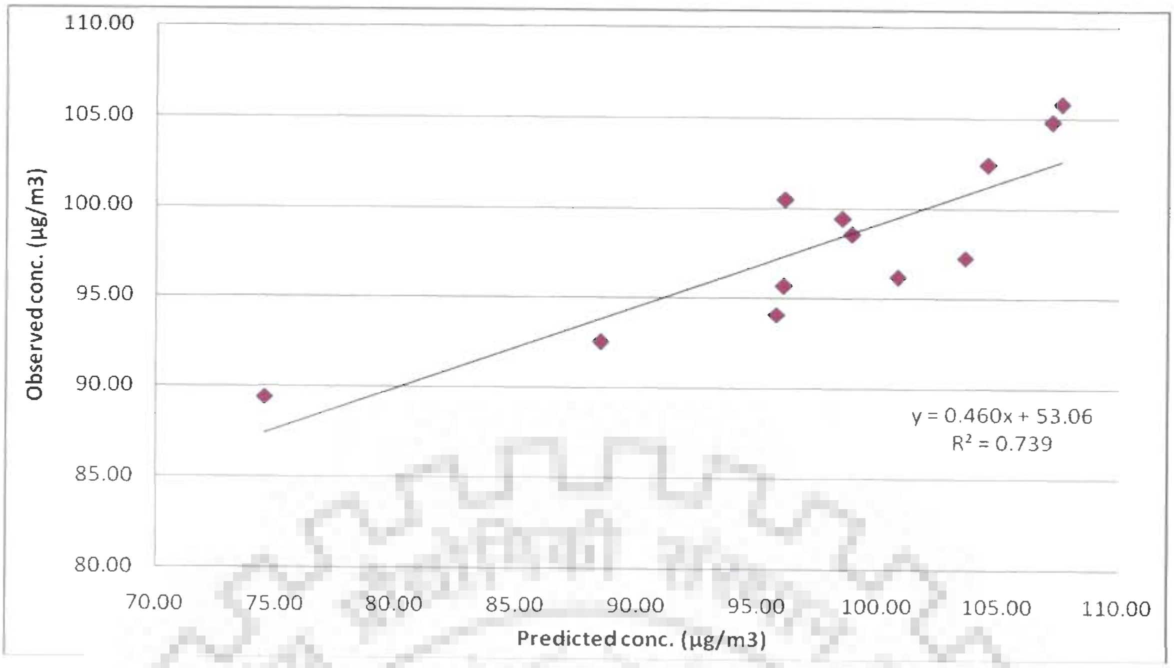


Figure 6.17: Regression Equation Developed for NOx at Kashmiri Gate

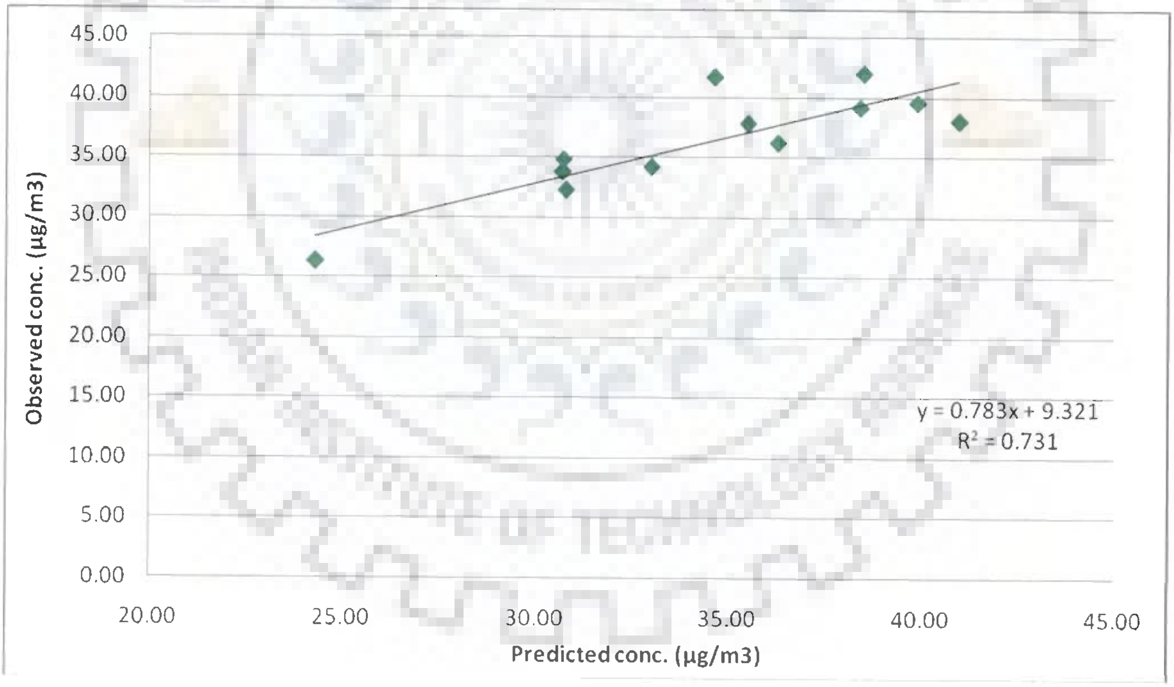


Figure 6.18: Regression Equation Developed for SO_2 at Kashmiri Gate

Table 6.4: Summarized Results of T-test at Kashmiri Gate

	CO	NOx	SO2
$\bar{d}$	68.66	0.42	1.88
Sd	186.31	7.15	4.61
N	12	12	12
D.O.F	11	11	11
t_{calc}	1.28	0.206	1.41
α	0.05	0.05	0.05
$t_{tabulated}$	2.179	2.179	2.179

6.2.2.4 Trend analysis of modelled and measured air concentration at Jhilmil

6.2.2.4.1 Modelling of CO

After analysis and modelling of data by using developed model, Figure 6.19 shows the highest concentration of predicted value during 19-20 hour (2421.85μg/m^3), whereas the minimum concentration is found during 8-9 hours with 1504.51μg/m^3. Taking into account the entire hour of study, the average predicted and observed concentration has been found 1980.71μg/m^3 and 2039.25μg/m^3 respectively, which is less than the CPCB prescribed limit (2000 μg/m^3).

6.2.2.4.2 Modelling of NOx

Along with the prediction of carbon monoxide, oxides of nitrogen have also been used for prediction by using model. The model has predicted NOx with the maximum and minimum observed concentration of 211μg/m^3 and 128μg/m^3 respectively and gave 197.03μg/m^3, 125.15μg/m^3, maximum and minimum modelled value with an average of 163.74μg/m^3 (Figure 6.20). It is concluded that the level of NOx in terms of observed and predicted concentration is found higher than the permissible limit (80μg/m^3).

6.2.2.4.3 Modelling of SO_2

The modelling estimates 48.74 μg/m^3, the average maximum predicted concentration at Jhilmil location, whereas the highest and lowest predicted concentration is found 58.10μg/m^{3}during 19-20 hours and 37.23μg/m^3 during 8-9 hours respectively (Figure 6.21). On the other hand, the average measured concentration is found 49.42μg/m^3 with maximum concentration of 60μg/m^{3}and minimum concentration of 39μg/m^3 at the same location. Both the concentration of SO_2 gas is found under control.

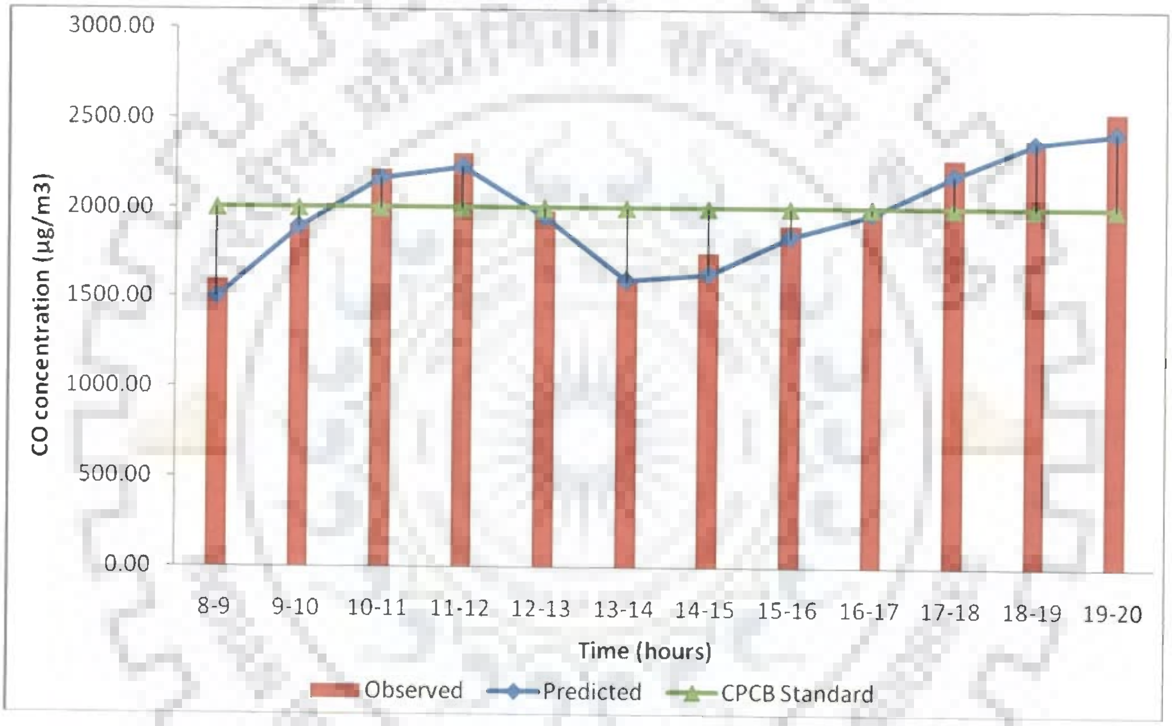


Figure 6.19: Predicted and Observed Concentration of CO at Jhilmil

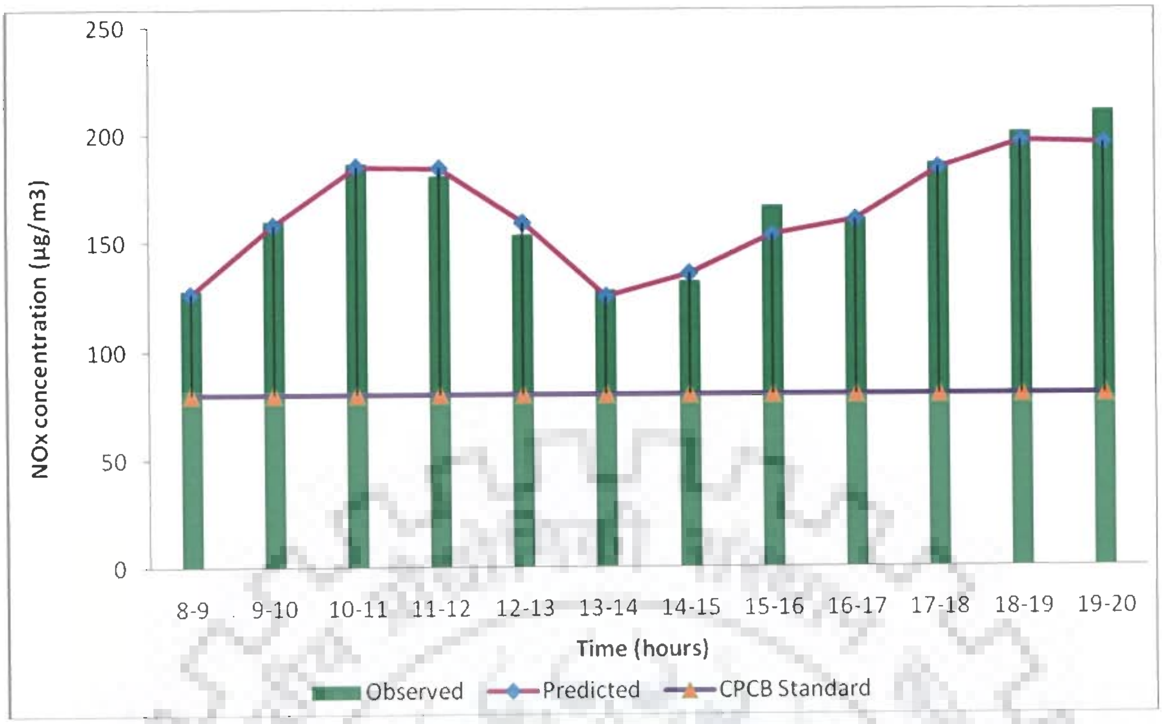


Figure 6.20: Predicted and Observed Concentration of NOx at Jhilmil

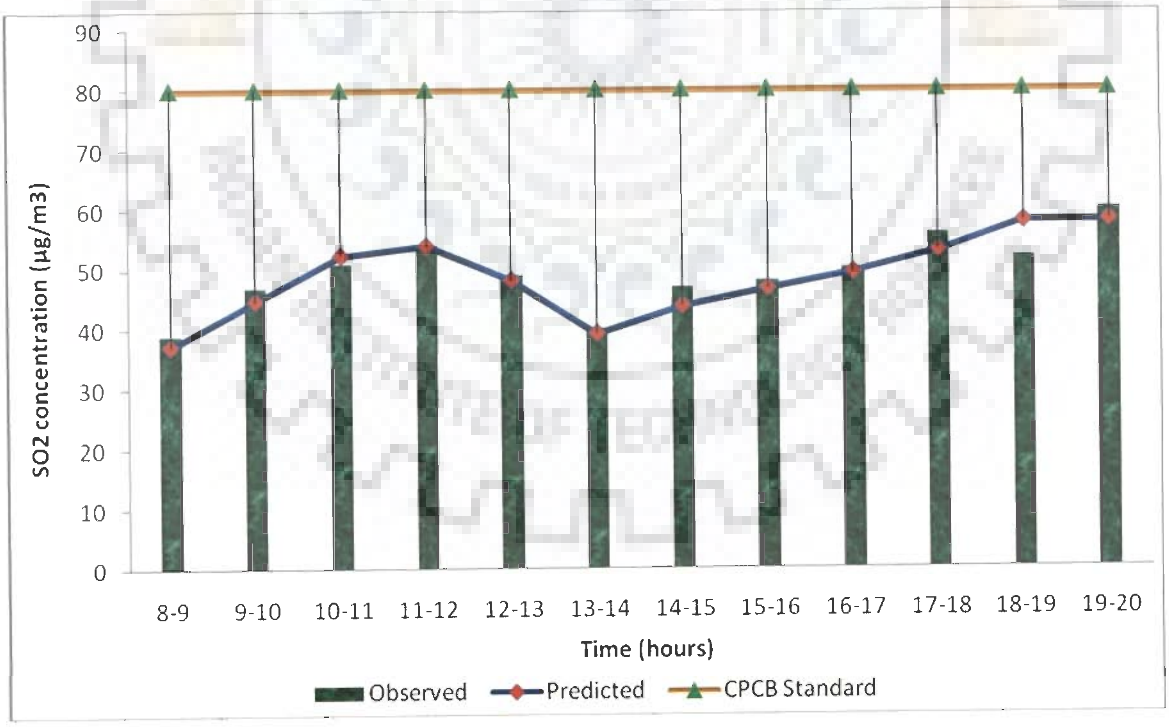


Figure 6.21: Predicted and Observed Concentration of SO_2 at Jhilmil

6.2.2.4.4 Performance assessment of KM based GFLS model at Jhilmil location

To examine the performance of GFLS model, regression equations have been developed (Figure 6.22 to 6.24). For CO, y = 1.004 x+ 49.47 with R^2 value of 0.981 (Figure 6.22). In case of NOx, the R^2 value is found 0.954 (Figure 6.23), whereas Figure 6.24 presents the value of 0.869 (R^2) for sulphur dioxide. All these three figures show a good relationship between observed and predicted concentration. The index of agreement is found 0.9853, 0.9839 and 0.9589 for CO, NOx and SO_2 correspondingly, which indicates the better performance of model at this location. During significance test between observed and predicted values, the t calculated value is found 0.68 for CO, 0.35 for NOx and 0.37 for SO_2 (Table 6.5), which is less than tabulate value (2.179) for degree of freedom 11 and level of significance 0.05. Therefore, it can be concluded that the developed model performs well in Indian condition.

