MODELLING AND EVALUATION OF AMBIENT AIR QUALITY LEVELS DUE TO MIXED TRAFFIC ON CITY ROADS

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DOCTOR OF PHILOSOPHY

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BY

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CERTIFICATE

This is to certify that the thesis entitled **MODELLING AND EVALUATION OF AMBIENT AIR QUALITY LEVELS DUE TO MIXED TRAFFIC ON CITY ROADS** is a bonafide record of original research work done by **Ms. CINI A.** under our supervision and guidance. The thesis is submitted to the University of Calicut for the award of the degree of **Doctor of Philosophy** in Civil Engineering. The matter contained in the thesis has not been submitted elsewhere for any degree.

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I hereby solemnly declare that the work presented in the thesis entitled **MODELLING AND EVALUATION OF AMBIENT AIR QUALITY LEVELS DUE TO MIXED TRAFFIC ON CITY ROADS**, submitted to the University of Calicut for the award of degree of Doctor of Philosophy, is a bonafide record of fully independent and original research work carried out by me at the Department of Civil Engineering, Regional Engineering College, Calicut-673 601 under the guidance of **Dr. Prasad,V.S.**, and **Dr.Nagaraj,B.N.**, during the period 1994-1999.

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DEDICATED TO

MY PARENTS, HUSBAND

AND

MY LITTLE SON NANDU

ABSTRACT

It has been generally established in the literature that about 60 per cent of the air pollution in many of our cities are due to the automobile exhaust emissions. At present, in the planning and designing of our highways, Economy and Safety of the traffic are given overriding importance and only cursory attention is being given to environmental problems that arise due to road traffic. These are problems whose detrimental effects at the best could only be minimised, though not completely eliminated, if their causes are understood at the planning stage itself and remedial measures are incorporated during the design phase. For such a type of rear-guard action, we need development of mathematical models to explain pollution concentrations in terms of causal variables and for evaluating the air quality.

Normally, Guassian dispersion models or their variants are used for prediction of pollutant concentrations and the literature is flooded with different types and forms of theoretical models for prediction of pollutant concentrations. The basic principles, the simplifying assumptions and the criticisms of these dispersion models, are well documented in the literature(Matzoros,1990).

Clean Air Act Amendments(CAAAs,1990) warrant continuous and co-ordinated air quality monitoring adjacent to heavily used travel corridors. In order to facilitate the assessment of air quality levels, models for air quality prediction which incorporate the traffic parameters like the speed, the volume, the composition, etc., are necessary to be established. These types of models are also required for the design and evaluation of alternative traffic management schemes.

However, the traffic system, in mixed mode environment, is transient in nature. That means, the variables like the speed, the composition and the volume of traffic change from instant to instant and the concentration of the pollutants at a particular instant is not only a function of those influencing variables at that instant and but also of the levels of the pollutants at some previous time intervals as well. Inclusion of such system changes and dynamic variations is possible by the use of econometric models, which have both cross sectional and time series components.

The sequence of the traditional four stage Urban Transportation Analysis of trip generation, trip distribution, modal choice and traffic assignment has remained relatively static for decades. However, the present day requirement of the assessment of impact of transportation system on the environmental quality for system selection, requires, the preparation of the Environmental Impact Assessment (EIA). This necessitates the development of models, which integrate the models of traditional Urban Transportation Planning System packages with models of air quality for prediction and evaluation of Ambient Air Quality near highways.

The main objectives of this study were:

i) the demonstration of usefulness of the combination of the time series based transfer function models with operational models for prediction of ambient air quality near highways, for evaluation of not only the existing traffic management scheme, but also many of the alternatives, which could be generated from other considerations.

ii) To develop procedure for the determination of traffic capacity standards of highways so that the recommended warrants of Clean Air Act Amendments are not violated.

The scope of the study was restricted to the development of capacity standards for two lane urban and semi-urban roads in mixed mode environment. For this purpose, Calicut city (a Coastal town of Kerala, India) was selected as the study area. The data required for this study were obtained by field surveys conducted at different locations within the study area. For modelling and evaluation purposes, the concentration of **Carbon monoxide(CO), Hydro carbons(HC) and Nitrogen oxide(NO)** were measured near highways, using, instrumentation generally used by Environmental Pollution Control Boards.

To obtain a fair idea about the air quality levels within the study area, a pilot survey was conducted in the first stage of this study. Using the data obtained from pilot survey, ambient air quality levels on the road network were predicted by the Guassian Dispersion model with its variants suggested by Transport Road Research Laboratory, London(TRRL,1982) and U.S.Environmental Protection Agency(U.S.EPA,1980). From the Evaluation of those models, it was established that the pollutant concentrations as predicted by them deviated very much from the actuals, which warranted calibration of models based on other hypotheses. Simultaneously, it was also established through causal models that the meteorological parameters were statistically less significant in the prediction of ambient air quality near highways. A comparison of observed data with National Ambient Air Quality Standards(NAAQS) showed that at most of the locations in the Calicut city, the level of pollutant concentrations exceeded the permissible values.

Mathematical models were then developed for prediction of pollution concentrations near highways, by combining the effects of traffic stream variables(Causal models) and the transient variations predicted by time series based transfer function modelling approach.

While, the travel demand data were generated using the link volume modelling philosophy of Low(1972) and the NIPTAC-NODIAC models developed by Nagaraj, et al.(1988 and 1990), the assignment model of SATURN(Simulation and Assignment of Traffic on Urban Road Network) package was used for prediction of traffic volumes required for evaluation of air quality levels.

The integrated models developed were then used for the evaluation of existing and alternate routing patterns of Calicut city for the air quality levels. A comparison of the predicted pollution concentrations with NAAQS indicated that the Carbon monoxide, the Hydrocarbon and the Nitrogen oxide concentrations exceeded the permissible values in the City of Calicut at 41, 61 and 24 roads, respectively. Based on this evaluation, several alternate routing patterns for vehicles were generated and an alternative which is found to be efficient not only from the point of view of traffic flow, but also from the point of view of limiting the ambient air quality within acceptable limits, has been developed.

A strategy for development of Environmental Capacity Standards for highways was then developed and used for two lane mixed mode environment of Calicut city. It has been observed that the Environmental Capacity of Calicut City roads are in the range of 50-75 percent of the traffic capacity.

The limitations and scope for further research are the other highlights of the thesis report.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Cini A. “Modelling and evaluation of ambient air quality levels due to mixed traffic on city roads” Thesis. Department of Civil Engineering ,Regional Engineering College, University of Calicut, 1999

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Traffic in general, has been identified as one of the major sources of air pollution, especially in urban areas. However, the attempts made in the prediction and the evaluation of air quality levels due to road traffic have not been found to be successful, because, the emission and the dispersion of pollutants depend on many factors like, the volume, the speed and the composition of traffic, the speed and the direction of the wind, the atmospheric conditions, the acceleration and the deceleration of vehicles, etc. In India, very few attempts have been made in the prediction of the ambient air quality levels near highways, incorporating all those influencing variables.

Clean Air Act Amendments(CAAAs,1990), warrant a continuous and a coordinated air quality monitoring adjacent to heavily used travel corridors. In order to facilitate the assessment of the air quality and modelling of concentration of air pollutants, incorporation of the effects of the various stream parameters like, the volume, the speed and the composition of the traffic, etc., becomes necessary. Such types of models are also required for the design and the evaluation of Traffic Management Measures, which are implemented in urban areas.

The Indian Road Congress(IRC) has brought out a publication on Guidelines for Environmental Impact Assessment of Highway Projects(IRC,1990). This has signalled a beginning in the systematic Environmental Impact Assessment study for the highway projects in India.

The prime aim of this research is to develop mathematical models for the prediction of ambient air quality near highways and to use those models for the development of Environmental Highway Capacity Standards which are aimed at limiting the concentration of the pollutants within acceptable limits.

1.2 GENESIS OF THE STUDY

There are very few attempts made in the development of models, which are aimed at the establishment of Environmental Capacity Standards. Even those models that are developed have been found to be limited to the prediction of concentration of pollutants. But such models are only useful for predicting the level of various pollutants for different Traffic Management Measures that are implemented.

Calicut is one of the fastest growing cities of Kerala State, which has great historical significance, as well as, commercial importance. This city is located on the West Coast of India. This is connected to other cities of Kerala and of other States of India, by road, rail and air. Fig 1.1 shows the map of the study area. This city has also registered a phenomenal increase in the vehicular population during the last few decades. This tremendous growth of vehicular traffic, coupled with lack of basic road infrastructure for transportation has contributed to the deterioration of environment of the city drastically. The scattered bus terminii, the number of railway crossings inside the city, insufficient width of roads, etc., are some of the causes, which create bottlenecks for the smooth flow of traffic. Because of the above mentioned factors, the emissions from the road vehicles increase. According to the studies conducted by the Kerala State Pollution Control Board, at a few locations within the city of Calicut, the level of pollutants far exceed the limit prescribed by the NAAQS.

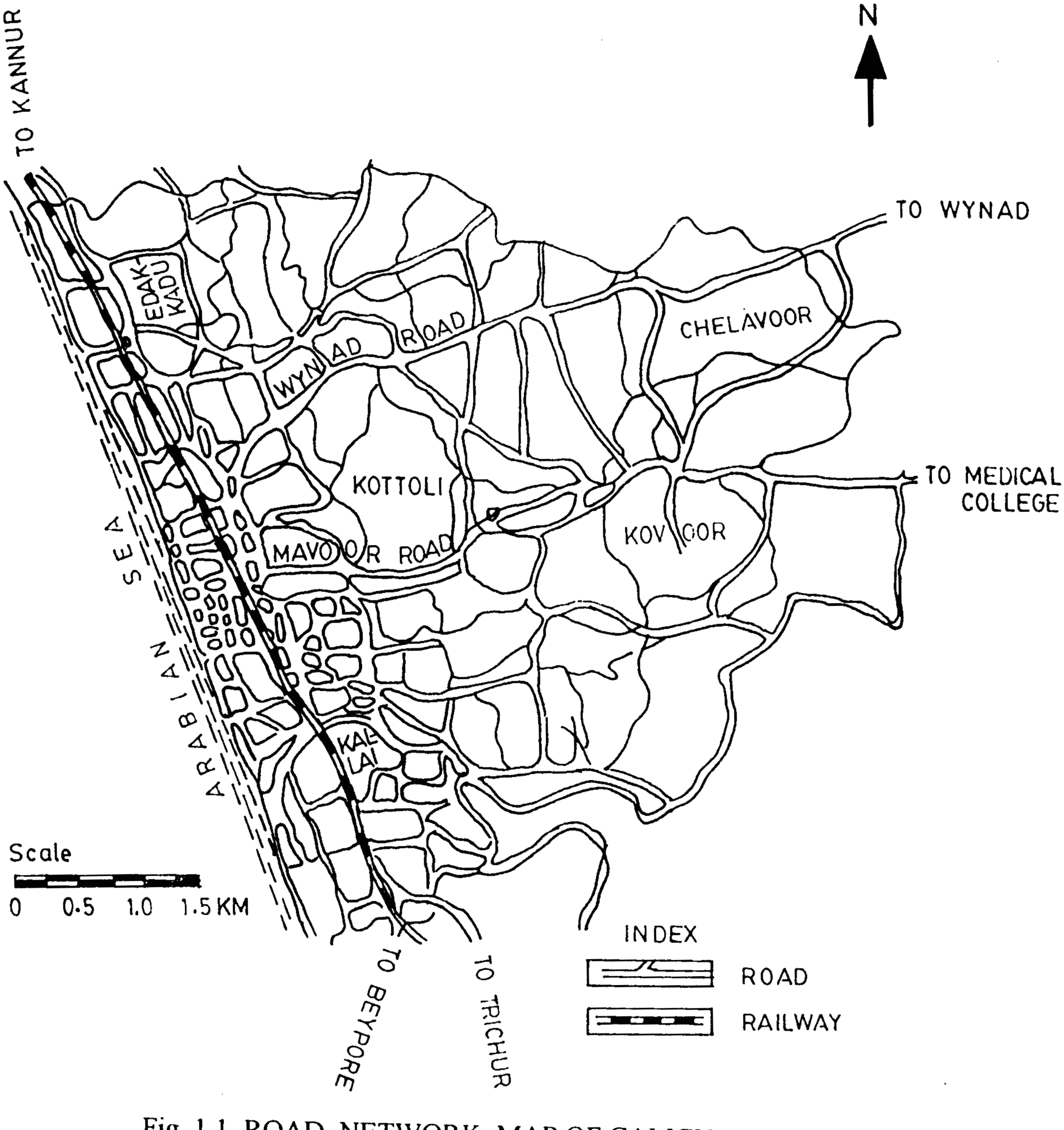

Fig. 1.1 ROAD NETWORK MAP OF CALICUT CITY

1.3 IMPORTANCE OF AUTOMOBILE EXHAUST EMISSION STUDIES IN TRANSPORTATION PLANNING

Fig. 1.2 gives the percentage contribution of different pollutants from various sources (Liptak,(1974)). As it is evident from the diagram, automobiles contribute significantly to air pollution. The main pollutants from the automobile exhaust are the carbon monoxide(CO), the hydro carbons(HC), the oxides of nitrogen(NO_x), the oxides of sulphur(SO_x), and the emission of free lead into the atmosphere.

Various studies show that among the contributing factors, the transportation accounts for 60-70 per cent of the total carbon monoxide, 45-55 per cent of the hydro carbons and 30-45 per cent of the nitric oxide emissions. There are at present, in India, more than 80 lakh vehicles cruising through the road network. Nearly 70 per cent of these vehicles are two wheelers used by the private owners and the rest are the public transport vehicles such as the autos, the taxies, the buses and the goods vehicles. The presence of those pollutants in the atmosphere, in excess quantities, results in adverse effects on human and plant life. Therefore, it is necessary to develop different measures to control those pollutant levels within the acceptable limits. For the development of such control measures, mathematical models are required for the prediction of ambient air quality, which incorporate the traffic stream variables also.

1.4 NEED FOR MODELS FOR THE PREDICTION OF POLLUTANT CONCENTRATION DUE TO ROAD TRAFFIC

In the earlier transportation studies, the important factors that were taken into consideration at the time of planning and designing of transport systems were economy and safety of the traffic flow and only cursory attention was given to environmental issues. Of late, there is a realisation that the environment is an

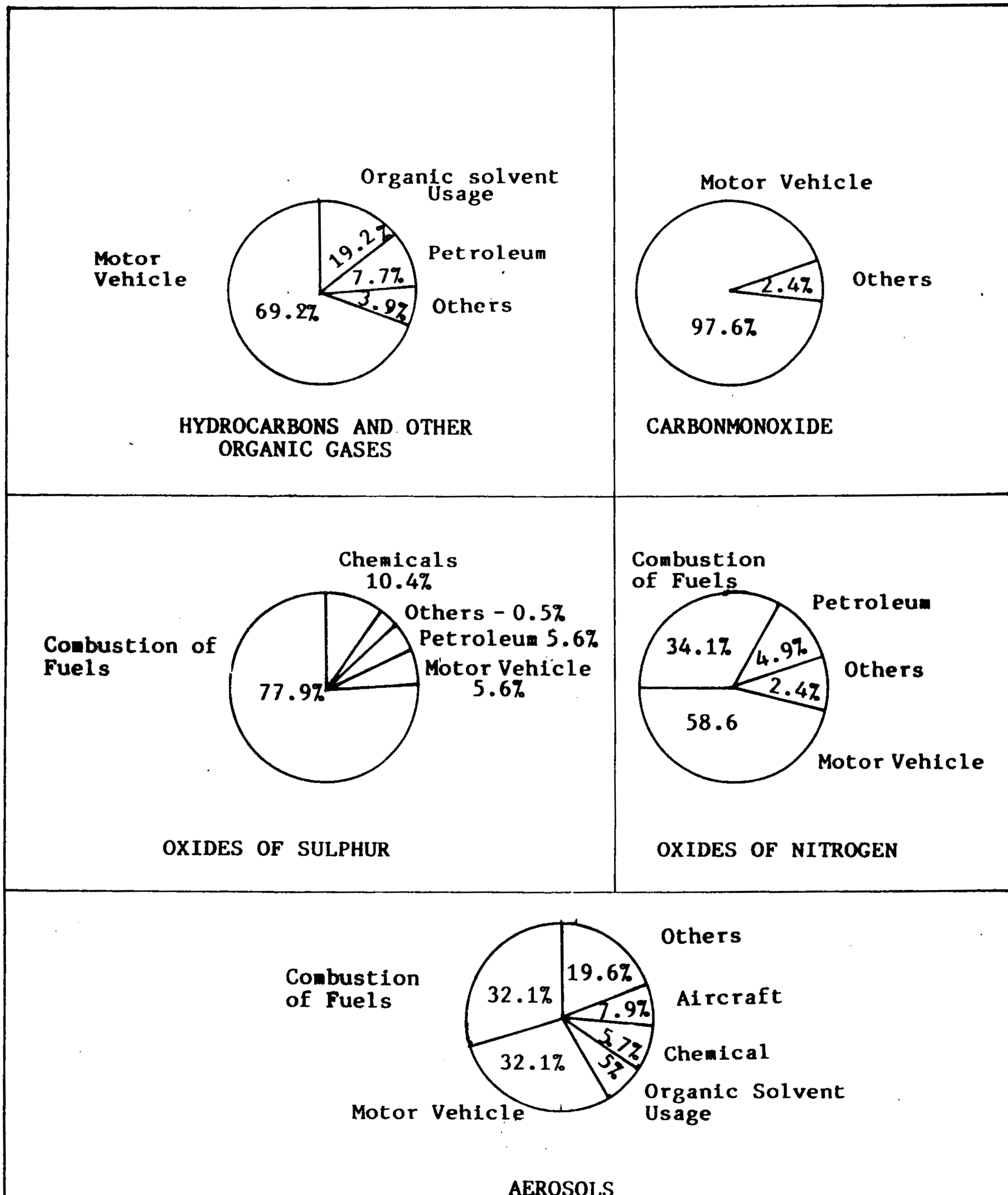

Fig.1.2 PERCENTAGE CONTRIBUTION OF POLLUTANTS FROM VARIOUS SOURCES [source : Liptak 1974]

important factor that has to be considered by highway engineers. When the urban mobility and the accessibility increase, the quality of the environment gets deteriorated more and more. Therefore, it was found necessary to develop different measures to control the pollutant levels within the acceptable limits.