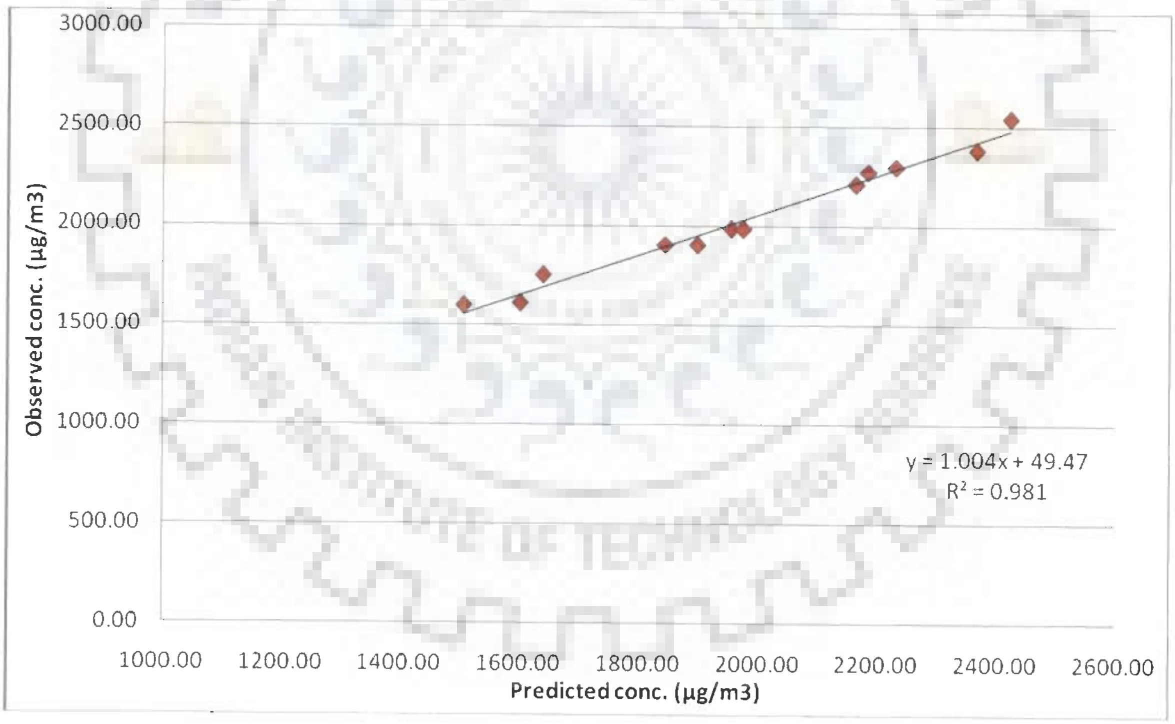


Figure 6.22: Regression Equation Developed for CO at Jhilmil

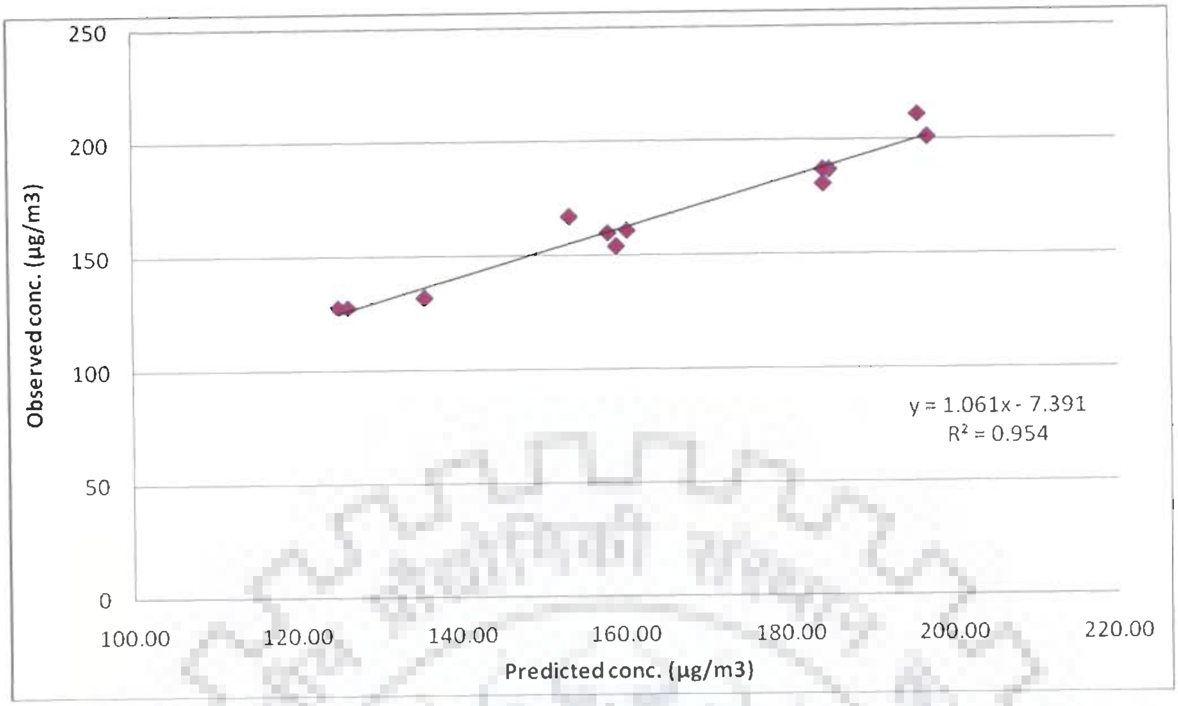


Figure 6.23: Regression Equation Developed for NOx at Jhilmil

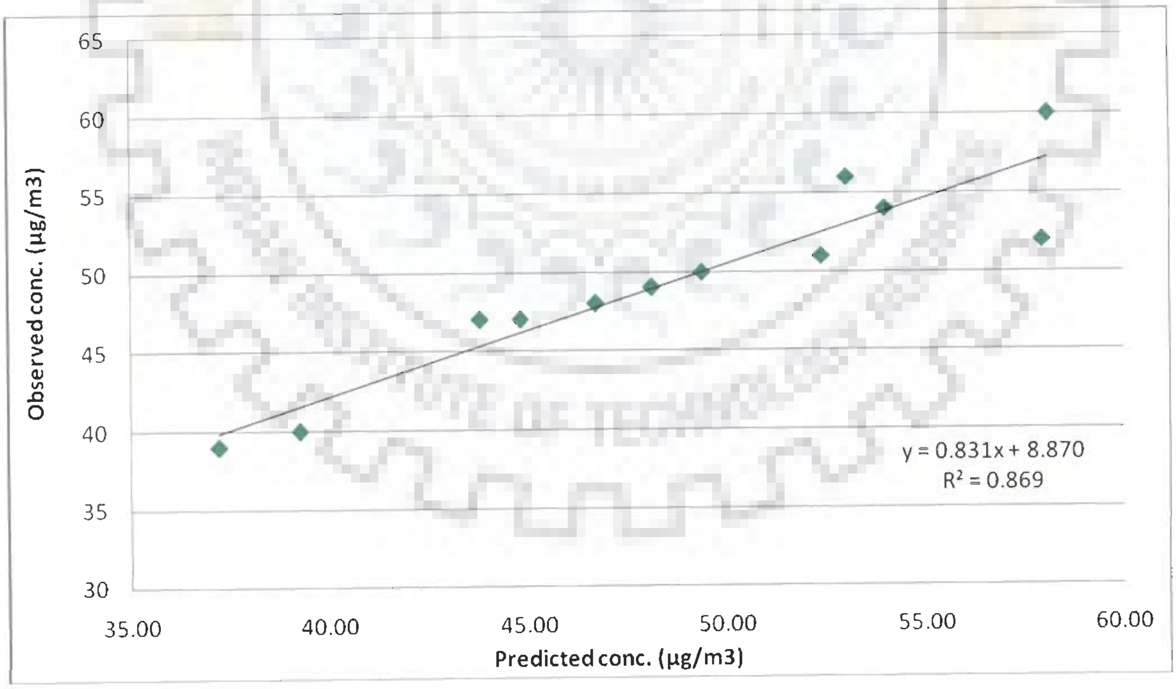


Figure 6.24: Regression Equation Developed for SO_2 at Jhilmil

Table 6.5: Summarized Results of T-test at Jhilmil

	CO	NOx	SO2
$\bar{d}$	58.54	2.67	0.68
Sd	297.89	26.32	6.25
N	12	12	12
D.O.F	11	11	11
t_{calc}	0.68	0.35	0.37
α	0.05	0.05	0.05
$t_{tabulated}$	2.179	2.179	2.179

6.2.2.5 Trend analysis of modelled and measured air concentration at Panchsheel Enclave of BRTS coridor

6.2.2.5.1 Modelling of CO

Due to majority of public transport at this location, the observed and predicted concentrations of carbon monoxide are not found to high. The temporal variation of predicted value in comparison to observed value and CPCB standard is presented in Figure 6.25. This figure indicates the highest and lowest measured concentration of CO i.e. 1278μg/m^3 and 826μg/m^3 respectively. Maximum and minimum predicted concentration is found 1178.89μg/m^3 and 818.66μg/m^3 respectively, which is lower than the air quality standard.

6.2.2.5.2 Modelling of NOx

At Panchsheel Enclave of BRTS corridor, 12 hours studies have been conducted to watch the existing condition of NOx concentration. Average concentration of studied time period is found 94.57μg/m^3. On the other hand, using primary and secondary data, the prediction has also been done and found 102.71μg/m^3 (maximum) and 75.14μg/m^3 (minimum) with an average of 91.95μg/m^3 (Figure 6.26). From the results it is concluded that both values have been exceeded the prescribed limit.

6.2.2.5.3 Modelling of SO_2

Like above process, the same modelling has been done for SO_2. Figure 6.27 depicts the hourly variation of predicted and observed value. The prescribed standard has also been mentioned in this figure. Pattern of variation can be observed in figure. From the figure, it is observed that the entire study shows the highest and lowest measured concentration of 39.42μg/m^3 and 26.67μg/m^3 correspondingly. The maximum and minimum predicted value is found 36.22μg/m^3 and 27.04μg/m^3 with an average of 30.99μg/m^3, which is much lower than national ambient air quality standard given by CPCB.

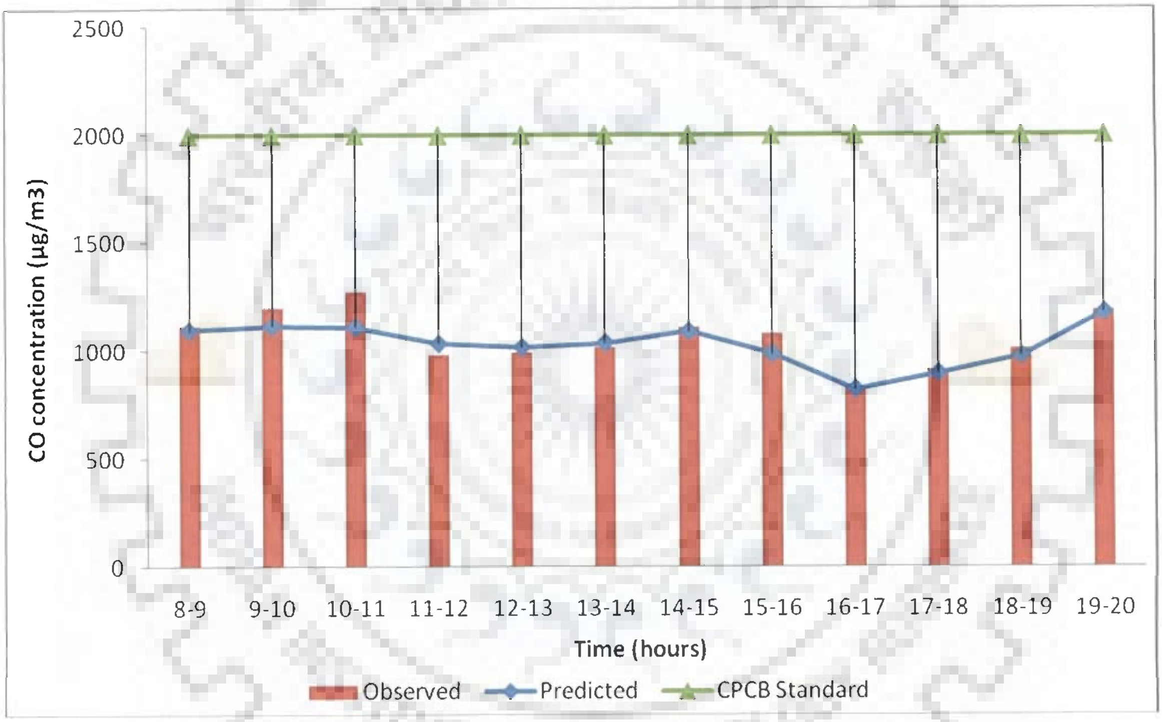


Figure 6.25: Predicted and Observed Concentration of CO at Panchsheel Enclave

Figure 6.26: Predicted and Observed Concentration of NOx at Panchsheel Enclave

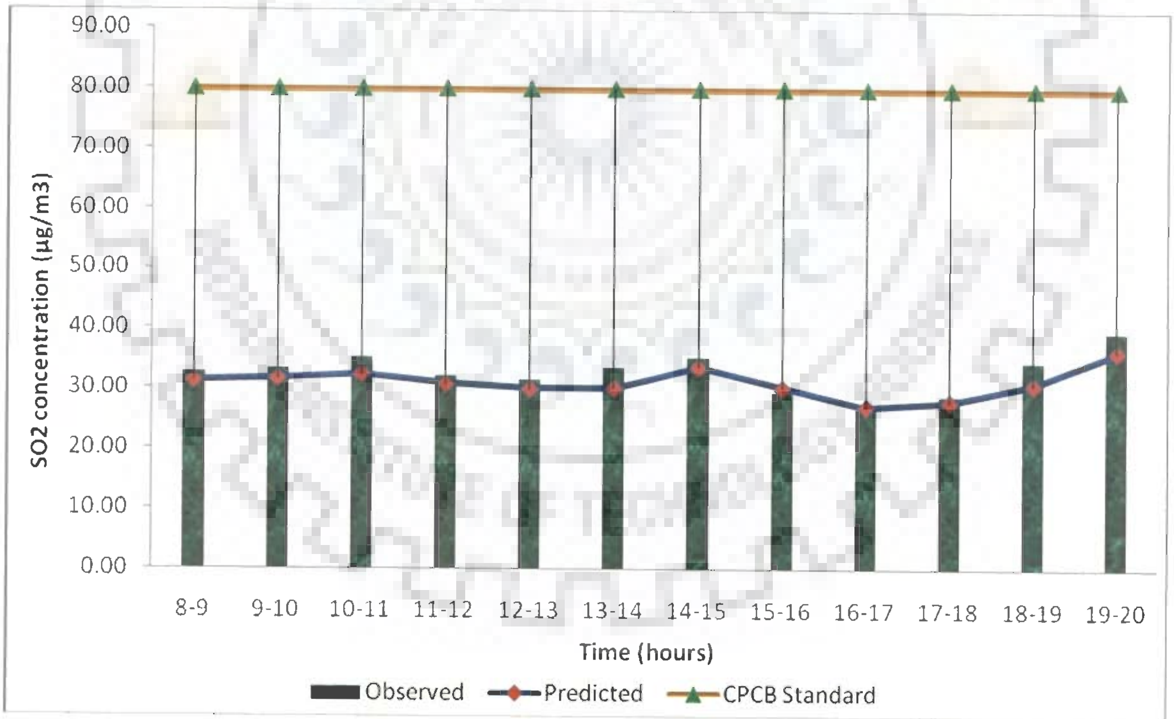


Figure 6.27: Predicted and Observed Concentration of SO_2 at Panchsheel Enclave

6.2.2.5.4 Performance evaluation of KM based GFLS model at Panchsheel Enclave

Performance evaluation of general finite line source based developed model for this location has been carried out through the generation of regression equation for CO, NOx and SO_2. The developed equations are illustrated in Figure 6.28 to Figure 6.30. In Figure 6.28, the R^2 value is found 0.795 for CO, which shows a good relationship between observed and predicted concentration. Likewise R^2 value is found 0.869 for NOx and 0.871 for SO_2 in Figure 6.29 and Figure 6.30 respectively. Both the values are indicated a good co-relationship between measured and modelled concentration. Index of agreement for CO, NOx and SO_2 has been computed and found 0.9104, 0.9361 and 0.8527 respectively, which demonstrates acceptable result with model performance. In addition to this, significance test between observed and predicted values gives $t_{calc=}$ 0.91 for CO, $t_{calc=}$ 1.12 for NOx and $t_{calc=}$ 1.99 for SO_2, which is found less than $t_{tabulated}$ =2.179, for degree of freedom = 11 and level of significance=0.05 (Table 6.6), hence the difference between observed and predicted value is insignificant and it proves the applicability of this model for particular location.

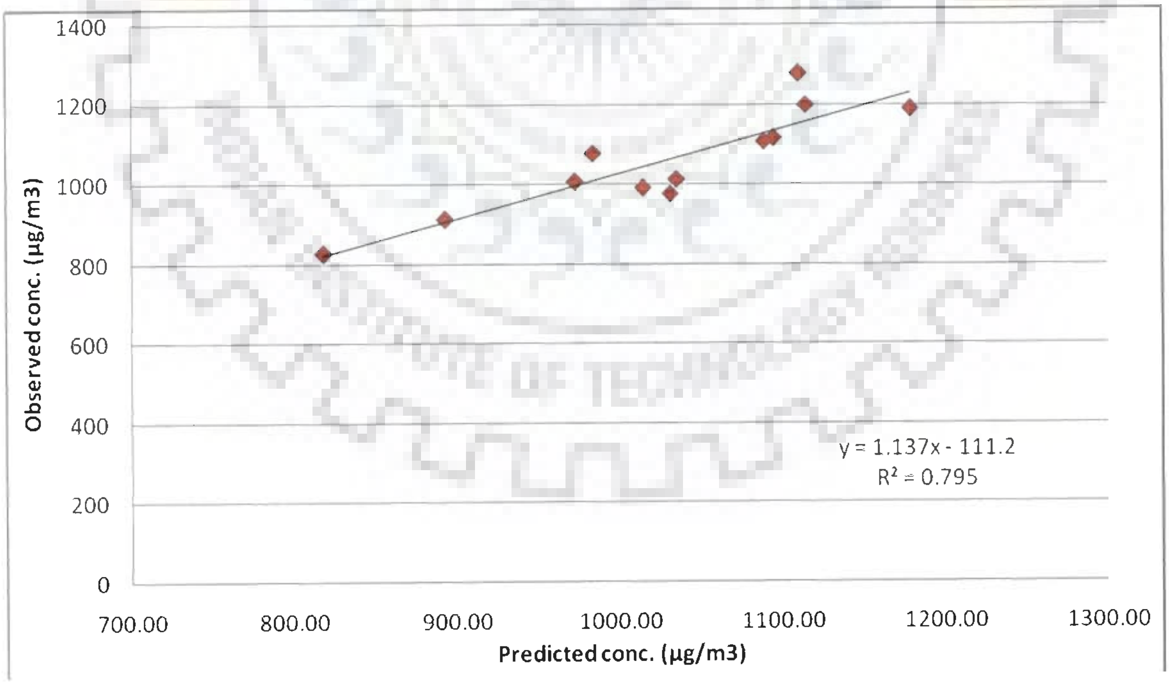


Figure 6.28: Regression Equation Developed for CO at Panchsheel Enclave

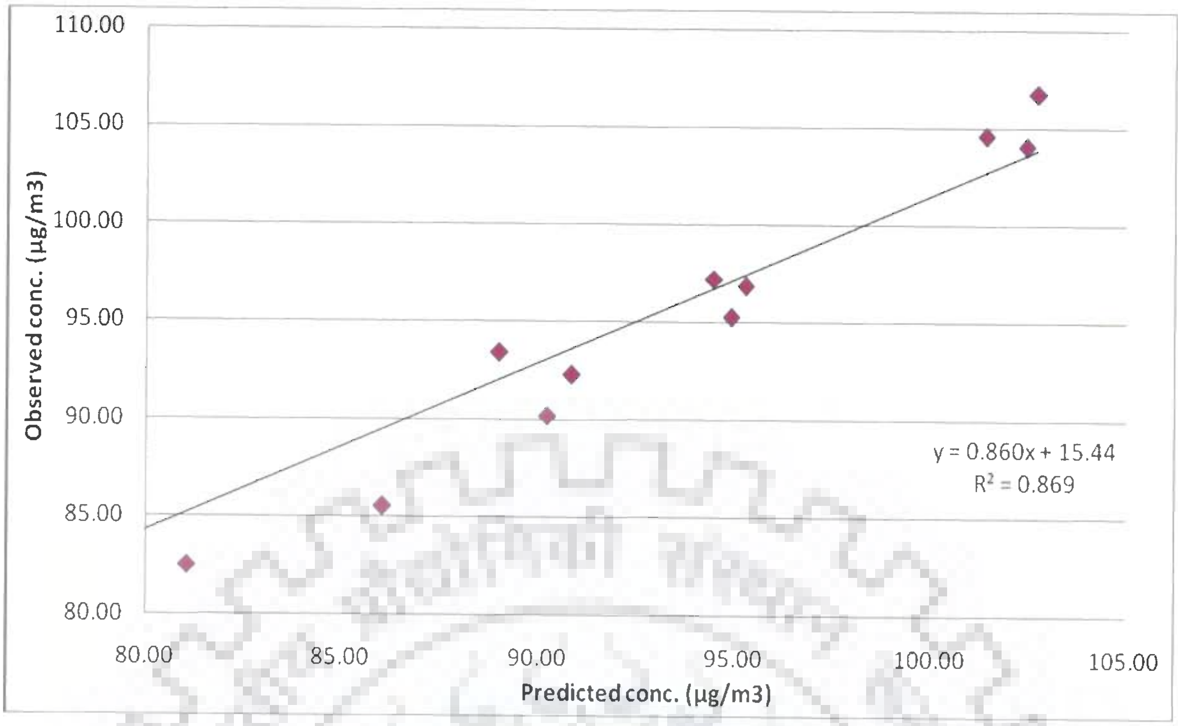


Figure 6.29: Regression Equation Developed for NOx at Panchsheel Enclave

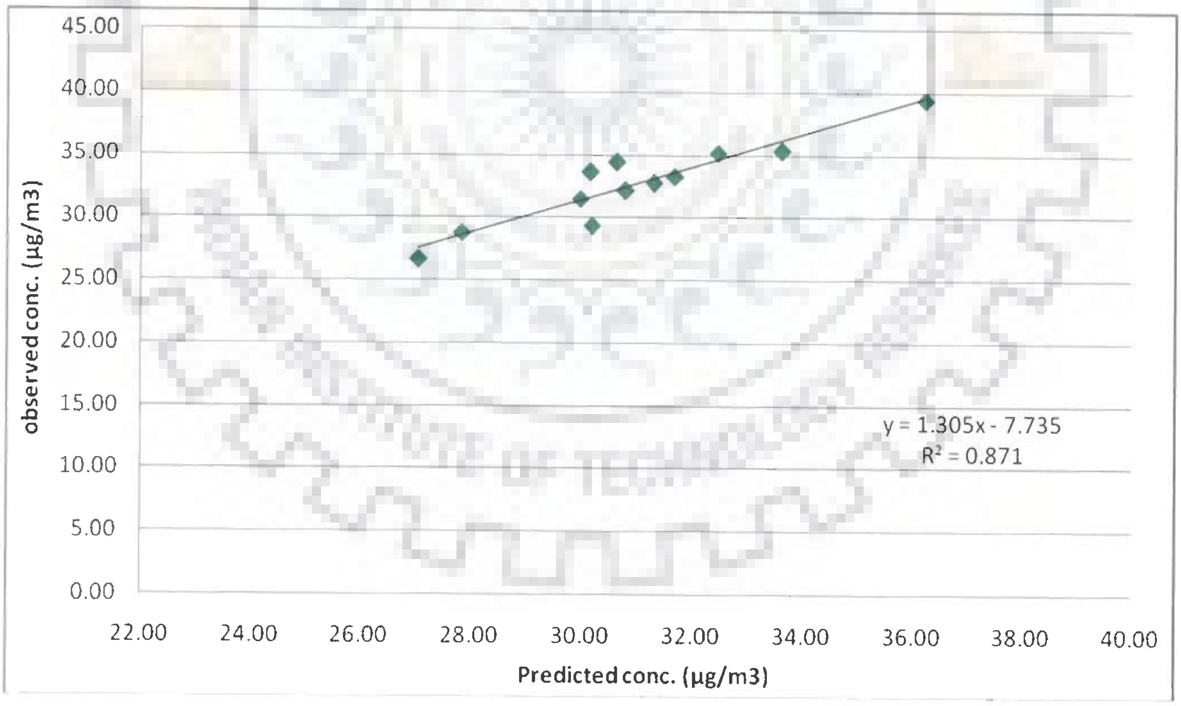


Figure 6.30: Regression Equation Developed for SO_2 at Panchsheel Enclave

Table 6.6: Summarized Results of T-test at Panchsheel Enclave

	CO	NOx	SO2
$\bar{d}$	29.90	2.62	1.74
Sd	114.34	8.08	3.03
N	12	12	12
D.O.F	11	11	11
t_{calc}	0.91	1.12	1.99
α	0.05	0.05	0.05
$t_{tabulated}$	2.179	2.179	2.179

6.2.3 Features and application of model

Manually it is very difficult and time taking to predict the concentration of different gaseous pollutants in each hour at different locations. To resolve such kind of problem the General Finite Line Source Model has been developed in MS EXCEL worksheet system. The reason behind the selection of such a platform is its flexibility, compatibility and user friendly properties. This spread sheet can be used at any level for the prediction of concentration of gaseous pollutants. By putting previously discussed inputs of this model (traffic volume, temperature, emission factor, wind angle, wind speed etc.) related to traffic, location and pollutants, one can get the predicted concentration of pollutants within no time. Only by changing emission factor, the single model can be used to predict the concentration of various pollutants like CO, NO_x and SO_2.

6.3 Summary

Traffic air pollution related modelling aspect has been discussed in this chapter. Another MS EXCELL based mini KM tool formulation and its application is explained by this section. The developed model validation through different statistical tests and analysis of air quality at each location has been described by this chapter. The important feature and application of the developed model is also talked about in current chapter.

Chapter 7

STUDY APPLICATIONS

7.1 General

Different aspects of study applications have been covered in this chapter. To mitigate roadway and railway noise, acoustical barrier has been designed along major public transport corridor in Delhi. In addition to this composite air quality index has been computed to show the degree of pollution in selected area and its impact on health of people. Considering the continuous vehicular growth and urban population, emission inventory has also been developed for the capital city. Another important component i.e. KM and Non-KM practices based model have been suggested to reduce the environmental problems in terms of noise pollution, air pollution and traffic congestion.

7.2 Design of Noise Barrier

Noise barrier designing is a very essential measure to mitigate the noise pollution. To calculate the height of barrier manually, is a lengthy and time taking process. To avoid such kind of mathematical and time taking calculation, a simple and user friendly modified FHWA based model has been generated in MS-EXCEL working system. The strength of this model is basically its simplicity and easy calculation. MS-EXCEL is a well known tool to everybody. Due to this, it is very trouble-free model for anybody to compute the height of barrier at any place. For the designing of barrier at elevated corridor of metro line, the developed model has already been discussed in Chapter 5 (As annexure II).

7.2.1 Description of developed model

This model is a spread sheet based modified FHWA model (Annexure-IV). This model can be used to evaluate the effectiveness of installed barrier and to design height of barrier as well. In this model too, a number of adjustments are incorporated. To assess the effectiveness of barrier, height of barrier, angle subtended by barrier, distance from source to barrier and barrier to receiver are required as inputs. During this study, this model has been used to compute the required height of barrier at various selected locations along public transport corridor. During the design of barrier through this model, number of trials is made till the desired noise limits are reached.

7.2.2. Provision of noise barriers

Noise barrier is an exterior structure designed to protect sensitive land use from noise pollution. It is also called sound wall, sound berm, sound barrier or acoustical barrier. The acoustical barriers are the most effective method to mitigate roadway, railway and industrial noise sources. Absorption is the most important feature of an effective noise barrier. If a noise barrier does not absorb, the noise will simply be reflected, moving the problem elsewhere in the local vicinity. When suppressing noise it is important that:

- Most noise is halted at the barrier in order to get a high total screen effect
- The noise insulation in the screen will be twice as high as the total desired screen effect
- The noise is absorbed and not be reflected

7.2.2.1 Design principle of noise barrier

Basically, noise barriers reduce the sound level reaching receivers by blocking the straight-line path from the source to the receiver, while the perceived noise does not disappear, it is significantly reduced. By blocking the straight line path even slightly, the noise barrier attenuates the sound level at the receiver by about 5 dB. This attenuation is roughly equivalent to reducing the source noise by a factor of three (one-third the traffic). Making the barrier even higher so that the sound is forced to travel along a longer path usually produces an additional attenuation of at least 3 dB. The combined effect (a noise attenuation of 8 dB) is roughly equivalent to reducing the traffic by a factor of 6. Effective noise barriers typically reduce noise levels by 5 to 12 dB (A), cutting the perceived loudness of traffic noise by as much as one half. A noise barrier must generally be tall enough and long enough to block the view of traffic on a road from the area that is to be protected.

7.2.2.2 Transmission loss in barrier design

During design of barrier, the most important factor need to be considered is transmission loss. The transmission loss associated with a barrier is the amount by which the sound is reduced when it is forced to travel through the barrier. It can be calculated using equation 7.1.

$$TL = 10 \log \left[\text{Incident noise/Transmitted noise} \right] \quad \ldots. (7.1)$$

A 30-dB transmission loss means that practically all (99.9%) of the sound is being blocked. The larger the transmission loss, the lesser energy gets through. Transmission loss of any wall depends on the wall's surface weight, loss factor, angle of incidence and the frequency of approaching noise. The surface weight density of the material is the most important parameter which affects transmission loss. The weight requirement of the barrier is given in Table 7.1. Surface weight can be calculated using equation 7.2.

$$\text{Surface weight} = \text{weight density} \times \text{thickness} \quad \ldots. (7.2)$$

Table 7.1: Minimum Surface Weight for Barriers

If barrier needs to reduce the diffracted noise by dBA	Minimum surface weight in kg/m^2
5	14.65
10	17.09
12	17.09
14	17.09
16	19.53
18	21.97
20	24.41
22	31.74
24	39.06

Source: Haris, (1991)

7.2.2.3 Types of noise barrier

On the basis acoustic performance, three types of barriers are there.

7.2.2.3.1 Reflective barriers

The work principle behind such kind of barrier is the reflection of noise back towards the source, although it can cause increases in noise on the opposite side of the road or rail track. This can be minimised by sloping the barrier to reflect the noise upwards to pass above any receivers. The performance of a reflective barrier is limited by the diffraction at the top edge. A sub-set of this type of barrier includes a range of modifications to the top edge, such as wide flat tops and multiple vertical edges to reduce the level of diffraction. These are transparent in appearance and include glass, metal and other hard surface. Figure 7.1 shows the examples of such kind of barrier.

Figure 7.1: Reflective Barriers

7.2.2.3.2 Absorptive barriers

These incorporate a porous element that absorbs noise like open structured concrete using wood fibres or small lightweight cementious spheres as the aggregate. In a single-sided barrier, this layer forms the surface and is supported by another of solid concrete that prevents sound passing through the barrier and provides structural integrity. The surface is usually quite highly profiled so as to increase its area and provide the maximum sound absorption. In double-sided concrete barriers, absorptive materials, such as mineral wool can be in an enclosed 'sandwich' layer. The side facing the noise is perforated. Both single-sided and sandwich barriers are precast, in lengths of 4 to 5 m and can be 140 to 190 mm thick with colour incorporated. The panels are usually supported by steel or concrete columns. This type of barrier is particularly useful where there are barriers on both sides of a road, as they repent the build up of reflected noise. These are opaque in appearance and these include those made with mineral wool, wood fiber, perforated metal etc.

Figure 7.2: Absorptive Barrier

7.2.2.3.3 Reactive barriers

These are specialized form of absorptive barrier that incorporate cavities or resonators designed to attenuate particular noise frequencies. Sound enters these cavities via small holes or slots in the perforated precast concrete blocks and the size of the cavity is tuned to permit phase cancellation at the selected frequency. The range of frequencies for which these resonators are effective can be increased by filling the cavity with sound absorptive materials.

7.2.2.4 Barrier mass adjustment

For highway noise barrier, any sound that is transmitted through the barrier can be effectively neglected since it will be at such a low level relative to the diffracted sound, i.e., the sound transmitted will typically be at least 20 dB (A) below that which is diffracted. That is, if a sound level of 100 dBA is incident upon a barrier and only 1 dBA is transmitted, i.e. 1 percent of the incident sound's energy, then a TL of 20 dBA is achieved.

$$M = 3 \text{ anti log } (\Delta_m - 10/(14) \qquad \ldots\ldots (7.3)$$

where,

Δ_m= barrier mass attenuation

M = surface weight of material in kg/m^2

$$T=M/\rho \quad \text{.... (7.4)}$$

where,

ρ = mass density of barrier material in kg/m^3

T = thickness of barrier in meters

In most cases, the maximum noise reduction that can be achieved by a barrier is 20 dB (A) for thin walls and 23 dB (A) for berm.

7.2.3 Features and application of model

MS EXCEL platform has been used to formulate this modified FHWA based model. The basic objective behind the development of this model is to evaluate the effectiveness of existing noise barrier as well as to calculate the required barrier height at noise sensitive locations. The model contains basically two sections. First section includes different input parameters in which all traffic related parameters and other site geometrical parameters are given and second section includes noise level calculations under which noise levels are predicted in the presence barrier as well as in the absence of barrier. This model is also very applicable in the designing of barrier height needed for satisfying target noise levels. This model is free from complex and long arithmetical calculations, which indicates the better and trouble-free application of this model.

7.2.4 Design of noise barrier along public transport corridor

From the study, it is found that all the selected locations along public transport corridor i.e. Rithala, Pitampura, Jhilmil, Dilshad Garden and Panchsheel Enclave (BRTS Corridor) are running under excessive noise level than prescribed limits. Such kind of situation may affect the health of people living in vicinity of those areas. These locations required specific measures to extenuate the problem of noise due to road and metro rail. Designing of barrier has been chosen as specific measures to mitigate the problem. The methodology adopted for designing barrier is presented in Figure 7.3.

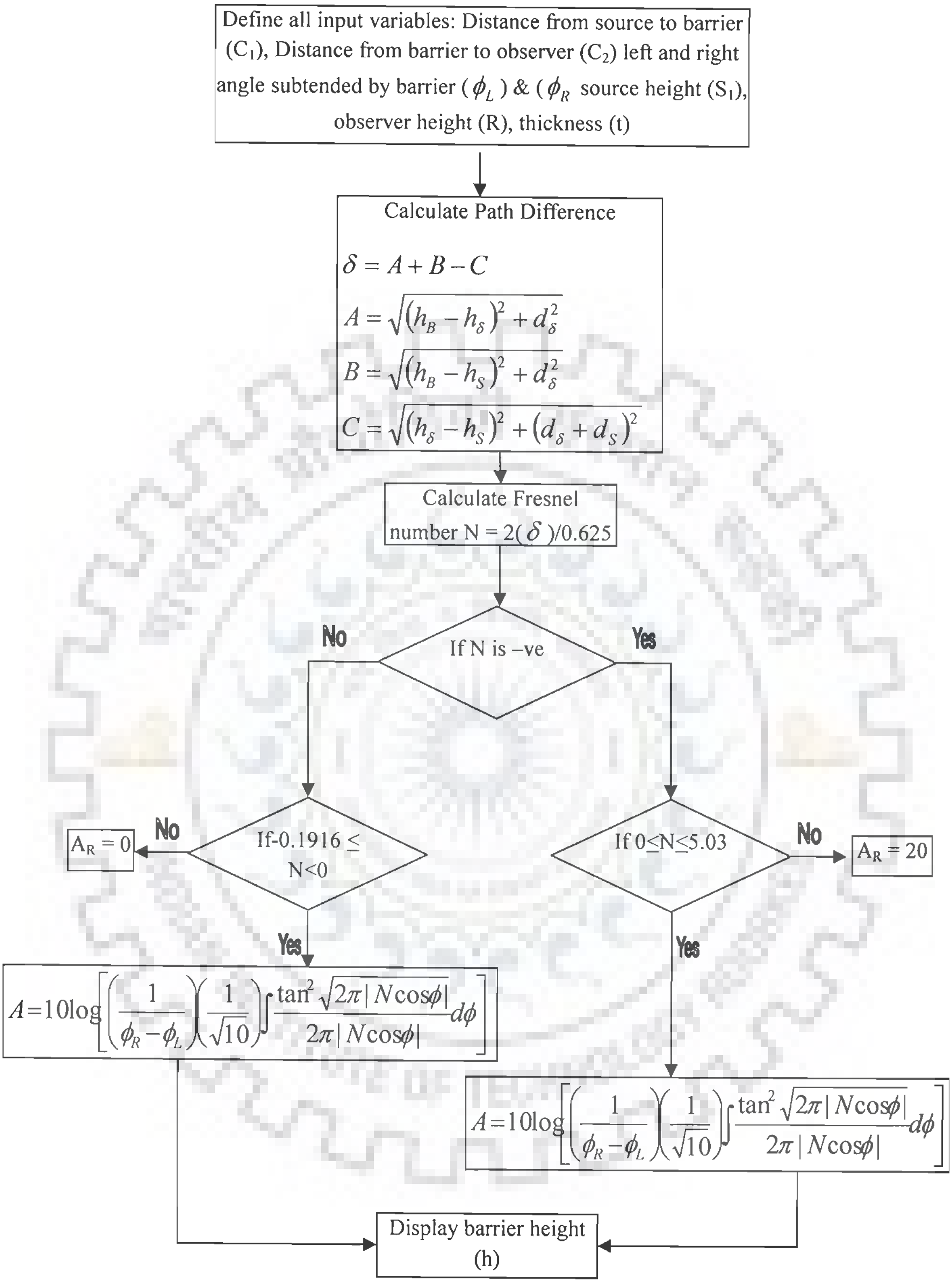


Figure 7.3: Flow Chart for Design of Barrier Height

7.2.4.1 Barrier designing at Rithala metro corridor

From the data analysis at this location, it is observed that the average maximum predicted and observed noise level has been exceeded the prescribed limits. The highest average predicted and observed noise level is found 76.1, 69.6 dBA respectively in the direction of Rithala whereas in the direction of Rohini East, this average value has been found 76.1 and 69.2 dBA respectively. On the other hand due to presence of metro trail, some noise is also incorporated in road traffic noise and affects the people living in high rise building along the metro rail. From this analysis, it is found that such a higher noise level may affect the physical and mental health of residents living in the surrounding area of this particular location. To keep away people from this noise pollution it is very essential to design noise barrier along the corridor as well as at elevated corridor. The barrier hight has been calculated by using the developed model and it presents the prerequisite of 2.9 meter height of the barrier at one side i.e. towards Rohini East direction. Due to the prior presence of 2 meter height of barrier as a brick wall, only 0.9 meter height of barrier is required, whereas the other side (towards Rithala) requires 2.2 meter height of barrier along the road to curb the noise pollution. Along with this, another barrier has been designed using the developed KM based model (Annexure II) and found the prerequisite of 1.6 meter height of barrier at elevated metro corridor to control the metro noise in the residential building residing along the metro line. Cross section and general layout of the Rithala location with the designed noise barrier are presented in Figure 7.4.

7.2.4.2 Barrier designing at Pitampura metro corridor

At this location, the highest average predicted and observed noise level has been found 75.1 dBA and 74.8 dBA correspondingly in the direction of Kohat Enclave. Likewise in the opposite direction (Towards Rohini East), the maximum average modelled and measured noise level is obtained 75.9 and 76.9 dBA. Such a high noise level requires some mitigatory measures. Design of barrier has been selected as a control measure at this location. After putting various inputs and category wise hourly equivalent noise level, the barrier height has been calculated for this location and it is found that there is requirement of 5.3 meter (Towards Kohat Enclave), and 4.4 meter (Towards Rohini East) height of barrier (Figure 7.5). After installing both the height of barrier (5.3 and 4.4 meter) in different direction of corridor, the noise has been reached up to 56.9 and 57.6 dBA respectively. Further decrement in noise level may be occurred through the use of different kind of barrier material. Like road traffic noise, metro rail noise has also been estimated and the modelled and measured noise level is found 67.4 and 78.1 dBA respectively. To reduce this level up to prescribed noise limit another barrier has been designed at elevated corridor of metro line. Through the developed metro rail noise model, it is found that there is a necessity of 1.8 meter height of barrier at elevated corridor of this location. Through the application of these barriers, the noise pollution can be reduced in surrounding area, which will save the health of people residing nearby areas and in high rise building.

7.2.4.3 Barrier designing at Jhilmil metro corridor

Due to heavy traffic at this location, noise level is found much more than prescribed standard. Average maximum predicted noise level is found 78.1 dBA in the direction of Manasarovar Park and 78.4 dBA in the direction of Dilshad Garden. Likewise due to metro rail, the modelled and measured noise level is found 69.1 and 78.8 dBA respectively. Due to the presence of residential building along the road in the direction of Dilshad Garden, 4.6 meter height of barrier is required. Through the installation of this barrier, the noise level can be reduced up to 60 dBA. Further reduction may occur through the use of barrier filling material. Due to the far distance of residential building from highway in the direction of Mansarovar Park, no barrier is required to curb the noise. But these building are affected due to metro rail noise. To restrain the metro noise and privacy of residential building, elevated noise barrier has been designed. From the model calculation, it is established that this location requires 2.1 meter height of barrier to resolve the noise problem in vicinity. Figure 7.6 depicts the cross section of location with designed barrier. With the help of the installation of this barrier, privacy and metro noise, both can be controlled.