Over the years, a number of Traffic Management Measures(TSMs) have been developed and implemented in our cities to control the urban congestion, based, purely on considerations other than those related to the environment. However, a stage has been reached in our cities, in which we can no longer neglect the environmental effects of many of those traffic management measures. Development of models relating pollutant concentrations with traffic system variables and meteorological variables have thus become necessary to test and select appropriate traffic system management scheme/schemes for the cities.

1.5 IMPORTANCE OF ESTIMATION OF TRAVEL DEMAND THROUGH SIMPLIFIED TECHNIQUES

To limit the pollutant concentrations within acceptable limits in the city, it is essential that appropriate steps are taken to ensure smooth flow of traffic on the city road network, using suitable traffic management measures. There are very many traffic management measures that are usually adopted in the cities. Many of those Traffic System Management strategies are being implemented without examining the environmental implications. It is necessary to predict the resulting traffic stream variables for each of those traffic management measures and the corresponding pollutant concentrations.

Traffic on the road network for those management measures can however be obtained only when one has a good estimate of an Origin and Destination (O-D) matrix. This matrix, when loaded on the network using suitable assignment technique will provide the requisite link volume counts. SATASS is one such assignment model of SATURN package, which will provide the link volumes, following Wardrop's first principle. Nagaraj et al.(~~1988~~ 1984 and ~~1990~~ 1986) have reported that the NIPTAC-NODIAC package developed by them could provide good seed O-D from link volume counts, incorporating the known basic travel characteristics as well as the urban structure specifications. It was therefore expected that NIPTAC-NODIAC package would provide the seed necessary for the assignment technique of SATASS in SATURN.

1.6 STATE - OF - THE – ART

Today's standard transportation planning techniques do not have sufficient refinement in-built into them for the assessment of air quality. There is a need to develop integrated models which combine traffic prediction models with models for prediction of air quality, which are useful for design and evaluation of alternate Traffic Control Measures to limit the resulting ambient air quality levels within the permissible limit. The models and the concepts available in the literature, which address towards air quality assessment, are mostly based on the basic Gaussian Dispersion theory.

Gaussian dispersion models and their derivatives are normally used for predicting the pollution levels at different points due to an emission from a source. Although, Gaussian models have serious limitations, they are being used for the prediction of pollutant concentrations. In the case of road traffic however, the system characteristics continously change from one instant to another and therefore we can also expect that the resulting pollutant concentrations to change. That means, variables like the speed, the composition and the volume of traffic and therefore the pollutant concentrations at any instant must be a function of not only those traffic stream variables at those instances but also concentration of those pollutants at a few previous time periods as well. The incorporation of such variables is difficult by the theoretical models like the standard Gaussian dispersion models. Inclusion of such system changes is possible only through a combination of causal and the time series based transfer function modelling approaches.

1.7 GAP IN THE LITERATURE

The work of Sawaragi, et al.(1979) for the statistical prediction of air pollution levels using non physical models, the work of Peterson(1980) on highway air pollution model(HIWAY-2), Hickman and Colwill's(1992) study for the effects of the moving vehicles on the pollutant concentrations and the work of Matzoros(1992) on modelling of air pollution from road traffic are some of the important works reported in the field of road traffic pollution modelling. Unfortunately, all those models were developed for nearly homogeneous traffic flow conditions and hence their use for predicting the actual pollutant concentrations in the mixed traffic flow conditions prevailing in our country is severely restricted. Hence there is an urgent need for the development of comprehensive models which are capable of not only predicting the pollutant concentrations but also help in the development of Environmental Capacity Standards.

1.8 NEED FOR INTEGRATED ECONOMETRIC MODELS

The traffic system, in mixed mode environment, is transient in nature. That means, the variables like the speed, the composition and the volume of traffic, etc., change from instant to instant and the pollutant concentrations at a particular instant is, not only a function of the influencing variables at that instant but also their levels at some previous time intervals as well. Inclusion of such system changes and dynamic variations is possible only by econometric models which have both cross sectional and time series components.

1.9 OBJECTIVES AND SCOPE

From the review of the literature it has been found that Gaussian Dispersion Model or its derivatives are normally used for predicting the air pollution due to road traffic. For the evaluation of traffic Control measures for limiting the air quality within the permissible levels, we require models that integrate both the effects of traffic stream parameters as well as air quality levels at previous time intervals. Therefore, the prime objective of this research work was to explore the possibility of building integrated models for the prediction of ambient air quality levels due to mixed traffic near city roads. Within this broad scope, the following objectives were identified for this research work:

i) To review the available techniques and to identify the proper technique(s) suitable for the prediction of ambient air quality near city roads.

ii) To conduct Pilot Surveys for getting a general idea about the air quality levels within the study area.

iii) To estimate the ambient concentration of the pollutants emitted from the motor vehicles, using models based on Gaussian dispersion Theory and their derivatives and to critically evaluate the performance of those models against the field data.

iv) To conduct detailed field surveys for collecting the data required for the study.

v) To examine the possibility of development of models for predicting the pollutant concentrations as a function of the traffic stream variables(regression models) and to combine this with time series based models, if necessary, to take care of lagged responses in relation to time.

vi) To develop O-D matrices of vehicles from a few link volumes and to predict traffic flow on links of the network using the assignment technique in SATURN package.

vii) To develop models integrating traffic assignment models and air quality prediction models for the prediction of air quality levels near city roads for different traffic control measures.

viii) To evaluate the existing and alternate routing patterns by the use of the air quality levels predicted by the integrated models.

ix) To develop procedure for the determination of Environmental Capacity Standards of urban and semi-urban roads so as to limit the resulting ambient air quality to the National Ambient Air Quality Standards.

x) To suggest scope for further research work based on the studies conducted.

A Research frame work which was developed for modelling and evaluation of air quality levels due to mixed traffic near city roads is presented in Fig. 1.3.