7.2.4.4 Barrier designing at Dilshad Garden metro corridor

To design barrier at this location, first of all, road traffic noise and metro rail noise has been computed by using developed model. The highest average predicted noise level is found 75.2 dBA in Jhilmil direction and 77.1 dBA in Ghaziabad direction. Similarly the maximum average observed noise level is obtained 70.2 dBA and 73.5 dBA in both the direction. Due to the presence of residential high rise building, the metro noise level has also been calculated at the different floors of building. The maximum predicted and observed noise level is found 67.2 dBA and 77.8 dBA. To control the roadway noise, noise barrier height is calculate using developed model and it is suggested that 4.1 meter height of barrier is required to install along road in the direction of Ghaziabd. No barrier has been suggested towards Jhilmil direction due to the absence of residential area. On the other hand, the residential buildings located along metro line, requires noise barrier of 1.7 meter height (Figure 7.7). By using such a hight of barrier the noise due to metro rail can be reduced up to 45 dBA. This barrier may also protect the privacy of people living in high rise residential buildings.

7.2.4.5 Barrier designing at Panchsheel Enclave of BRTS corridor

Panchshhel Enclave, basically a Bus Rapid Transit Corridor. Separate bus lanes are available at this location. Various traffic noise data have been generated at this location and analysed with the help of developed tool. The average predicted and observed noise is seen 71.9 and 78.9 dBA in Moolchand direction, whereas in the direction of Ambedkar Nagar, the average predicted and observed traffic noise level is found 64.9 and 71.8 dBA. The analysis of data for residential area of BRTS corridor shows the requirement of 4.4 meter height of the barrier. Two meter height of brick wall as barrier already exists near the residential area, on the road towards Moolchand. Calculation indicates that the existing barrier height should be increased by 2.4 meters. On the other hand due to the presence of open space (absence of residential or commercial area) on the other side, there is no need to give any acoustical treatment. The designed barrier along corridor is indicated in Figure 7.8.

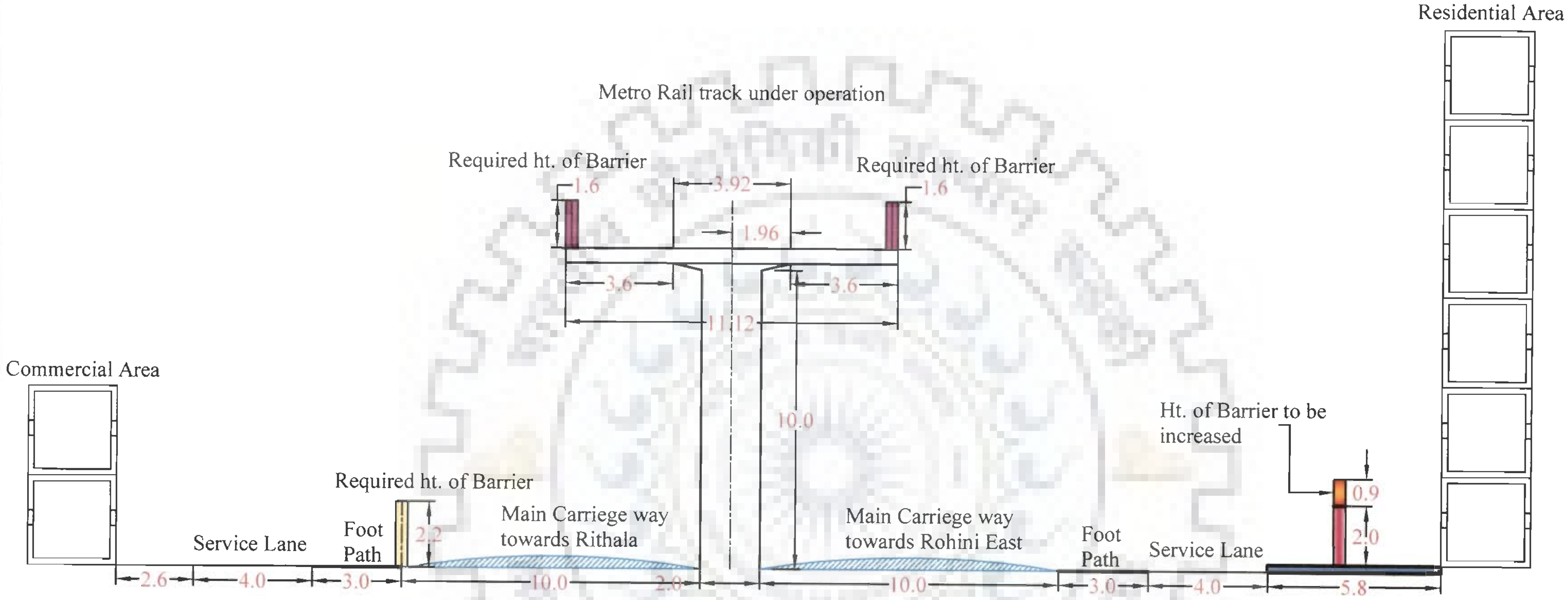


Figure 7.4: Design of Noise Barrier at Rithala

(All Dimensions in Meter)

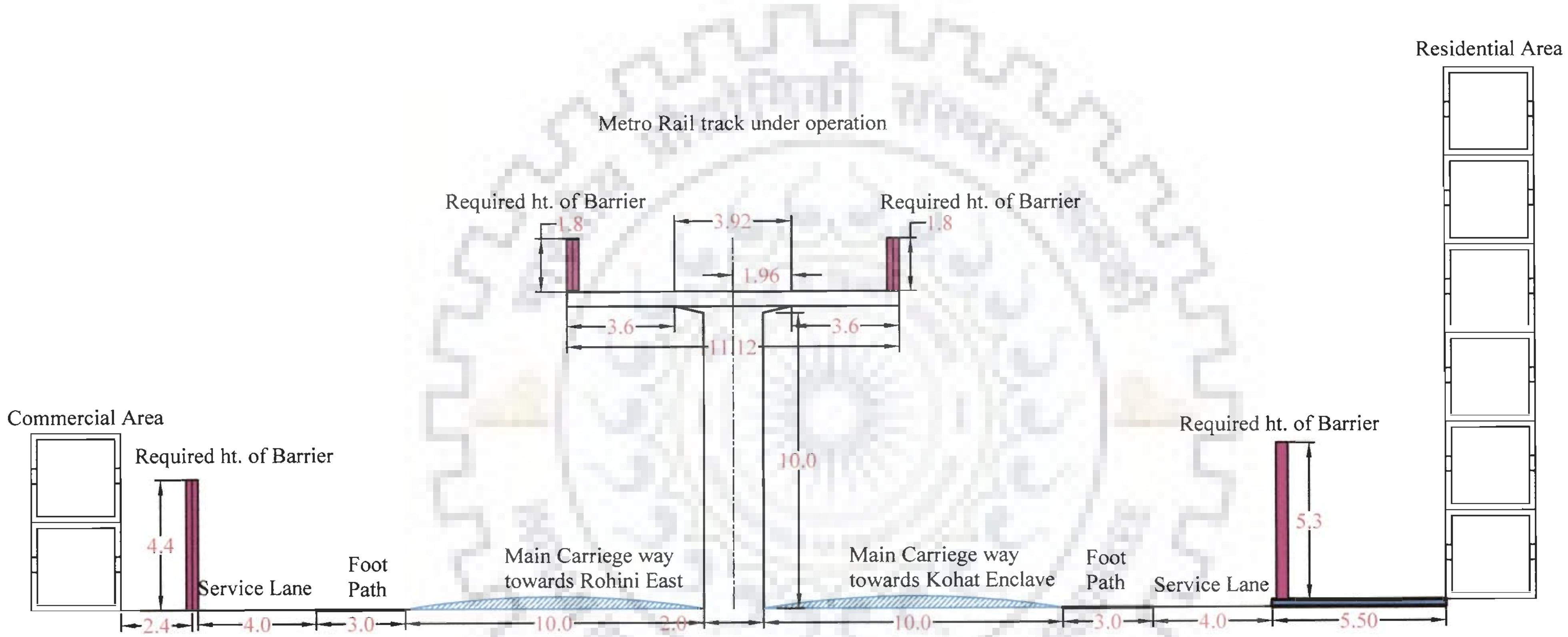


Figure 7.5: Design of Noise Barrier at Pitampura

(All Dimensions in Meter)

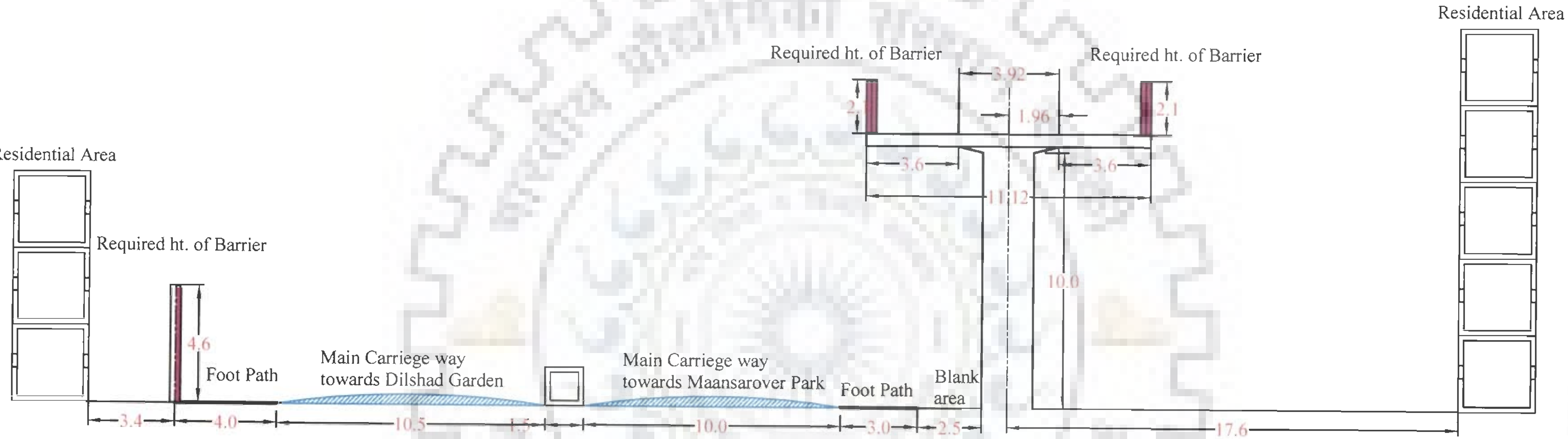


Figure 7.6:Design of Noise Barrier at Jhilmil

(All Dimensions in Meter)

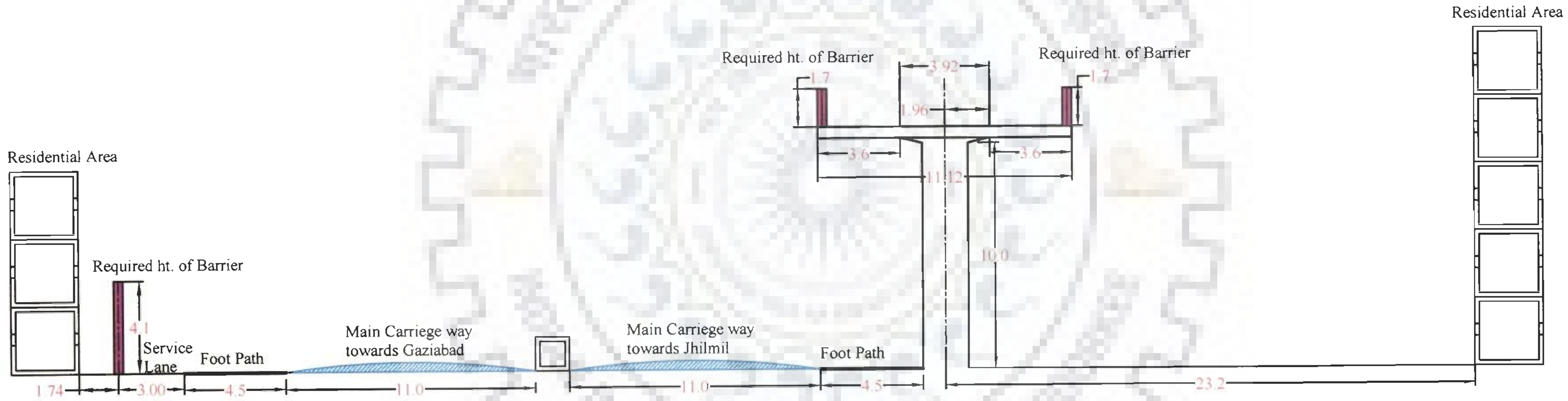


Figure 7.7: Design of Noise Barrier at Dilshad Garden

(All Dimensions in Meter)

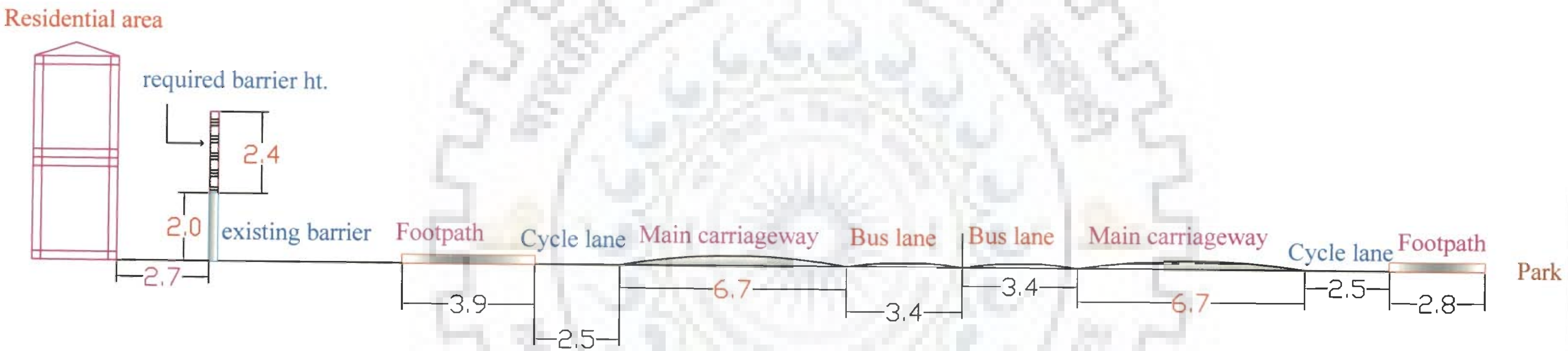


Figure 7.8: Design of Noise Barrier at Panchsheel Enclave

(All Dimensions in Meter)

7.3 Development of Composite Air Quality Index (CAQI)

During the study, human health impact due to air pollution has also been studied through composite air quality index estimation. The main objectives of CAQI are to inform and caution the public about the risk of exposure to daily pollution levels and to enforce required regulatory measures for immediate local impact. Composite Air Quality Index for a particular pollutant (Ri) has been calculated by using following equation:

$$Ri = \text{Concentration of Pollutant} / \text{Standard value of pollutant} \qquad \text{- - - - (7.5)}$$

The total air quality index for i number of pollutant is given by-

$$CAQI = (\textstyle\sum_i R_i / i) \times 100 \qquad \text{- - - - (7.6)}$$

It has been calculated at different selected locations in Delhi with the help of measured concentration of CO, NOx, SO_2, SPM and RSPM. After computation, it has been compared with the rating scale (Table 7.2) to assess the degree of pollution in the ambient air (Senthilnathan, 2007). On the basis of calculated composite air quality index, Table 7.2 has been taken as a base to explain the existing scenario of Delhi.

Table 7.2 – Rating Scale of Air Quality Index

AQI value	Remarks	AQI and level of Health Concern
0-25	Clean air	The AQI is normal. The quality of air is good and hence no cause for concern.
26-50	Light Air Pollution	The AQI is low. The quality of air is slightly polluted and hence little care is to be taken.
51-75	Moderate air pollution	The AQI is moderately high. The quality of air is moderately polluted and it is not good for sensitive groups of people with asthma compounds.
76-100	Heavy Air Pollution	The AQI is high. The quality of air is highly polluted and hence major attention is required to avoid further increase.
>100	Severe Air Pollution	The AQI is very high. The quality of air is severely polluted and it is very unhealthy to children, asthmatics and people suffering with bronchial disease.

Source: Senthilnathan, 2007

7.3.1 Development of CAQI at Rithala

Composite air quality index has been calculated on the basis of measured concentration of CO, NOx, SO_2, SPM and RSPM at Rithala location of mass rapid transit corridor. The highest observed concentration of these gases are found 1882 $\mu g/m^3$, 104.25 $\mu g/m^3$, 50.16 $\mu g/m^3$, 553.61 $\mu g/m^3$ and 361.21 $\mu g/m^3$ respectively, whereas the average value of the same gases are obtained 1396.06 $\mu g/m^3$, 83.13 $\mu g/m^3$, 40.91 $\mu g/m^3$, 519.66 $\mu g/m^3$ and 336.56 $\mu g/m^3$ accordingly. In this area, maximum and minimum composite air quality index is found 118.32 and 91.63 during 19-20 hours 8-9 hours respectively (Figure 7.9) with an average of 103.65. This obtained CAQI is compared with Table 7.2 and found higher than 100, which is indicative of severe pollution at this location.

7.3.2 Development of CAQI at Pitampura

Equation 7.6 has been used to compute the composite air quality index at this location. At Pitampura, the average concentration of different gases have been computed from the observed concentration of different pollutant and found 1243.17$\mu g/m^3$ for CO, 109.71$\mu g/m^3$ for NOx and 36.26 $\mu g/m^3$ for SO_2. On comparing these values with CPCB standard, it is found that all the three values do not exceed the prescribed limits. In addition to this the average concentration of suspended particulate matter and respirable suspended particulate matter has also been analyses and found 555.66$\mu g/m^3$ and 329.38$\mu g/m^3$ respectively. Figure 7.10 illustrates the time series variation of CAQI at Pitampura. It is clear from the figure that the highest and lowest CAQI is 122.2 and 89.49 during the same hour as found at Rithala. The average composite air quality index is found 108.85, which designates the stern condition of pollution at this location.

7.3.3 Development of CAQI at Kashmiri Gate

Kashmiri Gate is a prime location of Delhi due to presence of Inter State Bus Terminal as well as metro station. Due to continuous movement of people and vehicle especially buses, concentration of different gases i.e. CO, NOx, SO_2, SPM and RSPM have been measured to analyze the environmental air quality status of Kashmiri Gate. During the measurement, the highest concentration of above mentioned pollutants are perceived 1497 $\mu g/m^3$, 105.80 $\mu g/m^3$, 41.98 $\mu g/m^3$, 621.23 $\mu g/m^3$ and 499.34 $\mu g/m^3$ respectively. On the other hand the minimum is found 790 $\mu g/m^3$ (CO), 89.43 $\mu g/m^3$ (NOx), 26.34 $\mu g/m^3$ (SO_2), 591.17 $\mu g/m^3$ (SPM) and 439.15 $\mu g/m^3$ (RSPM) with the average value of 1231.08 $\mu g/m^3$, 98.07 $\mu g/m^3$, 36.33 $\mu g/m^3$, 608.94 $\mu g/m^3$ and 469.71 $\mu g/m^3$ respectively. The observed concentration of

CO and SO_2 is found lower than prescribed limits by CPCB whereas the observed concentration of NOx is found higher than the permissible standard almost throughout the entire study. The Composite Air Quality Index in this area is maximum i.e. 134.43 and minimum i.e. 119.99 found (Figure 7.11) with an average of 126.74. This value of CAQI in this area is also found higher than 100 which are symptomatic of serious pollution level.

7.3.4 Development of CAQI at Jhilmil

Like other locations, the observed concentration of different gases i.e. CO, NOx, SO_2, SPM and RSPM has been used as basis to estimate the air quality status of the particular location. The maximum and minimum concentration of CO is found 2543 $\mu g/m^3$, and 1600 $\mu g/m^3$ with an average of 2039.25 $\mu g/m^3$ during the entire observation period. Similarly, the highest, average and lowest concentration of NOx are 211$\mu g/m^3$, 166.4$\mu g/m^3$ and 128 $\mu g/m^3$. Likewise the maximum concentration of SO_2, SPM and RSPM are found 60 $\mu g/m^3$, 701 $\mu g/m^3$ and 402.03 $\mu g/m^3$ respectively. In the same way the average concentration of these gases have also been calculated and obtained 49.42 $\mu g/m^3$, 670.28 $\mu g/m^3$ and 369.37 $\mu g/m^3$ correspondingly. This location shows the maximum and minimum composite air quality index i.e. 162.11 and 121.57 consequently with an average of 140.22. Referring to Table 7.2, it is found that the CAQI of this location is more than 100 which is rated as critical pollution level at particular location (Figure 7.12). Such a higher value of composite air quality index may cause asthma and other bronchial diseases in people living around that particular zone. Due to this,, it is very essential to take appropriate mitigatory measures.

7.3.5 Development of CAQI at Panchsheel Enclave of BRTS corridor

Panchsheel Enclave is basically a BRTS Corridor. This location has been selected to measure the existing condition of air pollutant and the status of air quality. This location shows the maximum concentration of CO, NOx, SO_2, SPM and RSPM are 1278 $\mu g/m^3$, 106.73 $\mu g/m^3$, 39.42 $\mu g/m^3$, 578.63 $\mu g/m^3$ and 356.56 $\mu g/m^3$ respectively during the entire hour of study. Along with this, average concentration has also been estimated for all the above mentioned gases and found 1058.25 $\mu g/m^3$, 94.57 $\mu g/m^3$, 32.72 $\mu g/m^3$, 540.69 $\mu g/m^3$ and 330.54 $\mu g/m^3$ accordingly. On the basis of this observed concentration, the CAQI has been calculated to know the air quality of this location. Figure 7.13 depicts the hourly variation of composite air quality index and maximum and minimum CAQI is found during 19-20 hour (113.17) and 8-9 hour (99.31) respectively with the average value of 102.81.

On comparing with Table 7.2, it is concluded that the obtained value is higher than 100 which presents the severe pollution at identified location. Such kind of poor air quality may harm health of people residing in the surroundings of this area. Such bad air quality requires some alternative measures to improve the air quality condition of this location.

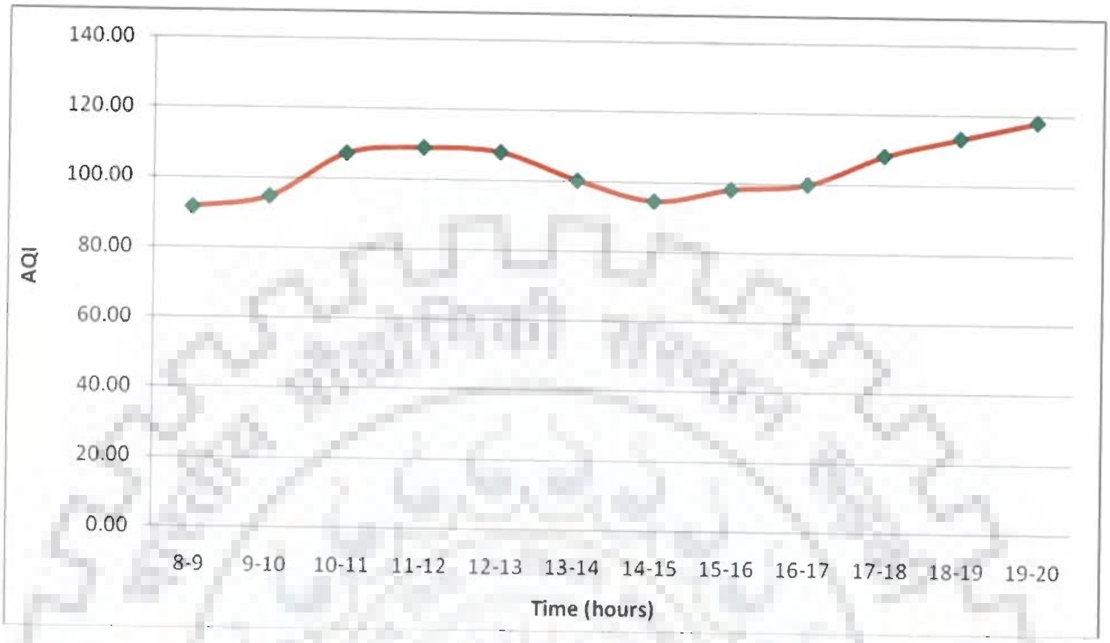


Figure 7.9: Temporal Variation of CAQI at Rithala

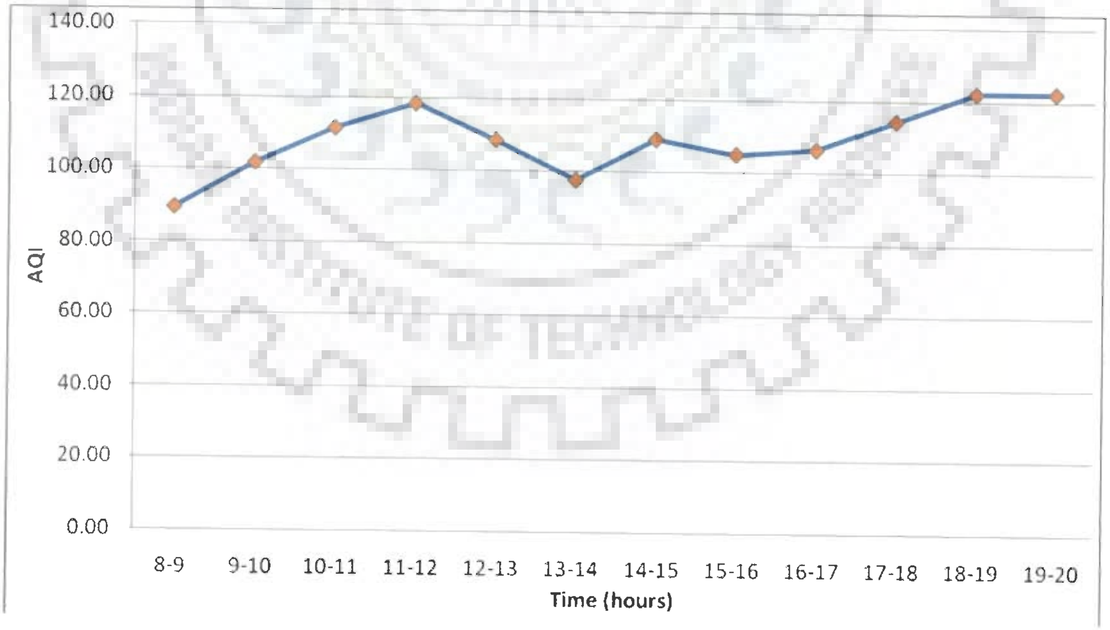


Figure 7.10: Temporal Variation of CAQI at Pitampura

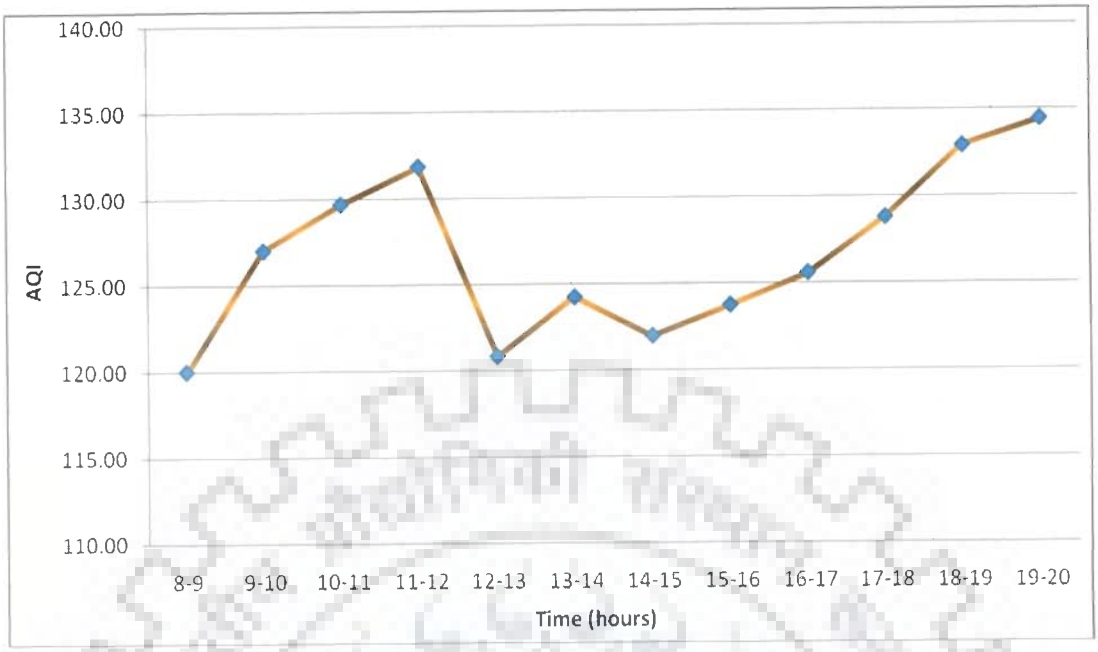


Figure 7.11: Temporal Variation of CAQI at Kashmiri Gate

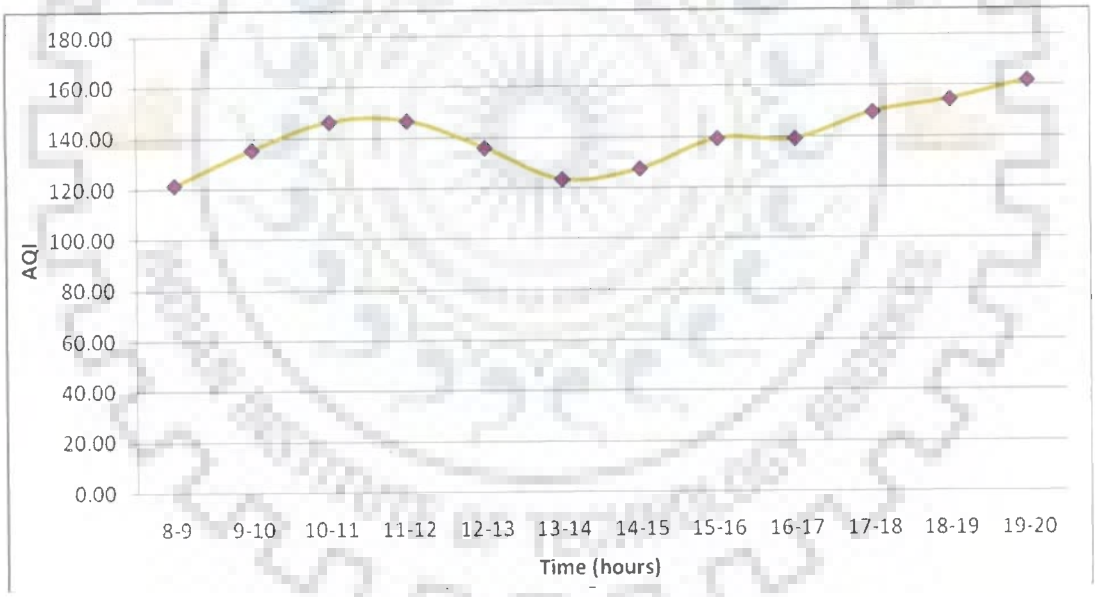


Figure 7.12: Temporal Variation of CAQI at Jhilmil

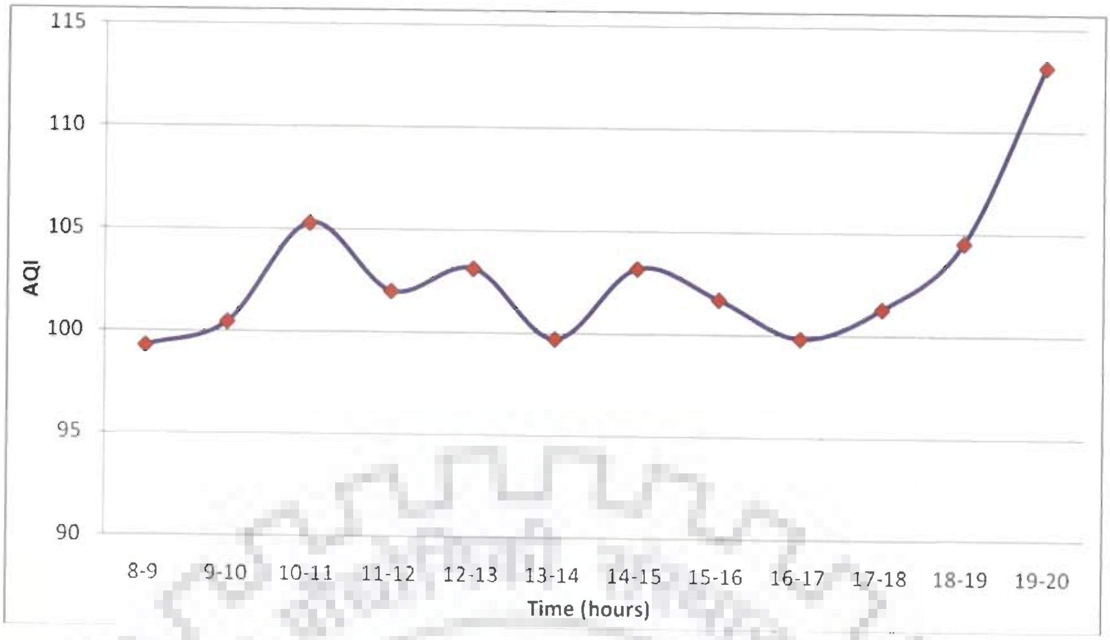


Figure 7.13: Temporal Variation CAQI at Panchsheel Enclave (BRTS corridor)

7.4 Development of Metropolitan Emission Inventory

In megacity like Delhi, road traffic is only the basic mode to transfer goods and people from one place to another place. Due to heterogeneous traffic in capital city, the average speed is comparatively very low. Equation 7.7 has been used to calculate emission from vehicular traffic (Gurjar, 2004).

$$Ei = \Sigma\ (Veh_j * D_j) * E_{i,j,km} \quad \text{....... (7.7)}$$

where,

Ei is emissionofcompound (i),

Veh_j is number of vehicles per type (j),

D_j distance travelled in a year per different vehicle type (j) and

$E_{i,j,km}$ is emission of compound(i), vehicle type (j) per driven kilometer.

The number of registered vehicles in Delhi (Table 7.3), average distance travelled by different category of vehicles (Table 7.4) and vehicle age (Table 7.5) has been taken from secondary sources. With the help of this secondary data, number of vehicles has been forecasted for the year 2011, 2016, 2021 and 2025 (Table 7.6). In addition to this, distance travelled in a year per different vehicle type has also been estimated. Intracity buses and autorickshaw are assumed to use CNG as fuel while intercity buses and goods vehicles use diesel as fuel. On the other hand car, taxi and motorcycle are assumed to use gasoline as fuel. During the development of emission inventory, the applied emission factor has been shown in Table 7.7.

Figure 7.3: Registered Number of Vehicles in Delhi

Year	Car /Jeeps	Two Wheelers	Auto-Rickshaw	Taxi	Bus	Goods Vehicles
1995-96	617585	1707528	77884	13384	27473	131877
1996-97	705923	1876053	80210	15015	29572	140922
1997-98	765470	1991710	85518	16654	32333	146668
1998-99	818962	2101876	86985	17136	35254	150243
1999-00	869820	2184581	87785	17762	37733	156157
2000-01	920723	2230534	90000	18362	41483	158492
2001-02	968894	2265955	86985	20628	47578	161650
2002-03	1214693	2517788	49538	9936	18731	129723
2003-04	1314672	2665750	52905	11495	21962	135671
2004-05	1431638	2844004	53656	13511	24235	140982
2005-06	1466641	3062536	73644	20693	43500	141996
2006-07	1589872	3299838	74189	24958	46581	149972
2007-08	1729695	3578199	75297	30704	52763	160726
2008-09	1859370	3797943	83948	40072	55148	175250
2009-10	2013680	4055229	86482	45240	58047	193205

Source: Delhi Statistical Abstract, (2010)

Table 7.4: Average Distance Travelled by Vehicles

Vehicles	Average distance travelled/day (km)
Car/Taxi	82
Two Wheelers	65
Auto	113
Bus	134
Truck	93

Source: CRRI Report, 2007

Table 7.5: Age of Vehicles

Vehicles	Vehicle age (years)
Car/Taxi	10
Two Wheelers	8
Auto	7
Bus	12
Truck	11

Source: CRRI Report, 2007

Table 7.6: Projected Figures of Vehicles in Delhi

Year	2011	2016	2021	2025
Car/Taxi	2446059	2876562	4350101	6288307
Two Wheeler	2489033	3594718	4739246	6056888
Auto	48886	70497	107922	151727
Bus	31981	85964	116146	167528
Truck	205051	237941	135125	135752

Table 7.7: Emission Factor of Different Vehicles

Vehicles	Emission Factor (gm/km-hr)				
	CO	NO_X	SO_2	HC	PM
Car	0.891	0.304	0.053	0.2486	0.0301
Two Wheelers	1.036	0.31	0.013	0.486	0.021
Mini Bus & Mini Truck	3.66	2.12	0.029	1.35	0.475
·Auto-Rickshaw	0.845	0.345	0.013	1.16	0.0665
Bus	3.72	6.21	0.15	3.75	NA
Truck	6	9.3	0.15	0.37	1.24

7.4.1 Emission inventory for CO

By using equation 7.7, carbon monoxide emission has been computed for 2011, 2016, 2021 and 2025. Figure 7.14 depicts the forecasted emission of CO in different years. The highest emission of CO is observed 178.71 metric ton/day, 210.17 metric ton/day, 317.83 metric ton/day and 459.44 metric ton/day in 2011, 2016, 2021 and 2025 respectively by cars/taxis, while the minimum emission i.e. 4.67, 6.73, 10.30 and 14.49 metric ton/day in 2011, 2016, 2021 and 2025 accordingly of the same gas has been found by auto-rickshaw. From this figure, the emission of CO is found in rising order.