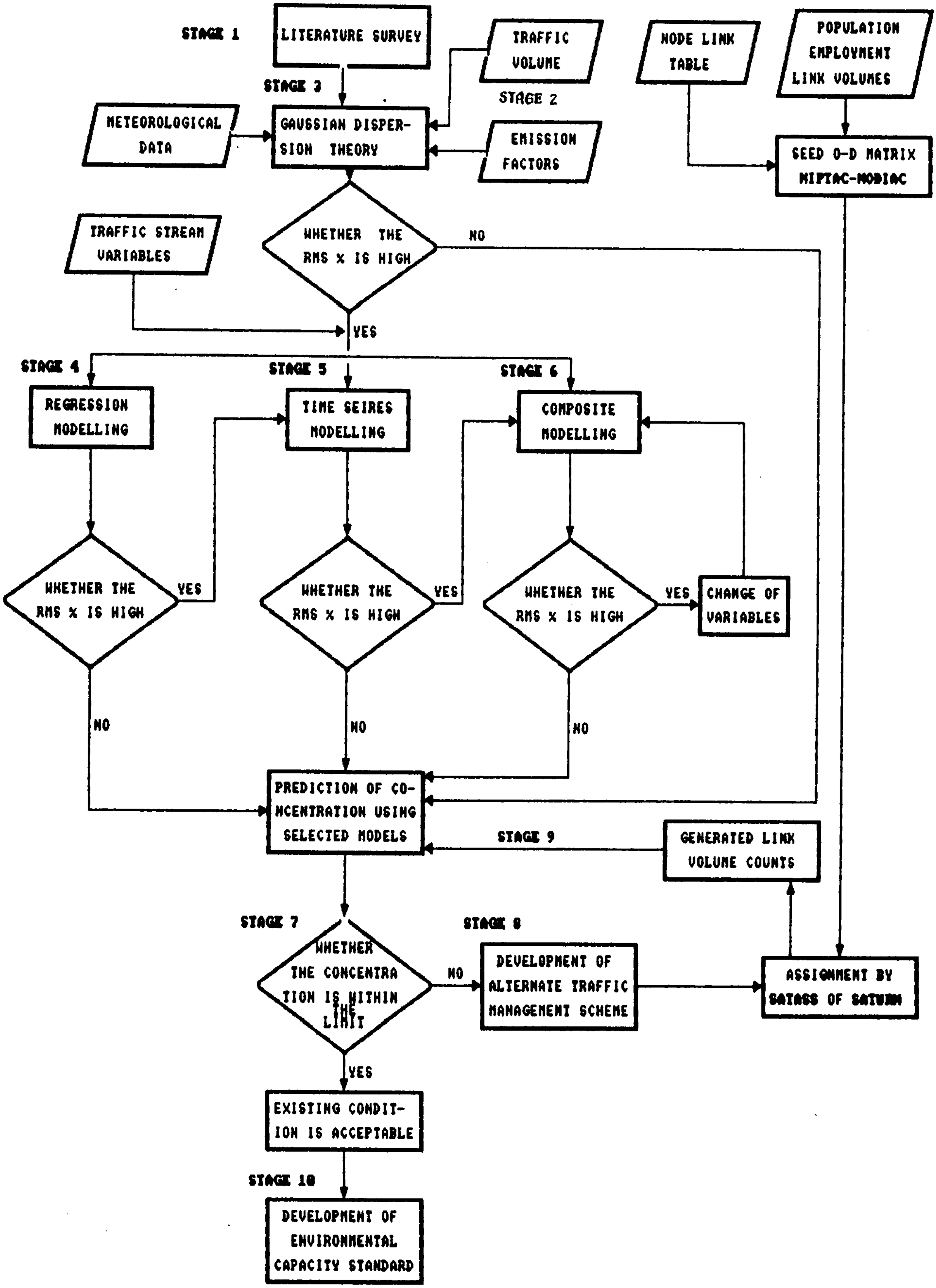

FIG. 1.3 FLOW CHART FOR THE RESEARCH FRAME WORK

1.10 REPORT ORGANIZATION

Including **Introduction**, there are nine Chapters in this research report. **Chapter 2** on **Literature Review**, while presenting the review of the air pollution problems due to road traffic, discusses the factors affecting the dispersion of pollutants. It also reviews the various modelling procedures available for the prediction of ambient air quality near highways. **Chapter 3** on **Pilot Survey and Applicability of Dispersion Theory,** while presenting the results of preliminary test surveys carried out for assessment of air quality due to road traffic in Calicut city, also elaborates on the investigation of the use of Guassian and its derivative models for predicting the ambient air quality levels. The need for the development of models, which was felt for combining the causal and time series approaches, is also established in this chapter. **Chapter 4** on **Data Collection and Analysis,** presents the systematic procedure that was adopted for data collection and efforts put forward to explain the ambient air quality levels due to identified causal variables of traffic system. **Chapter 5** on **Development and Validation of Models for Predicting Concentration of Air Pollutants**, presents the procedures used for the development of mathematical models for the prediction of ambient air quality levels due to mixed traffic conditions near city roads by combining the traffic flow variables and the pollutant concentrations predicted using the time series based transfer function modelling approach. **Chapter 6** on **Modelling and Evaluation of Air Quality Levels Due to Mixed Traffic on City Roads** presents the procedure that was used for integrating traffic and air quality models for the prediction of ambient air quality levels near highways. It also presents the procedure used for the evaluation of existing road network for ambient air quality levels. **Chapter 7** on **Generation and Evaluation of Alternate Routing Patterns of Vehicles** presents the procedure used for development and evaluation of alternate routing patterns of traffic for Calicut city for satisfying the recommended traffic and air quality standards. The procedure used for the development of Environmental Capacity Standards to limit the pollutant concentration levels within in acceptable limits is presented in **Chapter 8** on **Further extension towards the Development of Environmental Capacity Standards. The Summary, the Conclusions, the Limitations and Scope for Further study** are presented in **Chapter 9.**

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LITERATURE REVIEW

Cini A. “Modelling and evaluation of ambient air quality levels due to mixed traffic on city roads” Thesis. Department of Civil Engineering ,Regional Engineering College, University of Calicut, 1999

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The environmental problems created by road traffic have been well documented in the literature. This chapter presents a brief review of the existing models that was prepared for the prediction of air pollution from the road traffic, in which, existing atmospheric dispersion models and the factors affecting the dispersion of air pollutants were taken up. The purpose of this chapter is to describe the effort that was put in to identify the areas of weakness in the current modelling procedures and to highlight a possible alternative.

2.2 CONSTITUENTS OF AUTOMOBILE EXHAUST

Traffic in general, has been identified as a major source of air pollution in urban areas. The two types of automobile vehicles responsible for the emission are the gasoline powered internal combustion engines and the diesel engines. The number of gasoline powered vehicles are very high compared to that powered through diesel. Therefore, the major portion of the pollution emitted is by gasoline engines.

Carbon monoxide, hydrocarbons, nitrogen oxides, sulphur oxides and particulate matter emitted by moving vehicles, cause, air pollution, affecting public life, vegetation and materials (IRC(1990)). Various studies show that among the different contributing factors, the transportation accounts for 60-70 per cent of the total carbon monoxide, 45-55 per cent of the hydrocarbons and 30-45 per cent of nitric oxide emissions (Liptak(1974)). The identified effects of various pollutants on health of human beings are given in Table 2.1 (Perkins(1974)). National Ambient Air Quality Standards for various pollutants are developed by different agencies in different countries. In India, the Central Pollution Control Board (CPCB(1991)) has developed air quality standards for different pollutants. The purpose of these standards is to limit the concentration of pollutants to certain chosen level, so as to avoid undesirable effects. Table 2.2a and 2.2b give the limits for the pollutants, as stipulated by the concerned agencies in different countries based on their experience (Liptak(1994), and CPCB(1991)).

2.3 IMPORTANCE OF AMBIENT AIR QUALITY PREDICTION MODELS IN TRANSPORTATION PLANNING

At present, in the course of planning and designing a highway, the main aspects that are taken into account are those of economy and safety of the traffic flow, and very little attention appears to be given to many environmental problems that arise due to transportation. Such problems can be avoided if their causes are understood at the planning stage itself, and the remedial measures incorporated during the design phase. The IRC has recently brought out a publication on 'Guidelines for Environmental Impact Assessment (EIA) of Highway Projects'(IRC(1990)). This marks a beginning of systematic EIA study for highway projects in India. EIA is a procedure for bringing out the potential effects of human activities on environmental system.

Number of Traffic System Management Measures have been developed and implemented in our cities to control urban congestion, based purely on considerations other than those related to environmental issues. However, a stage has been reached in our cities, wherein, we can no longer neglect the environmental effects of many of these traffic management measures.

Table 2.1 EFFECTS OF POLLUTANTS FROM AUTOMOBILE EXHAUST

Sl.No.	Pollutant	Principal Effects
1	Carbon monoxide	Reduction in Oxygen absorbing capacity of blood in lungs
2	Hydro carbons	Lung cancer
3	Nitrogen oxides	Pulmonary irritation and Pulmonary hemorrhage
4	Suphur dioxide	Sensory and respiratory irritations, cough, shortness of breath
5	Lead compounds	Lead poisoning
6	Suspended	Sensory irritations, particulate visibility reduction etc.

Table 2.2(a) AMBIENT AIR QUALITY STANDARDS [source : Liptak 1974]

Pollutants	California Standards	Federal Standards
Carbon monoxide	10ppm(8hr) 40ppm(1hr)	9ppm(8hr) 25ppm(1hr)
Nitrogen oxide	0.25ppm(1hr)	0.05ppm(1hr)
Sulphur oxide	0.04ppm(24hr) 0.5ppm(1hr)	0.14ppm(24hr) 0.5ppm(3hr)
Hydrocarbons (corrected for methane)		0.24ppm
Lead compounds	1.5μg/m^3	

Table 2.2(b) MINIMUM NATIONAL AIR QUALITY STANDARDS, INDIA, CPCB(1990)(MINAS) [source : Liptak CPCB 1991]

Area	Category	Parameters (μg/m^3)			
		SPM	SO_2	CO	NO_2
A	Industrial and mixed used area	500	120	5000 (5ppm)	120 (0.06ppm)
B	Residential and Rural areas	200	80	2000	80
C	Sensitive area	100	30	1000	30

Sensitive areas - Hill stations, Forests, Sancturies, National parks, National monuments, Health centers etc.

Conventional Urban Transportation Planning System(UTPS) type model use a standard four stage process, estimating the trip production and attraction between zones, assigning the generated trips to zone to zone movements, assigning zone to zone trips to specific travel modes and assigning the vehicles trips to specific links on a network. The UTPS-type models are useful for estimating the future transportation demand. However, those models are not adequate to provide accurate vehicle activity estimates for air quality planning. Hence, the improvement to UTPS type models for air quality planning is necessary.

In **Traffic in Towns**, Buchanan(1963) introduced the concept of the environmental capacity of streets to cope with the traffic. This is a notion which has been with us ever since, but has not been developed into a practical and usable tool.

In all the above explained situations, we require mathematical models for the prediction of pollutant concentrations that are functions of traffic stream variables. Such models will be useful for the preparation of EIA, design and evaluation of Traffic Management Measures and for the development of environmental capacity. Following sections, present a brief review of mathematical models taken from the literature, their advantages and disadvantages.

2.4 FACTORS AFFECTING AMBIENT AIR QUALITY

Before reviewing the various components of the road transport pollution modelling process, it was of interest to summarise briefly the factors that affect the rates and concentrations of harmful emissions from the road vehicles. The purpose of this was to identify the key factors and relationships that should be included in the modelling of air pollution from the road traffic. In general, three major categories of factors were found to affect the levels and the concentrations of emissions from the road traffic. These were related to the vehicle, the traffic and the meteorological factors.

2.4.1 Vehicle Characteristics

Among the vehicle characteristics that affect emission levels, the engine type, the age and the maintenance of the vehicles are important. The main types of vehicles that are found on our roads are:

i) Passenger cars powered by four stroke gasoline engines.

ii) Motor vehicles, scooters and autorickshaws, powered mostly by small two stroke gasoline engines.

iii) Buses and trucks powered by four stroke diesel engines.

The principal source of emission in automobiles is the internal combustion engine. The following types of ignition are employed in I.C. engines:

i) Spark ignition, which uses petrol or gasoline exclusively for light vehicles and passenger cars.

ii) Compression ignition, which uses diesel oil (used in trucks and locomotives).

Internal combustion engines are again classified as two-stroke and four-stroke engines depending on the number of strokes of the piston required to complete one cycle. The products of combustion from the internal combustion engine cylinder are directly discharged into the atmosphere as exhaust emissions.

The constituents of exhaust gas from petrol and diesel engines are almost identical except that the former is known for its larger content of carbon monoxide and the latter for smoke. Apart from this major source of pollution, there is also a possibility of pollution from the fuel tank, the carburetor and the crank-case, which are essential components of any IC engine.

As for the age and the maintenance, emission rates tend to increase as the vehicle ages. This is due to the normal wear and tear of the engine parts and the inadequate maintenance. The composition of exhaust also depends on the variables like the air fuel ratio, the speed and the engine conditions etc. Driving conditions play a major role with exhaust emission: high in carbon monoxide at low and idling speeds and high in oxides of nitrogen at high engine speeds. At low speeds, especially when cold and the fuel mixture are fuel rich, incomplete combustion is common, resulting in the formation of more carbon monoxide. The amount of hydrocarbon emission is more during the acceleration and the deceleration of vehicles.

2.4.2 Traffic Stream Characteristics

It has been reported in the literature that the pollution levels generally increase with the increase in traffic volume and decrease with the speed for pollutants like the carbon monoxide and the hydrocarbons. But in the case of nitric oxide the concentration increases with the increase in average speed up to a certain level and then decreases. For a stream of traffic, the concentrations of emissions tend to be high near congested roadways and other locations where traffic densities are high. Figs. 2.1 and 2.2 (Hazim et al.(1988)) show the variations in concentration of HC and NO in automobile exhaust with traffic volume and speed.

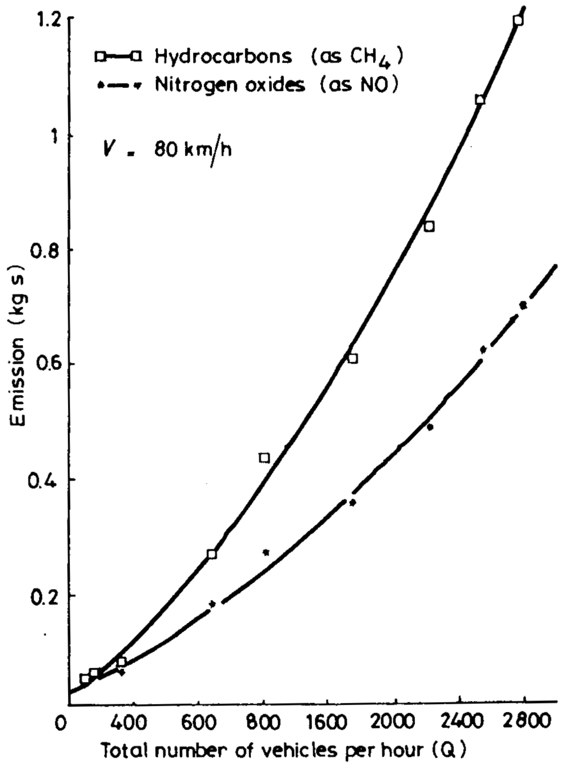


Fig. 2.1 Emissions of pollutants corresponding to the total number of vehicles per hour

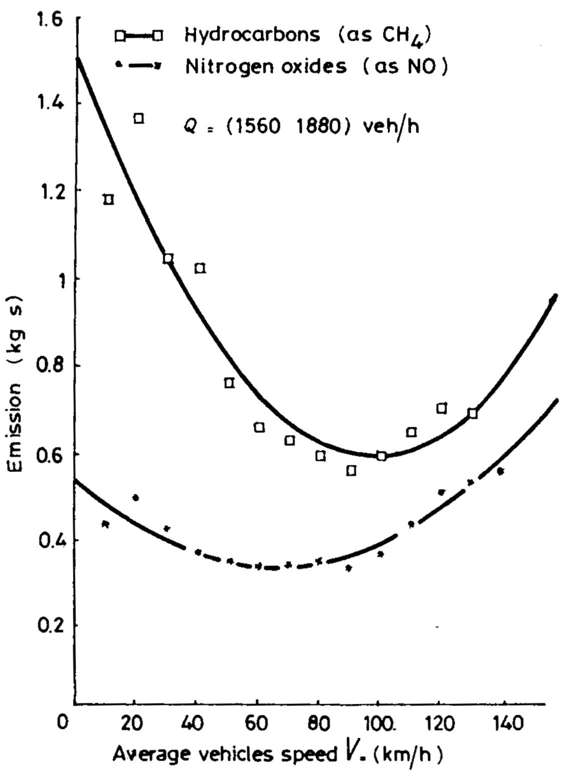


Fig. 2.2 Emissions of pollutants corresponding to the average vehicles speed

2.4.3 Meteorological Factors

Meteorological factors, which influence the diffusion of pollutants, are the wind speed and the direction, the atmospheric stability, the ambient temperature, the humidity, the precipitation, and others. The rate of dilution and the travel time of air pollutants depend upon the wind speed and the direction. The concentration of pollutants is usually higher downwind of an emission source than upwind of the source. Increase in wind speed reduces the amount of time any given air parcel spends in the vicinity of an emission source, thereby reducing the pollutant concentration in that parcel.

Atmospheric stability serves as an index of atmospheric turbulence. It is the ability of the atmosphere to disperse the pollutants emitted into it. Based on experimental observations of dispersion of pollutants, Pasquill and Gifford(1976) devised a guide for the selection of stability categories. These are presented in Table 2.3. Here stability categories are named as A,B,C,D,E and F. The stability categories A. B, and C are categorized as unstable, stability category D is categorized as neutral and stability categories E and F come under stable condition.

2.5 MODELS FOR THE PREDICTION OF AMBIENT AIR QUALITY LEVELS

When the pollutants are emitted into the atmosphere, they are immediately diluted, transported and mixed with the surrounding air. The problem of prediction and control of air pollutant concentration is considered as an important problem because its concentration causes dangerous effects on human health. When we try to predict the concentration with accuracy and to control it in such way that the predicted value

Table 2.3 KEY TO STABILITY CATEGORIES

Wind Speed (m/s) at Z=10m	Day			Night	
	Incoming solar radiation			Thin over cast or >4/8 low cloud	<4/8
	strong	moderate	slight		
< 2	A	A-B	B	E	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	E
>6	C	D	D	D	E

A : Extremely unstable B : Moderately unstable

C : Slightly unstable D : Neutral unstable

E : Slightly stable F : Moderately stable

Z : Receptor height from the ground

is kept below a safety level, we need to design models concerning the variation of the pollution level with time. These models are generally separated into physical and non-physical classes. The former is described by the diffusion equations and can estimate both the temporal and spatial distributions of the pollution level (Desalu(1974) and Kondo(1975)). The later are sometime described as statistical models and can estimate the pollution level by applying various prediction theories to them (Box and Jenkins(1976), Soeda and Ishihara(1974), and Sawaragi(1976)).

To study the environmental problems due to road traffic, knowledge of the dispersion of automobile emission for various traffic densities and at various atmospheric conditions are necessary. Mathematical models simulating the dispersion of automobile emission under various expected meteorological conditions may provide such useful knowledge at a reasonable cost. The dispersion models serve as convenient tools for the prediction of the concentration of air pollutants emitted from various sources. Given a system of pollutant sources, the main purpose of an atmospheric dispersion model is to estimate the concentration of each pollutant at any given location and time in terms of the rates of emissions.