7.4.2 Emission inventory for NOx

The above mentioned equation has also been applied for the computation of NOx emission from different categories of vehicles in different years i.e. 2011, 2016, 2021 and 2015. The calculated emission has been presented in Figure 7.15. From the figure, the increasing order of NOx emission can be observed. In 2011, the highest emission of oxides of nitrogen has been found 177.35 metric ton/day by trucks, whereas the minimum is found 1.91 metric ton/day by auto-rickshaw. The same pattern has also been observed in 2016, where the maximum emission is found due to truck i.e. 205.80 metric ton/day and minimum is found due to auto-rickshaw (2.75 metric ton/day). But in 2021 and 2025, the highest emission of NOx i.e. 157.96 metric ton/day and 227.84 metric ton/day has been occurred due to increasing number of buses using CNG as fuel, while the lowest is found due to auto-rickshaw.

7.4.3 Emission inventory for SO_2

Table 7.8 shows the estimated sulphur dioxide emission in metric ton/day in 2011, 2016, 2021 and 2025. From the table, it is clear that increasing number of cars/taxis in Delhi is responsible for higher emission of SO_2 i.e. 10.63 metric ton/day in 2011, 12.50 metric ton/day in 2016, 18.91 metric ton/day in 2021 and 27.33 metric ton/day in 2025. On the other hand in comparison to other vehicles, auto-rickshaws using CNG as fuel emit very little amount of SO_2 i.e. 0.07, 0.10, 0.16 and 0.22 metric ton/day in 2011, 2016, 2021 and 2025 correspondingly.

7.4.4 Emission inventory for HC

Time series estimation of hydrocarbons is presented in Figure 7.16. The hydrocarbon emission has been forecasted for the year 2011, 2016, 2021 and 2025. The basic reason behind the appearance of only these years is to show the divergence of HC emission from vehicular traffic. A gradual increment is found in hydrocarbon emission in different years. In 2011, the highest HC emission is observed 78.63 metric ton/day by two wheelers in Delhi, while in 2016, 2021 and 2025, it is found 113.56 metric ton/day, 149.71 metric ton/day and 191.34 metric ton/day from the same mode. On the other hand, auto-rickshaws emit least amount of HC i.e. 6.41, 9.24, 14.15 and 19.89 metric ton/day in year 2011, 2016, 2021 and 2025 respectively. Such a small contribution of HC emission in atmosphere by auto-rickshaw in comparison to other type of vehicles may be due to its CNG fuel.

7.4.5 Emission inventory for PM

Particulate emission plays very important in atmosphere due to its adverse impact on human health. PM<2.5 may cause several health problems like bronchitis, headache, lung cancer etc. in human beings. It is also estimated for different years and found that Buses are primarily responsible for the much more emission of particulate matter followed by trucks, cars/taxis, two wheelers and auto-rickshaws in city like Delhi (Table 7.9). In 2011, 2016, 2021 and 2025, the emitted particulate matter by buses is found 26.26 metric ton/day, 70.60 metric ton/day, 95.38 metric ton/day and 137.58 metric ton/day correspondingly. On the other hand the good carrying vehicles i.e. trucks are secondly accountable for higher PM emission. The emission is found 23.65 metric ton/day, 27.44 metric ton/day, 15.58 metric ton/day and 15.65 metric ton/day in year 2011, 2016, 2021 and 2025 respectively. In comparison to all kind of vehicles, auto-rickshaws are found very less particulate emitting vehicles. It shows 0.37 metric ton/day in 2011, 0.53 metric ton/day in 2016, 0.82 metric ton/day in 2021 and 1.15 metric ton/day in 2025.

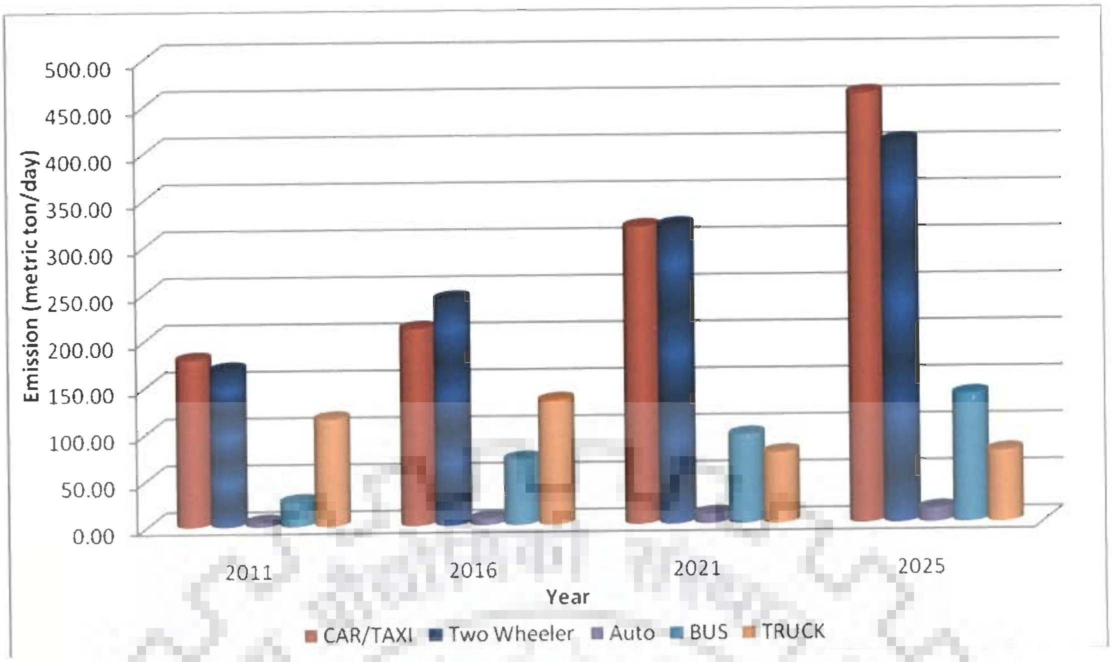


Figure 7.14: Yearly Variation of CO Emission (metric ton/day) in Delhi

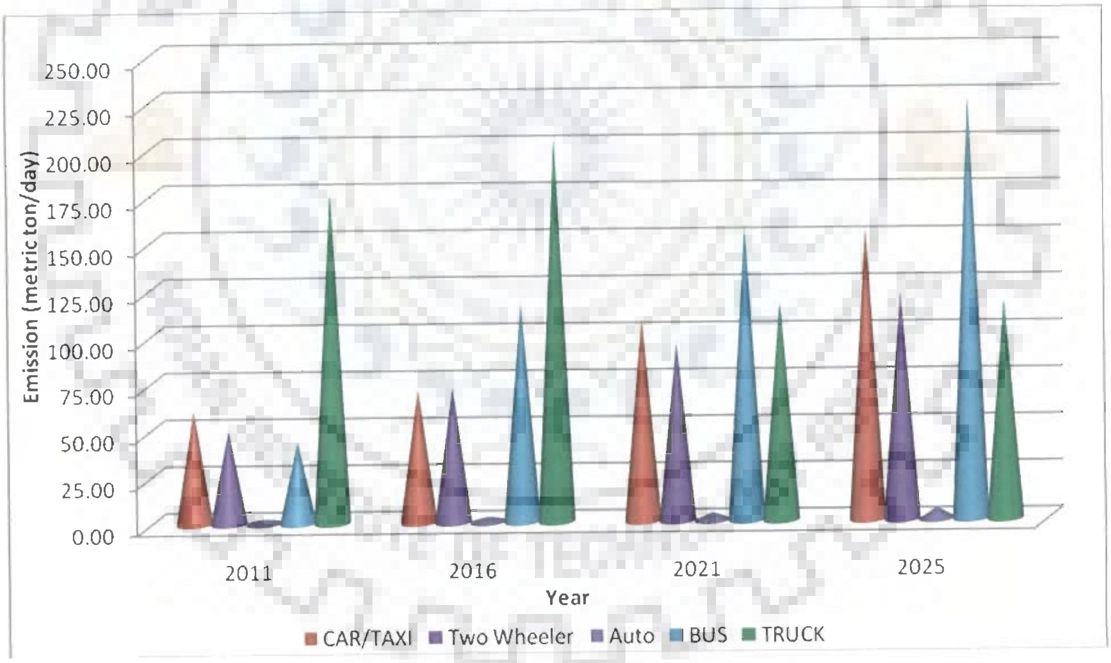


Figure 7.15: Yearly Variation of NOx Emission (metric ton/day) in Delhi

Table 7.8: Yearly Variation of SO_2 Emission (metric ton/day) in Delhi

	Emission (metric ton/day)			
Year	**2011**	**2016**	**2021**	**2025**
Car/Taxi	10.63	12.50	18.91	27.33
Two Wheeler	2.10	3.04	4.00	5.12
Auto-rickshaw	0.07	0.10	0.16	0.22
Bus	1.05	2.82	3.82	5.50
Truck	2.86	3.32	1.88	1.89

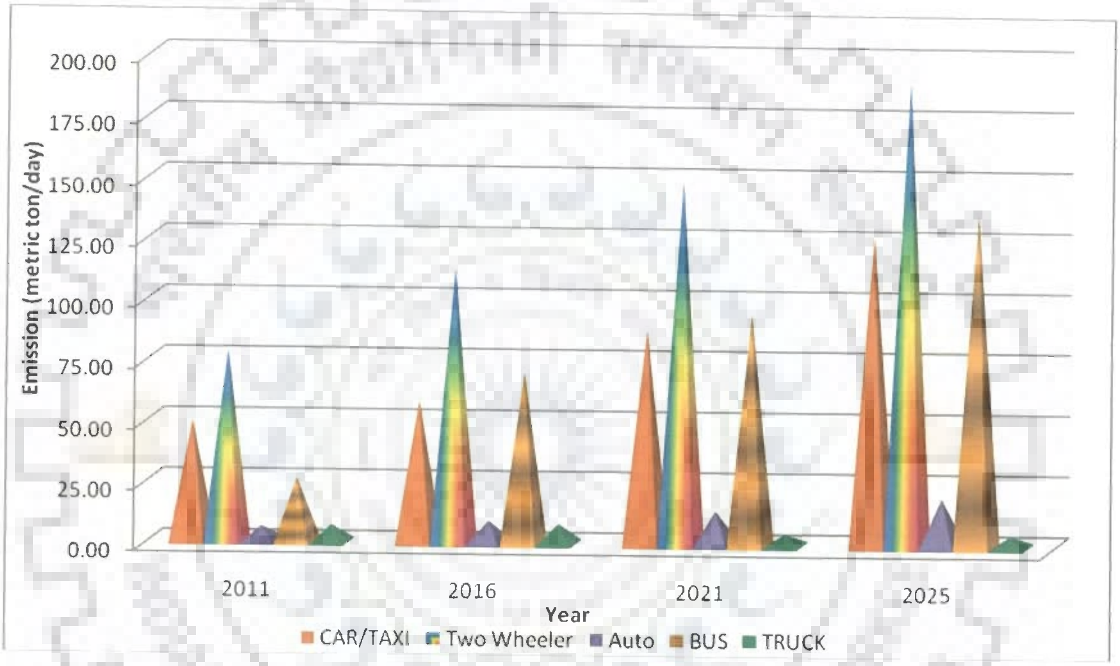


Figure 7.16: Yearly Variation of HC Emission (metric ton/day) in Delhi

Table 7.9: Yearly Variation of PM Emission (metric ton/day) in Delhi

	Emission (metric ton/day)			
Year	**2011**	**2016**	**2021**	**2025**
Car/Taxi	6.04	7.10	10.74	15.52
Two Wheeler	3.40	4.91	6.47	8.27
Auto	0.37	0.53	0.82	1.15
Bus	26.26	70.60	95.38	137.58
Truck	23.65	27.44	15.58	15.65

7.4.6 Effect of use of Public Transport on emission inventory in 2025

The above developed emission inventory is explained considering those vehicles which are moving inside the city. But there are so many vehicles which come every day from outside the city and enter into city and plying on the road of Delhi during the entire day. These vehicles also add their emission with the emission of intracity vehicles. Taking into all such kind of vehicles, the overall emission inventory has been developed for Delhi. The summarized emission inventory is depicted in Tale 7.10. To quantify the overall pollution load, emission factors and vehicle age of intercity vehicles has also been employed. Table 7.10 illustrates the estimated pollution load of different gases in different years. In 2011, the maximum pollution load is estimated for carbon monoxide followed by oxides of nitrogen, hydrocarbons, particulate matter and sulphur dioxide. The same pattern is also observed in 2016, 2021 and 2025. The aggregate emission of each pollutant is found in increasing order in 2011, 2016, 2021 and 2025.

Table 7.10: Summarized Emission Inventory for Delhi

Year	CO Emission/Day (metric ton/day)	NOx Emission/Day (metric ton/day)	SO_2 Emission/Day (metric ton/day)	HC Emission/Day (metric ton/day)	PM Emission/Day (metric ton/day)
2011	570.73	427.99	21.71	188.68	44.68
2016	771.80	587.59	29.09	289.24	53.71
2021	972.25	633.37	39.57	394.09	50.61
2025	1299.79	815.01	54.97	537.30	60.99

The developed emission inventory for 2025 has been compared with another emission inventory which has been developed on the basis of use of public transport in coming future. During this, it has been tried to show the effect of public transport on vehicular emission in 2025. Table 7.11 illustrates the impact of public transport on vehicular emission. Entirety emission of CO, NOx, SO_2, HC and PM is found 1299.79 metric ton/day, 815.01 metric ton/day, 54.97 metric ton/day, 537.30 metric ton/day and 60.99 metric ton/day respectively. On strengthen public transport in coming future, the reduction is found in automobile pollution load. On strengthen public transport in coming prospect, the emission reduction is found 949.37 metric ton/day for CO, 681.10 metric ton/day for NOx, 47.94 metric ton/day for SO_2, 370.66 metric ton/day for HC and 53.69 metric ton/day for PM with the percentage emission cut of 27% (CO), 16% (NOx), 13% (SO_2), 31% (HC) and 12% (PM). From the study, it is concluded that there is a requirement of comprehensive environmental management policy to minimize the adverse environmental impacts arising out of road transport activities and to achieve the objective of sustainable mobility. It is established from the estimation that public transport system is an essential part of transport system and can bring down the pollutant emission in coming future.

Table 7.11: Emission Reduction in 2025 on Strengthen Public Transport in Delhi

Air Pollutant	Total Emission (metric ton/day)	Emission Reduction on strengthen public transport (metric ton/day)	Percentage Cut in Emission
CO	1299.79	949.37	27%
NOx	815.01	681.10	16%
SO_2	54.97	47.94	13%
HC	537.30	370.66	31%
PM	60.99	53.69	12%

7.5 Models of KM and Non-KM Practices to Control Transport-Environment Issues

Due to existing traffic-related environmental problems in Delhi, it is very essential to employ knowledge management practices in transport system and the users. The addition of knowledge based practices shall be useful to operators as well as users to be familiar with traffic problem by which the operator will be able to give the best choice of strategic control actions to the city and people will also be able to take the best decision in that particular situation. It is necessary to build systematic, knowledge practices based tool to analyze and manage the recent or potential traffic noise issues and air quality issues followed by improper traffic management issue. Figure 7.17 presents the combined KM model for the reduction of traffic noise and air pollution. This model includes both kinds of KM and Non-KM practices.

7.5.1 KM practices for traffic noise and air pollution reduction

To overcome the problem of traffic noise in city like Delhi, it is required to use the knowledge management based practices in various traffic noise related issues. Different kind of practices have been extracted from the past literature and on the basis of those practices some apposite practices have been suggested to execute in the transport related problems like noise & air pollution in the capital city. KM practices that can be employed in the mitigation of noise pollution are acoustical insulation in building codes, installation of barrier at different sensitive locations and high noise absorbing material as a filler in barrier. From the location study and analysis it is found that all the selected locations along public transport corridor requires different height of noise barrier. The required height of barrier for all the selected sensitive locations have been estimated through the developed mini knowledge management based tool. Rithala location demands the installation of 2.9 and 2.2 meter height of barrier in both the direction. Likewise Pitampura location requires 5.3 and 4.4 mt height of barrier in both directions, Jhilmil demands 4.6 mt height of barrier. On the other hand, Dilshad Garden needs 4.1 mt height of barrier to reduce the road traffic noise, whereas due to the presence of open space on one side of Panchsheel Enclave of BRTS Corridor, only 4.4 meter height of barrier is necessary to design in one side.

During the design of barrier it is also very essential to focus the kind of material which is going to be used as filler in barrier. Polycarbonate sheets are found very much effective in this regard. The other problematic side of increasing traffic is air pollution. A number of practices are suggested in different research papers to control traffic air emission. For the city like Delhi, practices those are found suitable to the existing conditions are application of prototype expert system, decision support system, expert system, group decision support system and spatial decision support system. Along with these practices, there are some other KM based practices which may act effectively towards the reduction of air emission i.e. use of hybrid and electric vehicles as well as designing of vehicle size.

7.5.2 Non-KM practices for traffic noise and air pollution reduction

Theses practices are general or traditional practices that can decrease expeditiously environmental pollution problems in megacity like Delhi. Limitation of vehicle speed, alternation of roadway surface structure, change in tire design, enforcement of environmental rules and regulations are some of the significant conventional practices that can be incorporated to achieve the reduction in traffic noise pollution. Along with this, other kind of practices have also been suggested to diminish the traffic air emission i.e. proper inspection and maintenance of in-use-vehicles, technology standards like vehicle fitted with catalytic converters, scrappage or repair of old and most polluting vehicles, increase in engine efficiency etc. In addition to this green labelling of vehicles, application of fuel economic standards, use of alternative fuels and motivation towards the use of public transport vehicles are the considerable Non-KM practices to accomplish the effective air pollution level.

7.5.3 Traffic management through the appliance of KM practices

Traffic management plays significant role in urban transport scenario. Proper traffic management can reduce traffic problems like congestion, travel time and environmental problems like air pollution, noise pollution and fuel consumption too. Due to continuous increasing urban traffic pressure on road, sometimes it does not work properly and fails to handle the critical traffic conditions. Knowledge management based practices to traffic management operation may act as an efficient tool. A KM-based traffic management model is presented to control the improper traffic operations in megacity like Delhi (Figure 7.18). This models has discussed different kind of knowledge based approaches like KITS approach, FLUIDS intelligent management approach, SCOOT approach, TRYS approach, CLAIR and FRED approach that can be implemented in city like Delhi for proper traffic management. These practices also depend on traffic condition and causes of traffic congestion.

7.5.4 Traffic management through the appliance of Non-KM practices

In addition to KM practices, the Non-KM practices have the same importance for traffic management. Various traditional practices like advance traffic management system, decision support to traffic operation centre, development of traffic control manager, incremental technologies for traffic signal network, diversion of heavy vehicles through by-pass and better passenger information system in the form of variable message signs have been suggested to control the heavy traffic congestion. Application of intelligent transport system technology, construction of bridges, flyovers and road network are the additional common practices to manage the traffic. From the study, it is also found that the use of public transport system and car pooling is the best way to reduce heavy pressure of traffic on road. Application of these practices will ultimately help in the reduction of traffic noise and air pollution generated due to traffic congestion and improper traffic management.

The both kind of discussed model and its practices may act as Decision Support System (DSS) which will be very supportive and helpful in traffic control system as well as in the reduction of environmental pollution i.e. traffic noise and air pollution. It will also help in the creation of environmental knowledge and awareness among people. With the help of this DSS the traffic controller can analyze the various transport-environmental problems and develop decision for the same. This KM based Decision Support System may support in better air & noise pollution management. With the help of this DSS the various decisions can be taken for a city by traffic controller in diverse transport related problems like congestion and environmental problems.