In the past, Chen and March(1971) used analytical solutions for the diffusion of concentrations near a highway. Danard(1972) used a numerical model based on the semi-empirical diffusion equation to calculate carbon monoxide concentrations near two highways in Toronto. Ludwig et al.(1977), described simplifications that will reduce the computation time and memory requirements of Gaussian diffusion model. A detailed experimental comparison of the capability of different dispersion models was undertaken by Sistla et al.(1979). It has been reported that the Gaussian dispersion model gives better agreement with the observed concentrations.

Sawaragi et al.(1979), developed and evaluated non-physical models (Regression and Time series) for the prediction of air pollution levels. They found that the prediction accuracy of the multiple regression models is better than the time series models. Benson(1979) developed "CALINE-3, A Versatile Dispersion Model for predicting Air Pollution levels near highways and arterial streets.

These models are capable of modelling intersections, based on Gaussian dispersion theory and have been approved for use by U.S. Environmental Protection Agency (U.S.EPA). Madhukuri(1982) described two dimensional numerical model, that can be used to study the dispersion of Carbon monoxide emissions from automobiles travelling on highways. The model is based on the semi-empirical equation of turbulence diffusion.

Nelli et al.(1983) developed a model called **Texas Intersection Model (TEXIN)** for calculating the dispersion of pollutants downwind of the intersection by incorporating CALINE-3(Benson(1979)) Gaussian dispersion model. Hitoshi Kono(1990) describes a micro scale dispersion model (OMG volume -source) for the motor vehicle exhaust gas. The model is applicable for estimating the concentration of pollutants in an urban area within 200m from the side of the road.

In general, there are three main approaches to the dispersion modelling: the Eulerian approach, the Statistical approach and the Langrangian approach. The **Eulerian approach** uses the continuity equation of mathematical physics to develop a description of the physical and chemical processes that govern the relationship between the emissions and the concentrations. Eulerian atmospheric dispersion models are complicated and rarely used in modelling transport-related emissions. The **Statistical approach** of dispersion modelling attempts to establish a relationship between the pollutant concentrations and the emissions by using statistical best fit techniques. This approach is not highly developed yet and its use in modelling transport related emissions has been limited.

Among the three existing approaches for modelling atmospheric dispersion, the **Langrangian approach** is the most frequently used in the estimation of pollutant concentrations near highways. The Langrangian approach consists of using a probabilistic description of the motions of pollutant particles in the atmosphere to derive the expressions for pollutant concentrations. The most widely used Langrangian models are the Gaussian dispersion models.

2.5.1 Dispersion Models

In the case of a point source emitting at a uniform rate and being at the origin of the coordinate system, the Gaussian model is specified as follows (Rau and Wooten(1988)):

$$C(x,y,z) = \frac{E}{\pi u \sigma_y \sigma_z} \exp(-1/2(y/\sigma_y)^2)\exp(-1/2(z/\sigma_z)^2) \qquad (2.1)$$

where:

C(x,y,z)	-	denotes the pollutant concentration at a receptor point with coordinates x, y, z (g/m^3)
E	-	denotes the emission rate (g/s)
u	-	denotes the mean wind speed (m/s)
z	-	denotes the receptor height (m)
x	-	down wind distance (m)
y	-	cross wind distance (m)

σ_y, σ_z - denote the horizontal and vertical Gaussian dispersion coefficients (m)

Fig. 2.3 shows the Gaussian dispersion of pollutants in the horizontal and the vertical directions.

Dispersion Coefficients

The Gaussian models require information on the values of the dispersion coefficients σ_y and σ_z. They are a measure of the spread of the plume horizontally and vertically and are functions of the downwind distance (x), the stability condition of the atmosphere, and the wind speed. Fig. 2.4 shows the variation of dispersion coefficients with the downwind distance and the atmospheric turbulence (Pasquill and Gifford(1976)). Table 2.4 gives the fitted values for the dispersion coefficients σ_y and σ_z. The coefficients are calculated as:

$$\sigma_y = ax^p \tag{2.2}$$

$$\sigma_z = bx^p \tag{2.3}$$

where:

a, b, and p are the fitted values for the coefficients.

In the Gaussian dispersion theory, the atmosphere is assumed stationary and homogeneous. The downwind concentrations of a pollutant along the vertical and cross wind axes of a plume are assumed to be normally distributed (Brebbia(1976)). Gaussian dispersion models are normally used for predicting the pollution levels at

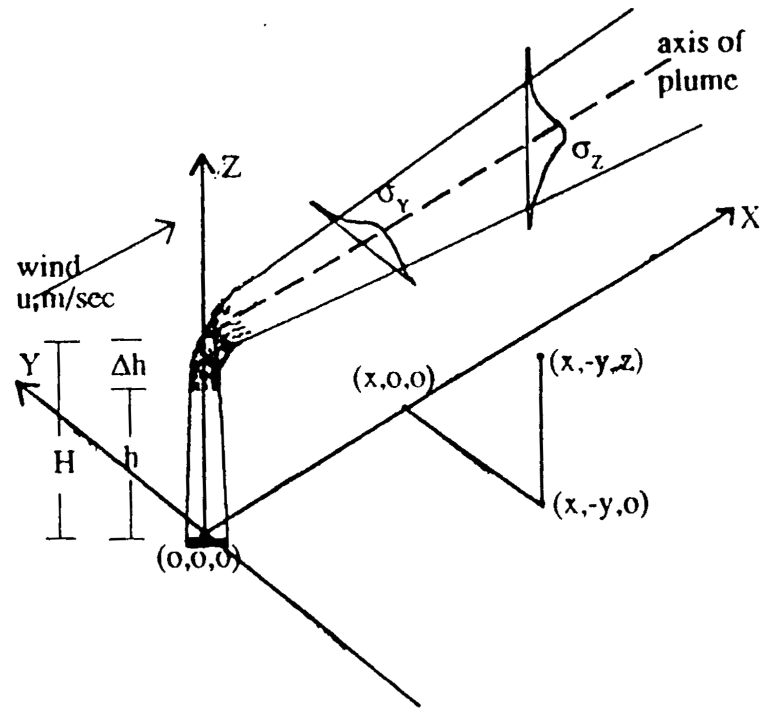
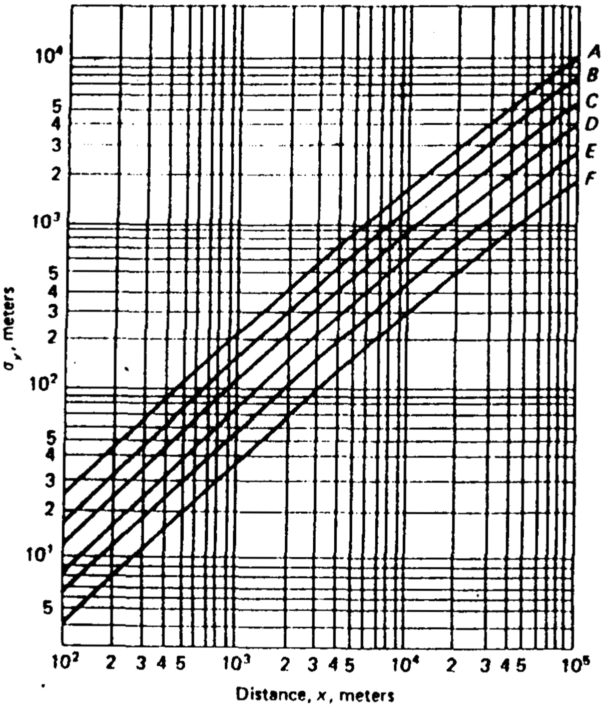
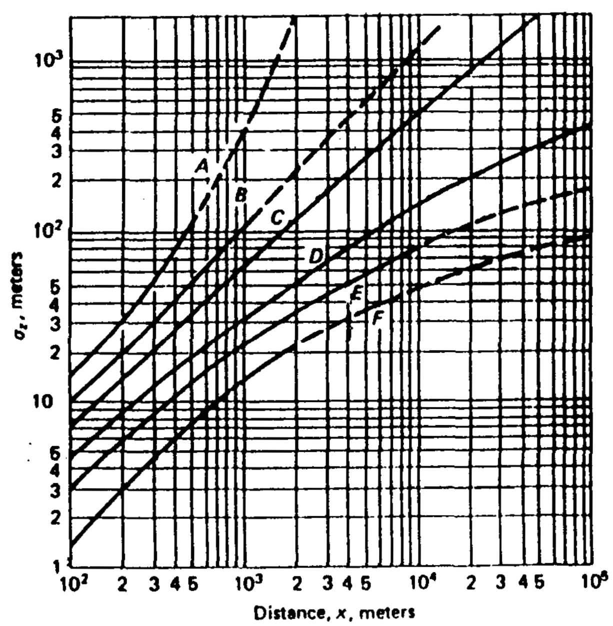


Fig. 2.3 GAUSSIAN DISPERSION MODEL



σy as a Function of
Downwind Distance and Stability



σz as a Function of
Downwind Distance and Stability

Fig.2.4 Variation of dispersion coefficients in horizontal and vertical direction

Table 2.4 FITTED VALUES FOR σ_y and σ_z

Class	a	x_1(m)	$x < x_1$		x_2	$x_1 < x < x_2$	
			b	p		b	p
A	0.400	250	0.125	1.030	500	0.0089	1.51
B	0.295	1000	0.119	0.986	10000	0.0579	1.09
C	0.200	1000	0.111	0.911	10000	0.1110	0.91
D	0.130	1000	0.105	0.827	10000	0.3920	0.64
E	0.098	1000	0.100	0.778	10000	0.3730	0.69

A : Extremely unstable B : Moderately unstable

C : Slightly unstable D : Neutral unstable

D : Slightly stable F : Moderately stable different points due to automobiles, but its restrictive steady state assumptions are violated near roadways by the turbulence created by the movement of vehicles. Various researchers have proposed modifications to overcome the deficiencies of the Gaussian model. Among them the important ones are the modification for wind speed suggested by Hichman and Colwill(1982) and the modified dispersion coefficients of Gaussian formula by TRRL (Bevan, Colwill and Hogbin(1974)).

While, Gaussian model and/or its derivatives may be useful for predicting the pollutant concentrations from a point source, the situations in which traffic engineers are often called upon to find remedial solutions, warrant the prediction of pollutant concentrations resulting from the operation of a combination of traffic stream vehicles. For tackling such problems, it becomes essential to build models, which relate pollutant concentrations to causal variables identifying the traffic stream characteristics. Such models often may need input of pollutant concentrations at a few time periods or periods earlier to the time at which the pollutant concentrations are desired to be combined with the traffic stream variables. Inclusion of these variations is not possible through the dispersion theories. For such type of situations, we require causal and time series based transfer function modelling approaches. Thus a family of models could be built combining these two streams. Only through such models, it will be possible to investigate the effectiveness of alternate traffic management measures.

2.5.2 Transfer Function Models

In the case of road traffic pollution, the emission process is dynamic, that means the pollutant concentration at any instant depends not only on traffic variables at that instant and but also on variables at previous time periods. Inclusion of such type of variations may be possible only through time series based transfer function modelling approach. Basic philosophy of transfer function modelling approach is that the influence of input series dynamically distributed over future time periods.

There is an output series Y_t, which is influenced by an input series X_t and a lot of other input, influences of which cannot be judged. These are collectively grouped and called as disturbance or noise n_t. Bivariate transfer function model can be written as:

$$y_t = V(B) * x_t + n_t \tag{2.4}$$

where:

$V(B)$ = transfer function

$= V_0 + V_1 B^1 + \dots + V_k B^k$

k = order of transfer function

B = differential operator

$V_0, V_1, \dots V_k$ = transfer function weights

Transfer function model can also be written as:

$$y_t = \frac{w(B)}{\delta(B)} x_{t-b} + \frac{\theta(B)}{\phi(B)} a_t \tag{2.5}$$

where:

$$\frac{w(B)}{\delta(B)} = V(B)$$

$$w(B) = w_0 - w_1 B^1 - w_2 B^2 - \ldots - w_s B^s$$

$$\delta(B) = 1 - \delta_1 B^1 - \delta_2 B^2 - \ldots - \delta_r B^r$$

$$\theta(B) = 1 - \theta_1 B^1 - \theta_2 B^2 - \ldots - \theta_q B^q$$

$$\phi(B) = 1 - \phi_1 B^1 - \phi_2 B^2 - \ldots - \phi_p B^p$$

y_t = Transformed value of Y_t

x_t = Transformed value of X_t

a_t = A random noise value

$\theta(B)$ and $\phi(B)$ are the moving average and the autoregressive operators of the noise term and **r**, **s** and **b** are the parameters of the transfer function model connecting $\mathbf{x}_t$ and $\mathbf{y}_t$, p and q refer to the parameters of the noise model.

2.6 PREDICTION OF LINK VOLUMES FOR AIR QUALITY MODELLING

Ambient concentrations of pollutants near roads are necessary for the design and evaluation of traffic management schemes. For predicting the concentration of pollutants near roads within the study area, the data regarding the traffic flow and the composition are required. But it is practically impossible to conduct physical surveys to obtain the traffic flow on all the roads. Traffic flow can be estimated if the Origin-Destination data are available. However, in situations where such data are not available, it was felt that, it may become necessary to generate the data through some indirect procedure like 'Estimating O-D Matrix from Link Volume Counts.

SATURN is a computer model for the simulation and assignment of traffic on urban road networks. The objective of the assignment model SATASS of SATURN is to select for each element in the trip matrix, minimum time routes through the network, bearing in mind the relationship between the travel time and the flow (Hall et al.(1980)).

Unlike the conventional models which consider travel time as link travel time, SATURN takes care of turn specific delays and banned turns, while determining the travel time (Van Vliet(1982)). From its application to cities of Harrongate (Hall et al.(1980)) and Bangkok (May (1993)), it was found that SATURN is an improvement over conventional assignment models.

2.7 IDENTIFICATION OF THE RESEARCH FRAMEWORK

From the literature it was observed that, most of the developed models for the prediction of ambient air quality levels are based on purely homogeneous traffic conditions. For such type of situations the emission factors generally remain invariant. In mixed traffic conditions, the composition changes from time to time and the emission process is dynamic. That means, the traffic stream variables like the composition and the speed of flow vary and the pollutant concentrations at a particular instant is not only a function of variables at that instant but also function of variables at previous time periods.

Even though Gaussian models have many limitations because of their simplifying assumptions, they are still used for the prediction of ambient air quality levels. But in the case of mixed traffic flow, these models were suspected to be incapable of predicting the actual concentrations due to a system of moving vehicles. In this context it was felt that we may require causal models which have time series components also combined with them for predicting the actual concentrations. Such models will be useful for the prediction of pollutant concentrations resulting from different systems of Traffic Management Measures and thus may aid in the choice of appropriate Traffic System Management action plans.

2.8 CONCLUSIONS

In this chapter, a brief review of the modelling approaches that were developed for the prediction of ambient air quality levels has been presented. While, describing many of the models that use the Gaussian dispersion theory for air quality prediction, the effort made to identify the factors that affect the concentration of pollutants is also described. A major outcome of the critical review of the literature that has been brought out in this chapter is that there exists a need to develop alternate modelling approaches to Gaussian dispersion model for the prediction of ambient air quality near highways due to road traffic. Chapter 3 presents the findings of the applicability of Gaussian Dispersion theory to model the pollution.

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PILOT SURVEY AND APPLICABILITY OF DISPERSION THEORY

Cini A. “Modelling and evaluation of ambient air quality levels due to mixed traffic on city roads” Thesis. Department of Civil Engineering ,Regional Engineering College, University of Calicut, 1999

CHAPTER 3

PILOT SURVEY AND APPLICABILITY OF DISPERSION THEORY

3.1 GENERAL

To get a general idea about the air quality levels near major trunk roads of Calicut city, a Pilot survey was organised at different locations within the study area. Based on the data collected by the Pilot survey, the pollutant concentrations were predicted using dispersion theory. Generally Gaussian dispersion theory is used for predicting the pollution due to automobiles, but its restrictive steady state assumptions are violated near highways by the turbulence created by the movement of vehicles. In the first stage of this study, the concentration of pollutants were predicted using Gaussian dispersion model with modifications suggested by TRRL (1982) and (Matzoros, 1992) U.S.EPA (1980). The performance of those models was evaluated with the help of the observed pollution levels obtained from the Pilot survey. This chapter, while describing the results of the exploration in the use of Gaussian models for modelling the pollutant concentrations also presents the procedure used for identifying the variables for causal models.

3.2 DISPERSION THEORY

Given a system of sources for pollutants, the main purpose of an atmospheric dispersion model is to estimate the concentration of each pollutant at any given location and time in terms of the rate of emission, location of pollutant source and the meteorological and topographical factors. Different approaches are available for dispersion modelling. A detailed experimental comparison of the capability of different deterministic models was undertaken by Sistla et al.(1979). In that study, the Gaussian dispersion model gave better agreement with observed pollutant concentrations. That model calculated the concentration of pollutants at a particular receptor. In case of a point source which is emitting at a uniform rate and which is located at the origin of the co-ordinate system, the Gaussian dispersion is specified as:

$$C(x,y,z) = \frac{E*\exp(-1/2(y/\sigma_y)^2)*\exp(-1/2(z/\sigma_z)^2)}{\pi*u*\sigma_y*\sigma_z} \quad (3.1)$$

where:

C denotes the pollutant concentration at a point receptor with coordinates x, y, z (g/m^3)

x down wind distance (m)

y cross wind distance (m)

z receptor height (m)

E denotes the emission rate (g/s)

u denotes the mean wind speed (m/s)

σ_y, σ_z denote standard deviations of the plume concentration distribution at a down wind distance **x**

The standard deviations are a measure of the spread of the plume horizontally and vertically and are functions of the downwind distance and the atmospheric turbulence. Their variation with downwind distance and atmospheric turbulence is given by the Pasquill-Gifford Curves(Rao (1990)).