7.5.5 DSS framework for sustainable transport system

Due to the expansion of the road network and the growth of vehicles, the Delhi traffic control has installed traffic signals at short distances. There are more than 700 signalized intersections located all over Delhi to control traffic operations and ensure smooth flow of traffic. But these signalized intersections have led to excessive time and fuel consumption for all vehicle trips. To overcome such type of problems, there is a need to incorporate KM based DSS to provide real time management system to cater to changing traffic needs. The proposed Decision Support System (DSS) is going to be a better alternative to solve traffic problems like congestion, delays, pollution management. It will also help in the creation of knowledge and awareness among people. With the help of this DSS, the traffic controller can analyze the various transport-environmental problems and develop decision for the same. The corresponding Expert System is showing in Figure 7.19. In the first phase of the study a general understanding of the problem is developed.

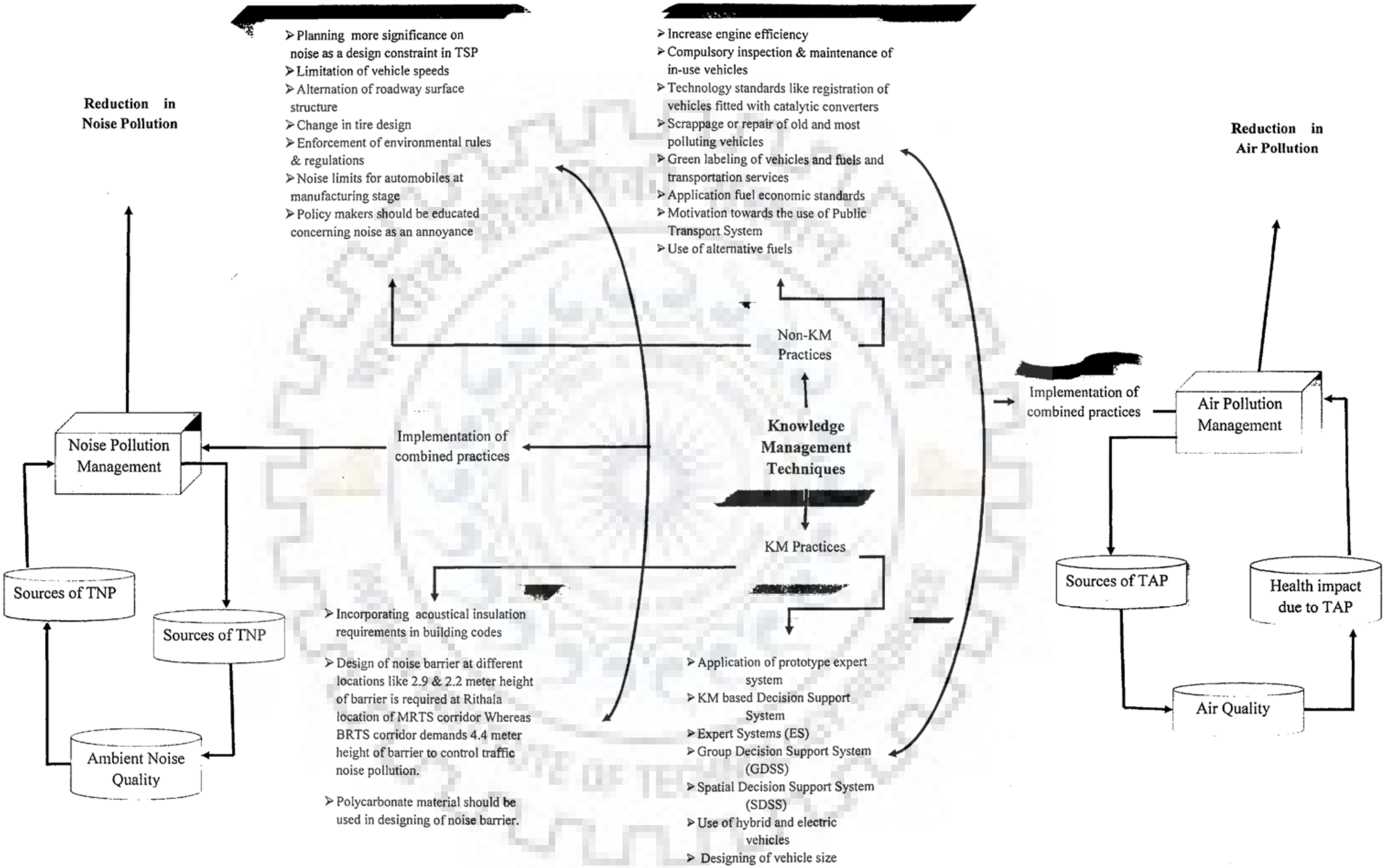


Figure: 7.17: KM Model to Control Traffic Noise and Air Pollution

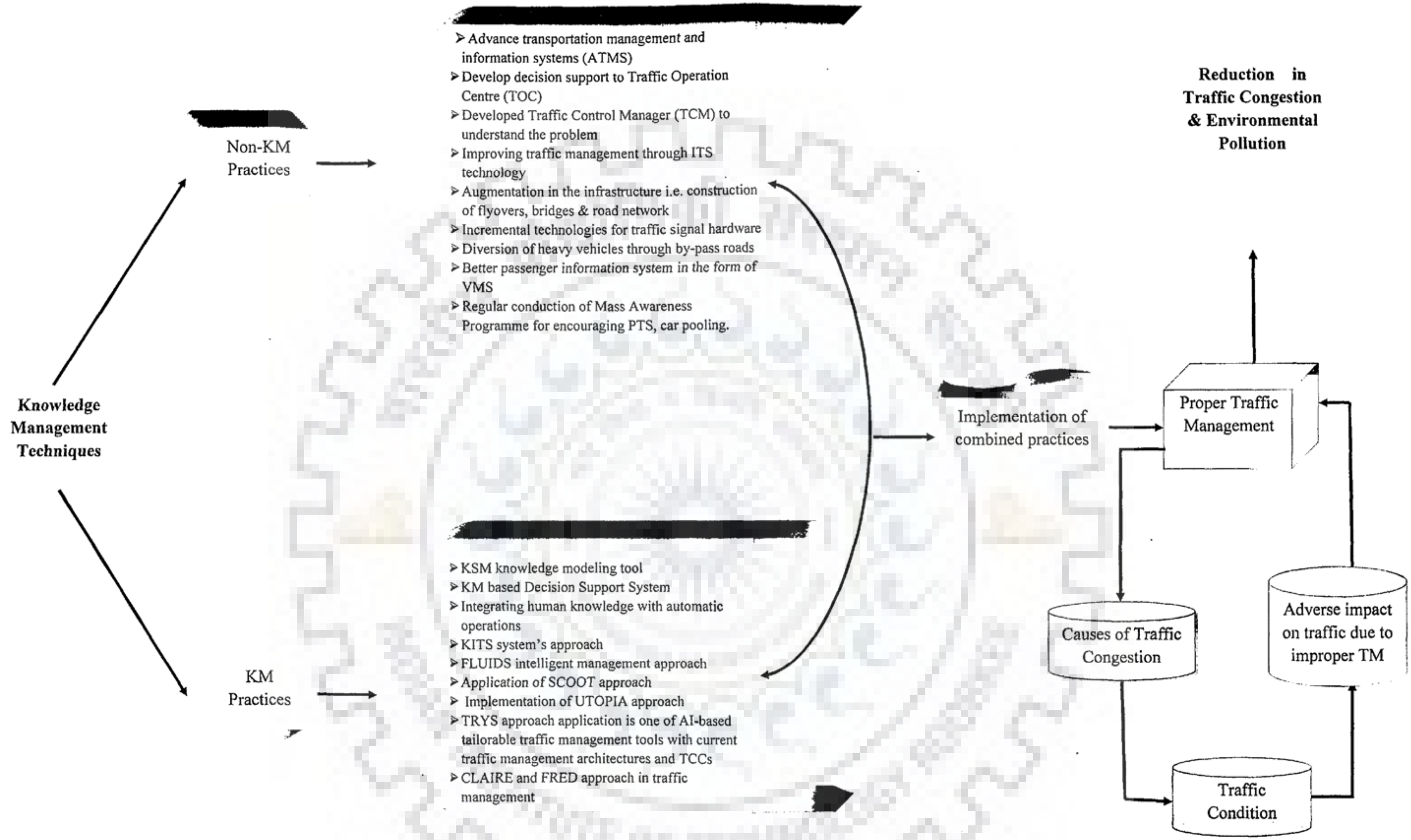


Figure 7.18: KM Model for Traffic Management

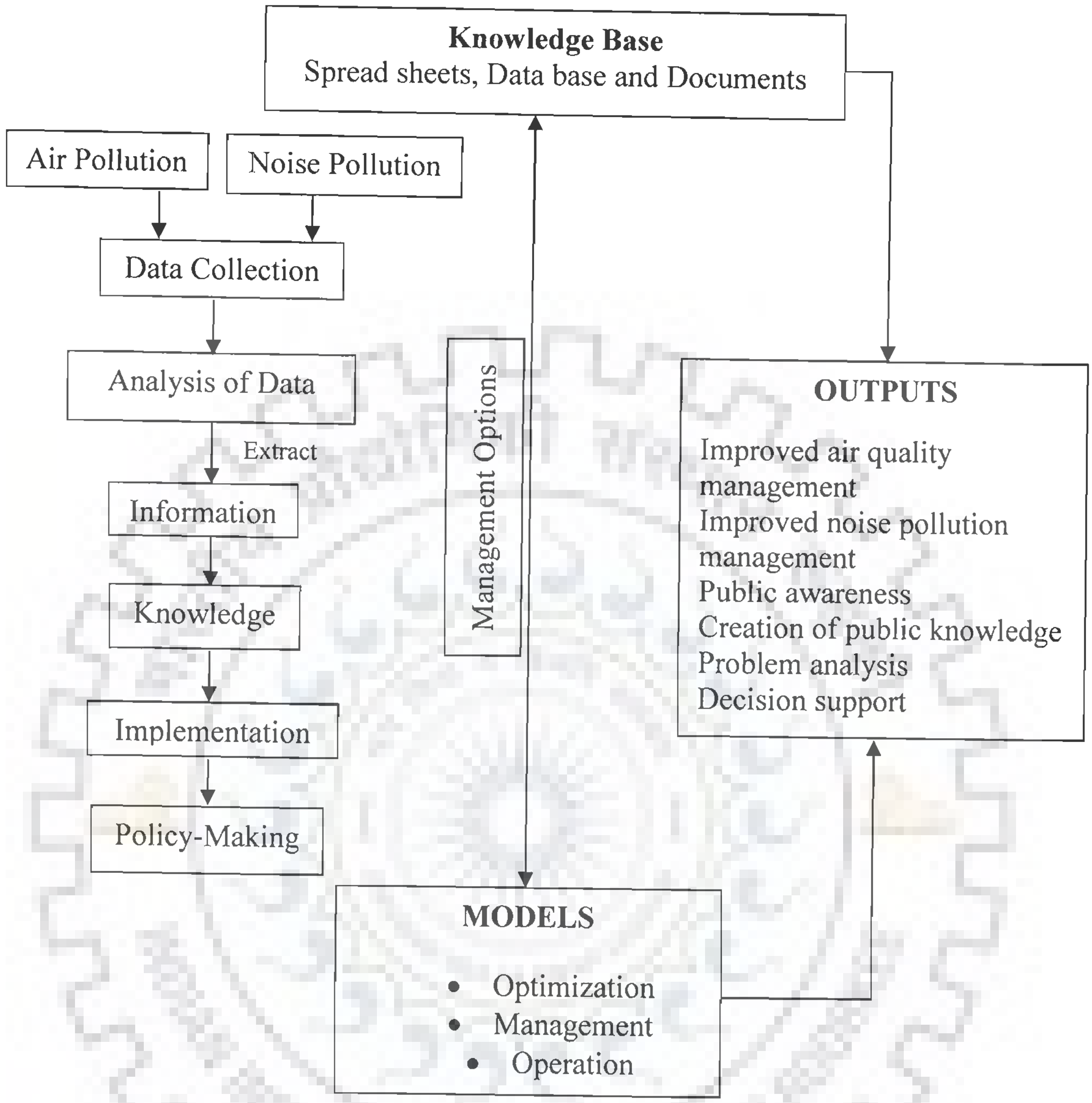


Figure 7.19: Framework of Decision Support System

This is carried out at various locations of Delhi, the capital of India, where data are collected with the objective of development of data model. The developed data sheet generates information which is further with help of knowledge base (spreadsheets and documents) and other applicable models viz. optimization, management/operation converted into knowledge base tools. This KM based Decision Support System support in better air & noise pollution management. It also helps in the creation of public awareness and public knowledge. With the help of this DSS, the various decisions can be taken for a city by traffic controller in diverse transport related problems like congestion and environmental problems.

7.6 Summary

This chapter covers the application of research study. The application involves the model development for barrier designing, composite air quality index, emission inventory development for capital city and development of KM model. Through the application of developed model, different barrier height for different locations have been calculated and discussed in present chapter. In addition to this, air quality status of all the identified locations with the development of emission inventory for Delhi is also described in this chapter. To restrain the exceeding noise pollution, bad air quality and traffic congestion, two additional KM models are exposed in this chapter. The chapter portrays about developed models and KM and Non-KM practices as well as its applications in current transport system.

Chapter 8

CONCLUSIONS AND FUTURE VISTAS OF RESEARCH

8.1 General

The entire study has covered different aspects of transport-environment facets. During this research study transport related environmental problems like traffic noise, metro rail noise and vehicular emission problems have been taken up. The present study is based on the capital city of India i.e. Delhi. The study is basically focussed towards the MRTS and BRTS corridor. The study has been conducted at the locations of operationalized metro line 1 i.e. Rithala, Pitampura, Kashmiri Gate, Jhilmil, Dilshad Garden and one location of BRTS corridor i.e. Panchsheel Enclave. A number of data related to traffic, noise and air have been collected through monitoring at selected locations and analyzed to assess the status of noise and air pollution and to develop model for the prediction of traffic noise, metro rail noise and air pollution. The studies also deal with the impact of vehicular taffic on urban noise and air its adverse impact on people. Along with the estimation of urban air quality, emission inventory has been developed for the megacity like Delhi. A number of mitigatory measures have been suggested to lessen the existing transport-environment problems in Delhi. These measures basically include barrier designing for road traffic noise and metro rail noise and application of KM and Non-KM practices in transport sector. On the basis of these practices, two KM models have been suggested to control the traffic related environmental issues i.e. noise, air pollution and proper traffic management. These KM and Non-KM practices will enhance the environmental knowledge among people as well as users and provide more reliable and consistent decisions, more useful information and improved reaction times. The conclusions drawn from the entire research study have been covered in following modules:

8.2 Ambient Noise Level

It can be seen from the measured equivalent noise level that all the locations exceed the permissible noise level prescribed by CPCB. The following observations are found during the study at major public transport corridor:

(1) On comparing observed noise level with CPCB standards, all the locations are found exceeding the permissible limits. Not a single location along public transport corridor is found under prescribed noise limit.

(2) In view of the importance of locations and CPCB standards, Jhilmil area is found in most critical condition (77.6 dBA) followed by Rithala, Pitampura, Panchsheel Enclave and Dilshad Garden.

(3) It has been observed that the peak noise level (L10) is found maximum at Jhilmil location whereas the minimum is found at Dilshad Garden (74.8 dBA).

8.3 Modeling of Ambient Noise Level

An MS EXCEL based modified FHWA model and FTA metro noise model has been developed to predict the noise level due to vehicles and metro rail respectively. The model performance has been evaluated through statistical tests and quantitative analysis. Both the developed models have been tested at all the selected locations along major public transport corridor in Delhi and outcomes are mentioned below:

(1) The statistical analysis shows the percentage difference between predicted and observed values are found in the range of -6.11 to -9.93, -0.18 to 5.06, 0.6 to 1.4, 1.58 to 9.9 and -7.8 to -9.4 at Rithala, Pitampura, Jhilmil, Dilshad Garden and Panchsheel Enclave location respectively. This analysis elucidates the applicability of developed model for the prediction of traffic noise in Delhi city.

(2) On the other hand, statistical test has also been applied at all the identified locations to validate the metro rail noise model. It is found that developed FTA based metro rail noise model is more reliable for rail noise prediction under the studied conditions of Delhi. Using FTA methodology, metro rail noise prediction models have been developed for each identified metro corridor.

8.4 Design of Noise Barrier

To curb the road and metro rail noise, design of noise barrier has been designed along the selected corridor as well as at elevated corridor. For designing purpose another MS EXCELL based modified FHWA model has been formulated. Through the application of this model, barrier heights for all the selected locations have been calculated. The findings about required barrier height at different locations are specified below:

(1) From the study, it is found that Rithla location requires 2.9 meter and 2.2 meter height of barrier in the direction of Rohini East and in the direction of Rithala respectively. Likewise the height of barrier has been calculated for Pitampura location. It is found 5.3 meter (towards Kohat Enclave) and 4.4 meter (towards Rohini East). Along with

this there is a requirement of 4.6 meter height of barrier at Jhilmil (towards Dilshad Garden), 4.1 meter height of barrier at Dilshad Garden (towards Gaziabad) and 4.4 meter at Panchsheel Enclave (towards Moolchand).

(2) Due to incorporation of metro rail noise with road traffic noise, the overall noise has been exceeded which creates health problems to people living in high rise buildings near to metro corridor. To control this noise, different barrier height has been recommended for different elevated corridor of metro line one and it is computed that there should be a height of 1.6 meter barrier at Rithala, 1.8 meter barrier at Pitampura, 2.1 meter barrier at Jhilmil and 1.7 meter barrier at Dilshad Garden.

8.5 Ambient Air Quality Study

Like road traffic noise and metro rail noise study, air quality has also been conducted at different locations of Delhi. It is analysed on the basis of daily average concentration of different pollutants and air quality index. The important conclusions extracted from this analysis are presented in following points:

(1) During ambient air studies in Delhi at all the identified locations, the highest average observed concentration (2039.25μg/m^3) of CO is found at Jhilmil followed by Rithala, Pitampura, Kashmiri Gate and Panchsheel Enclave. In addition to this, the same location i.e. Jhilmil shows the maximum average observed concentration of NOx i.e. 166.42 μg/m^3 trailed by Pitampura, Kashmiri Gate, Panchsheel Enclave and Rithala. In the same way the SO_2 shows its highest concentration at Jhilmil (49.42 μg/m^3) chased by Rithala (40.91 μg/m^3), Kashmiri Gate (36.33 μg/m^3), Pitampura (36.26 μg/m^3), and Panchsheel enclave (32.72 μg/m^3).

(2) Maximum average observed concentration of SPM is obtained at Jhilmil location (670.28 μg/m^3) followed by Kashmiri Gate, Pitampura, Panchsheel Enclave and Rithala. Likewise, the average highest concentration of RSPM is found at Kashmiri Gate (469.71 μg/m^3) and minimum at Pitampura (329.38 μg/m^3).

(3) Composite air quality index of all the selected locations have been calculated and all the locations are found under severe pollution. CAQI of Jhilmil is found 140.22, indicative of severe pollution followed by Kashmiri Gate, Pitampura, Rithala and Panchsheel Enclave.

8.6 Modelling of Air Pollutants

One of the important modules of this research study is to develop MS EXCELL based General Finite Line Source Model for the prediction of monitored ambient air concentrations. Through the application of this model, concentration of air pollutants has been predicted at all the locations. To show the applicability of this model, different statistical tests have been applied and some of the important results related to its performance are given in following sections:

(1) On comparison, a good correlationship is found between predicted and observed value of CO, NOx and SO_2 at all the locations. Regression equations have been developed for different pollutants at all identified locations.

(2) The maximum R^2 value for CO, NOx is found at Jhilmil (0.98 and 0.95)), whereas the minimum is found at Panchsheel Enclave and Kashmiri Gate respectively. On the other hand, for SO_2 the maximum R^2 value is obtained at Pitampura metro corridor (0.96), while the minimum at Kashmiri Gate location. This indicates the model's applicability at selected locations for discussed gaseous pollutants.

(3) Along with this, Index of agreement and t test has also applied to check the performance of developed model. At Rithala, Pitampura, Kashmiri Gate, Jhilmil and Panchsheel Enclave, the index of agreement for CO is found 0.97, 0.95, 0.91, 0.98 and 0.91 respectively, which indicate the better performance of developed model at this location. In the same way, for NOx, the index of agreement has been calculated and find out 0.93, 0.94, 0.84, 0.98 and 0.94 correspondingly, which also shows the good performance of the developed model. The same model has been tested for the prediction of SO_2 also, and index of agreement for the same pollutant at all the above mentioned locations is found 0.97, 0.98, 0.87, 0.95 and 0.85 correspondingly. This also illustrates the applicability of the model for SO_2 at identified locations. In addition to this statistical test, the t-test performance of the developed model at all the selected locations is also found satisfactory.

8.7 Emission Inventory for Delhi

In support of air quality and climate change in Delhi, a comprehensive emission inventory has been developed for the year 2011, 2016, 2021 and 2025. In 2025, percentage reduction in vehicular emission due to continuous use of public transport system has also been covered in this research study. The subsequent findings are pulled out from this study:

(1) For the year 2011, 2016, 2021 and 2025, the emission has been forecasted and for the year 2011, it is found 570.73 metric ton/day for CO, 427.99 metric ton/day NOx, 21.71 metric ton/day for SO_2, 188.68 metric ton/day for HC and 44.68 metric ton/day for PM.

(2) In 2025, enormous increment has been found in the emission of same gases in comparison to 2011 and it is obtained 1299.79 metric ton/day (CO), 815.01 metric ton/day (NOx), 54.97 metric ton/day (SO_2), 537.30 metric ton/day (HC) and 60.99 metric ton/day (PM).

(3) On strengthen public transport in coming future, the percentage reduction is also estimated and found 27% reduction in CO, 16% reduction in NOx, 13% reduction in SO_2, 31% reduction in HC and 12% reduction in PM. It can be concluded from the study that public transport system is an essential part of transport system and can bring down the pollutant emission in coming future.

8.8 KM and Non-KM Practices in Transport-Environment Problems

This is very significant phase of the present study. Due to continuous growing environmental pollution problem in megacities like Delhi, it is very indispensable to implicate knowledge management practices in transport sector. A number of KM and Non-KM practices has been identified and on the basis of those practices a model has been recommended to minimize the traffic related environmental pollution as well as to reduce traffic congestions. Following findings are pulled out from the study:

(1) For the reduction of traffic noise and air pollution, the suggested KM practices are installation of building codes, prototype expert system, decision support system, expert system, group decision support system and spatial decision support system.

(2) Some of the Non-KM practices have also been discussed to mitigate the above mentioned problem. These practices are limitation of vehicle speed, alternation of roadway surface structure, change in tire design, proper inspection and maintenance of vehicles, green labelling of vehicles, use of catalytic converters, increase in engine efficiency etc.

(3) Traffic congestion is frequent problem in city like Delhi. Proper traffic management is an important asset in this regard. It can help in the reduction of time delay, fuel consumption, traffic noise pollution as well as air pollution also. The required KM practices to handle such kind of situations are KITS approach, FLUIDS intelligent management approach, SCOOT approach, TRYS approach etc.

(4) Likewise some Non-KM practices i.e. intelligent transport system technology, construction of bridges, flyovers, car pooling and use of PTS are also available to lessen traffic clogging.

8.9 Future Vistas of Research

Surface transport noise and vehicular emissions are the critical and challenging global problems and it requires proper attention of people and policy makers. For their mitigation, it is very indispensable to assess the overall condition of present and future scenario from management point of view. The present research study wraps the analysis of ambient noise level, ambient air quality, modelling of road traffic noise, metro rail noise and vehicular emissions at various selected locations along major public transport corridor in Delhi. In addition to this, during the study, noise barrier has also been designed at all the noise pollution affected areas. Application of KM and Non-KM practices in transport sector has been discussed and two KM models have been recommended to reduce the transport related environmental problems. From the entire study and its outcomes, following suggestions are recommended for further research:

(1) In the present study, all the locations are taken at Line 1 of the metro corridor and bus rapid transit corridor, whereas the locations of other metro corridor i.e. Line 2 and Line 3 can also be focused to assess the overall noise and air quality scenario in Delhi.

(2) The measured noise level at different locations in Delhi is the combined noise status of all the vehicles. Noise contribution from different parts of the vehicles can also be evaluated, which can enhance the performance of the developed model.

(3) For the modelling purpose of road traffic noise level, modified FHWA has been used during the study. Along with this, the other available model i.e. CORTN, Stop and GO can also be used to see the different noise scenario at various locations of Delhi.

(4) Development of urban noise mapping studies needs to be done taken into account different types of surface transport noise.

(5) For future study on metro noise in Delhi, in spite of FTA based metro noise model, French and RLS-90 model can also be employed to observe the effect of metro on noise level and on residents.

(6) For modelling purpose and air quality study in capital city, different pollutants i.e. CO, NOx, SO_2, HC and PM have been covered, whereas O_3 needs to be taken to gauge the overall air pollution scenario in Delhi.

(7) Health impact on people living in surrounding areas due to excessive concentration of various pollutants should also be estimated to understand the negative impacts of higher vehicular emission and climate change.

(8) KM and Non-KM practices have been discussed in current study for reduction of environmental pollution. To enhance the consequence of these practices, air and noise quality management plan should be embedded in coming year.

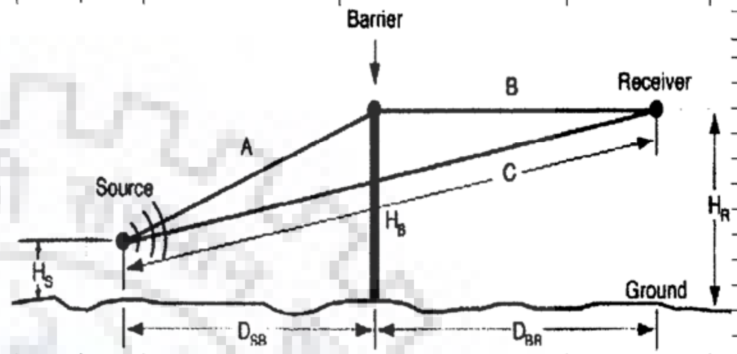
(9) Combined KM practices has been mentioned in present study for the reduction of environmental pollution, whereas these practices can be divided into social, political, e-based, legal and technological (SPELT) practices to get the clear cut understating about various kind of knowledge management practices.

ANNEXURE - I

MODIFIED FHWA HIGHWAY NOISE PREDICTION MODEL (MINI KM TOOL)

Application Distance (m) > 15		Speed	≥	50 kmph																
INPUT PARAMETERS :																				
Site identification:		Location: Delhi		Site:		1			Part of segment angle in °			40.3425								
Dist.: Observer to highway center(m):	30.13	Shielding:				0														
									Type	Site	α	A_F	ϕ							
Segment angle in °:	-81.43		79.94			161.37			1	Hard	0	-0.47	161.37							
									2	Soft	0.5	-0.8	149.382							
Grade:						0														
Vehicle class	Car			Mini bus			Truck			Bus			Motorcycle			Auto			Tractor trailer	
Lane	Near	Far		Near	Far		Near	Far		Near	Far		Near	Far		Near	Far		Near	Far
Speed(KMPH)	52.01	33.31		37.27	34.66		35.57	28.85		38.48	38.19		53.59	39.81		38.65	29.51		0	0
Traffic Volume(VPH)	1009	1058		33	24		5	6		37	36		1621	1145		490	436		0	0
NOISE LEVEL CALCULATIONS :																				
Reference emission level (dBA)	**71.44**	**65.18**		**72.31**	**71.32**		**73.68**	**69.75**		**74.47**	**74.33**		71.00	66.37232		61.85949	61.83369		#NUM!	#NUM!
Flow/Speed adjustment	24.64	26.78		11.23	10.16		3.24	4.94		11.59	11.50		26.57	26.35		22.79	23.46		#DIV/0!	#DIV/0!
Distance adjustment					Near		Far													
					-2.731		-3.308													
Finite segment adjustment							-0.474													
Grade adjustment	NA	NA		NA	NA		0	0												
Shielding adjustments						0														
Hourly Leq	67.88	63.18		55.33	52.70		48.71	45.90		57.85	57.05		69.37	63.94		56.45	56.51		0.00	0.00
Total Hourly Leq in dBA						**73.42**														

MINI KM TOOL TO PREDICT METRO RAIL NOISE AND TO DESIGN BARRIER



INPUT PARAMETERS :

Vehicle Class:	Rapid Transit Vehicle
Ground Type	1
Track type	b
Type of Volume	1
Speed(miles/hour)	50
Passbys(night weighted)	20
Number of Cars (Ncars)	4
Sound Exposure Level(SELref)	82
Average hourly train volume(trains/hour)	20
Number of trains between 7am to 10pm	
Number of trains between 10pm to 7am	
Number of trains in peak hour	
Height of Source from ground(Hs)	42.65
Height of Barrier from ground(Hb)	48.65
Height of Reciever from ground(Hr)	35
Distance of Barrier from Source(DSB)	6
Distance of Barrier from Reciever(DBR)	74.7
Observer Distance,D (feet):	80.7

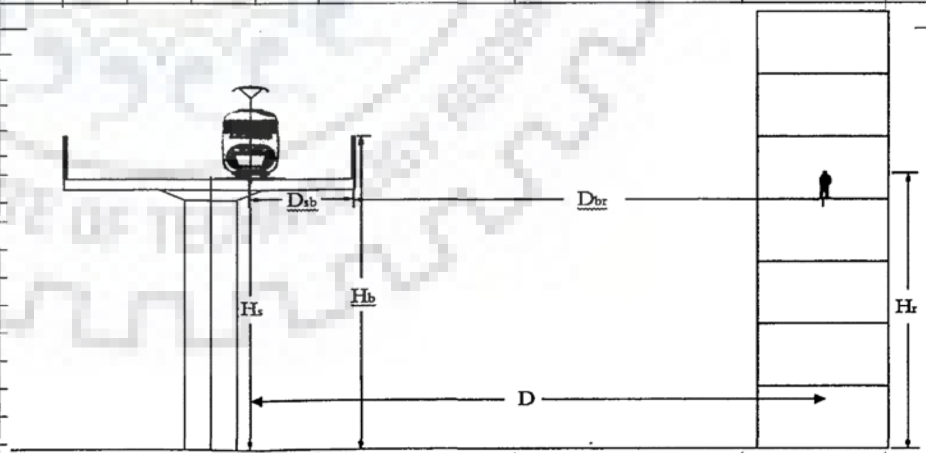
TYPE	GROUND	FACTOR
1	Soft	G
2	Hard	0

S.NO	TYPE	VOLUME
1	Hourly(V)	20
2	Day time(VD)	0
3	Night time(VN)	0
4	Peak hour(VPK)	0

TYPE	TRACK	ADJUSTMENT FACTOR(Cadj)
a	Jointed Rail Track	5
b	Aerial Structure with sl	4
c	Embedded Track on gra	3

NOISE LEVEL CALCULATIONS :

Leq at 15.24 mt (50 feet)	69.4309
Leq at height, Hr	66.2832
Barrier Shielding, Abarrier	21.244
Barrier Insertion Loss,Ashielding	21.244
Final Leq	45.0392



MINI KNOWLEDGE BASED TOOL TO PREDICT CONCENTRATION OF AIR POLLUTANTS

Location :	DELHI
Time :	

INPUT PARAMETERS:

Mean ambient wind speed(m/s), u	1.1
Wind direction, θ	78
Temperature(^{o}k), T	294
Volume(vph), V	439
Length of the source(m), L	542.67
Distance of the receptor from the line source(m), x	12.5
Receptor distance from thr roadway centre line along the line source(m), y	89.6
Stability class	3
Line source height(m), h_0	0.5
Acceleration due to gravity(m/s^2), g	10
Height of receptor relative to ground(m), Z	1.8

Table 1:Parameters Used

Parameter	Stable(A to C)	Neutral (D)	Unstable(E to F)
a	1.49	1.14	1.14
b	0.15	0.1	0.05
c	0.77	0.97	1.33
α	20.7	11.1	11.1
U_1	0.18	0.27	0.27
U_0	0.23	0.38	0.63

Table 2: λ for Different Stability Classes

For stable (A to C) λ =	0.458
For neutral (D) λ =	0.386
For unstable (E to F) λ =	0.301

CALCULATIONS:

a	1.49
b	0.15
c	0.77
a	20.7
U_1(m/s	0.18
U_0(m/s)	0.23
Speed(miles/h),S	18.8

Table 3: value of (sinθ) when θ = 0:

For class (A - D) =	0.224
For class (E - F) =	0.147
When θ=0, sinθ =	0.224
When θ=0, σ_z =	5.822
When θ≠0, sinθ =	0.978147601
When θ'0, σ_z =	2.57
expo. part =	1.163272419
erf.part =	2

1).Calculation of Emission Rate(g/mile-s):

CO pollutant emission factor, E_f	0.555
Emission rate per unit length(g/mile-s),Q	0.068

2).Calculation of Plume Centre Height H(m):

Buoyancy flux, F_1 =	0.042
U (m/s) =	0.404974
Plume rise, h_p =	2.17
Plume centre height(m), H =	2.67

3).Calculation of Dispersion Parameters σ_y,σ_z:

σ_{zt} =	3.45
σ_{yt} =	6.90
λ =	0.46
σ_{ya} =	2.87
Horizontal dispersion parameter,σ_y =	7.47
Vertical dispersion parameter,σ_z =	2.570

4).Prediction of CO/NOx/SO2 Concentration:

Constant A =	0.004884316	
erf 1	177.0912347	
erf 2	353.7201238	
CO/NOx/SO2 Concentration(μg/m^3), C =	0.011363581	g/m^2-mile
=	7.06251E-06	g/m^3
=	7.062511499	mg/m^3

ANNEXURE - IV

MINI KM TOOL TO DESIGN NOISE BARRIER

Application Distance (m) >	15	Speed ≥	50 kmph

INPUT PARAMETERS :

Site identification:		Location:	Delhi				
Dist.: Observer to highway center(m):	21.03						
Distance from source to Barrier (C_1) near&far:	11.25	14.95					
Distance from receiver to Barrier(C_2):		7.93					
Barrier: 1	Barrier ht. in m	4.16					
	Car	Minibus	Truck	Bus	Motorcycles	Auto	Tractor trailer
Source height S_1(m):	0.279	0.54	0.7	0.86	0.34	0.203	0.584
Receptor ht w.r.to Road :	1.5						
Angle subtended by barrier:	-74.76	81.92	156.68	Part of subtended angle in °	39.17		

N	A_B	A_B	A_B	A_B	A_B	A_B	A_B	A_B	A_B	A_B	A_B	A_B	A_B	A_B
<=5.03	-15.63	-15.0185	-15.368	-14.7878	-15.19	-14.64	-15.02	-14.50	-16	-14.97	-15.71	-15.08	-15.32	-14.75
>5.03	-20													

Vehicle class	Car		Mini bus		Truck		Bus		Motorcycle		Auto		Tractor trailer	
Lane	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far
$L_{eq\ hr}$ in dBA 1st Hr	58.53	59.61	48.50	47.16	56.99	57.53	54.893	54.06	58.71	60.62	50.47	50.15	60.17	64.70
	53.50	54.60	38.96	44.15	57.57	55.63	54.69	52.94	60.18	61.77	50.51	50.49	64.27	64.32
	55.50	56.80	41.97	41.14	56.99	57.25	52.93	51.78	61.31	61.16	51.13	49.68	64.03	63.68
	57.30	56.90	41.97	44.15	56.99	58.35	53.77	53.19	60.01	60.76	50.00	50.03	62.14	62.35
	58.70	57.60	43.73	45.12	57.67	57.05	51.88	52.40	58.48	60.17	49.84	49.64	61.72	61.69
	57.60	58.20	45.95	45.12	57.98	57.44	52.26	54.62	57.22	59.26	48.45	49.55	63.18	62.65
	59.30	57.20	38.96	41.14	59.40	59.53	54.02	54.44	58.63	59.58	49.95	49.86	65.34	61.31
	60.78	56.46	45.95	42.90	57.78	58.43	52.93	55.11	59.34	60.62	50.33	50.56	65.87	63.45
	54.67	55.21	44.76	45.87	57.68	58.65	53.76	54.45	58.68	57.87	51.44	50.98	64.78	65.76
	59.30	57.98	43.89	44.64	56.78	58.55	55.67	56.76	60.65	61.54	49.78	50.87	65.76	66.78
	53.90	50.80	45.67	46.43	58.98	57.43	54.76	56.45	59.45	58.65	51.56	56.76	65.86	64.67
	57.89	52.30	43.21	43.67	57.87	58.65	57.78	57.64	58.87	61.50	57.76	58.85	66.56	65.98
$L_{eq\ 12hr}$ in dBA	**59.541**	**58.47**	**46.19**	**46.40**	**59.55**	**59.74**	**56.17**	**56.60**	**61.19**	**62.20**	**53.53**	**54.57**	**66.27**	**66.02**

NOISE LEVEL CALCULATIONS :

Noise path geometry (m)	Car Near	Car Far	Mini bus Near	Mini bus Far	Truck Near	Truck Far	Bus Near	Bus Far	Motorcycle Near	Motorcycle Far	Auto Near	Auto Far	Tractor trailer Near	Tractor trailer Far
A	11.90	15.45	11.82	15.38	11.77	15.35	11.724	15.30988	11.88	15.43	11.93	15.46	11.80	15.37
B	8.36	8.36	8.36	8.36	8.36	8.36	8.3642	8.364239	8.36	8.36	8.36	8.36	8.36	8.36
C	19.22	22.91	19.20	22.90	19.20	22.89	19.191	22.88895	19.22	22.91	19.22	22.92	19.20	22.90
Pathlength difference	1.05	0.90	0.98	0.85	0.94	0.82	0.90	0.79	1.03	0.89	1.07	0.91	0.97	0.84
Fresnel No. N	3.36	2.88	3.14	2.72	3.01	2.62	2.88	2.52	3.31	2.84	3.42	2.93	3.10	2.69
Barrier adj(dBA)	-15.62998	-15.0185	-15.36801	-14.78777	-15.19288	-14.64	-15.02	-14.4958	-15.5682	-14.96505	-15.71	-15.0845	-15.316	-14.748
Hourly Leq	43.91	43.45	30.82	31.62	44.36	45.10	41.15	42.10	45.62	47.24	37.82	39.48	50.95	51.27

Total Hourly Leq in dBA	**57.00**

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