3.3 DATA COLLECTION

Calicut is one of the fast growing cities of Kerala, which has registered a phenomenal increase in the vehicular population during the last few decades. This tremendous growth of vehicular traffic coupled with lack of basic road infrastructure for transportation has contributed to the deterioration of environment of the city drastically. To evaluate the existing level of pollution and for the dispersion modelling, the data regarding the volume and the composition of traffic, the ambient levels of pollutants, the meteorological parameters like the wind speed and the temperature and the emission strength of vehicles are required.

The required data for this study were obtained from the field surveys conducted at 16 locations on four major trunk roads of Calicut viz., Trichur, Mavoor, Wynad and Kannur roads. The survey locations were selected in such away that they were well distributed within the study area. Fig.3.1 shows the study area with survey locations. Simultaneous observations of both the traffic flow and the pollutant concentrations were observed for a period of half-an-hour(evening peak period) at each of those locations. The volume and the composition of traffic were measured by manual methods.

The ambient concentrations of pollutants like carbon monoxide and hydrocarbons were measured with portable electronic sensors. The instruments used gave the concentration of pollutants directly in ppm. At each location, the pollutant concentrations were measured at heights of 1.5m and 2m above the ground level on

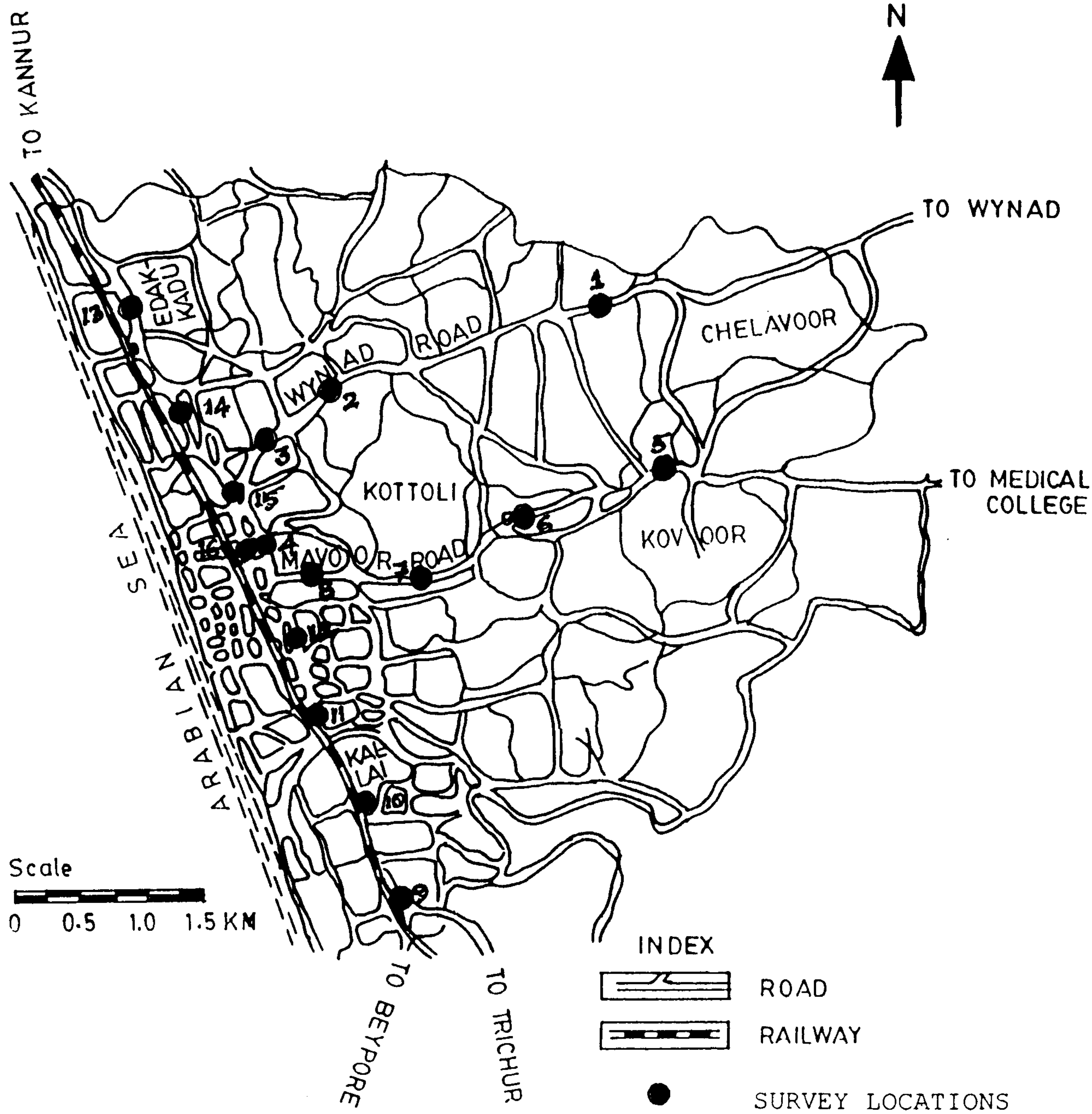

Fig. 3.1 ROAD NETWORK MAP OF CALICUT CITY

WITH SURVEY LOCATIONS

either side of the road, both at the edge of the carriage-way and at the end of the shoulder. In this survey, it was observed that there was not much of variation in the concentrations of the pollutants on both sides of the road and at the heights of 1.5m and 2m. Table 3.1 gives the tabulated survey data.

From the comparison of the observed air quality levels with NAAQS, it was found that, while, in all the locations the concentration of HC exceeded the permissible level, the concentration CO was above the permissible limit in most of the locations. That only meant that the Calicut city was highly polluted with concentration of CO and HC. From the observed concentrations it was also observed that the intensity of pollutant decreased with the distance from the city center.

For the dispersion modelling, apart from the traffic volume, the wind speed and the emission strength of vehicles are also required. The data regarding the wind speed were collected from the data files of CWRDM (Center for Water Resource Development and Management) Calicut.

3.4 ESTIMATION OF EXHAUST EMISSION STRENGTH

The estimation of pollutant emission strength due to vehicular traffic is a major task of air quality modelling. Exhaust emission strength depends on the number and the type of vehicles plying on a road. Emission rates of various pollutants from different vehicles are different. The exhaust emission strength can be determined by using the following equation.

$$E = V * e \qquad (3.2)$$

Table 3.1 TABULATED SURVEY DATA (at 1.5m Height)

Survey Locations	Traffic Volume (veh/hr)	Speed in kmph	Concentration in ppm CO	HC
1	463	29.27	2	2
2	1866	31.46	2	2
3	1578	30.30	3	1
4	2166	30.39	7	2
5	606	25.26	3	1
6	1161	25.21	2	1
7	2586	25.09	5	2
8	993	20.28	3	1
9	1653	24.56	3	2
10	729	25.56	2	2
11	598	28.26	3	1
12	654	28.98	2	1
13	1050	33.26	3	1
14	1322	32.16	4	2
15	1476	29.28	6	1
16	795	27.34	3	1

Where:

E = the exhaust emission strength in g/m/s

V = volume of traffic in veh/s

e = emission factors in g/m

The motor vehicle exhaust emission factors for different pollutants were obtained from the Report on Vehicular Emission published by IIP (Indian Institute of Petroleum), Dehradun. Table 3.2 lists the exhaust factors of the various pollutants viz. HC, NO, and CO for two wheelers, three wheelers, cars, buses, and trucks.

3.5 DEVELOPMENT OF DISPERSION MODEL

The structure of the model developed is shown in Fig.3.2. The procedure advanced starts by feeding road network and the trip matrix details into the traffic model, which in turn produces traffic data like the traffic flow, the composition and the speed. Then the distribution of emission on every link is estimated from the traffic flows and emission rates. Finally, the dispersion model reads these distributions as well as the meteorological data and the network and receptor geometries and outputs the pollutant concentration.

An interesting feature of traffic pollution is that its "worst case" receptors are people walking in the streets or car passengers who are exposed to the direct emission because they are located at the height of the car exhaust. Further, if we assume that, exhaust gases rise before they disperse and the turbulent wake of vehicles promote their rising further, we can practically ignore the height differences and treat the problem as a two dimensional one (Matzoros (1992)). Eq.3.2 then

Table 3.2 EXHAUST EMISSION FACTORS IN g/km (IIP, DEHRADUN)

Vehicle type	CO	HC	NO
Two-wheelers	17.0	10.0	5.18
Car	40.0	6.0	3.51
Bus	12.7	2.1	21.00
Auto	25.5	10.0	3.18
Truck	12.7	2.1	21.00

IIP - Indian Institute of Petroleum

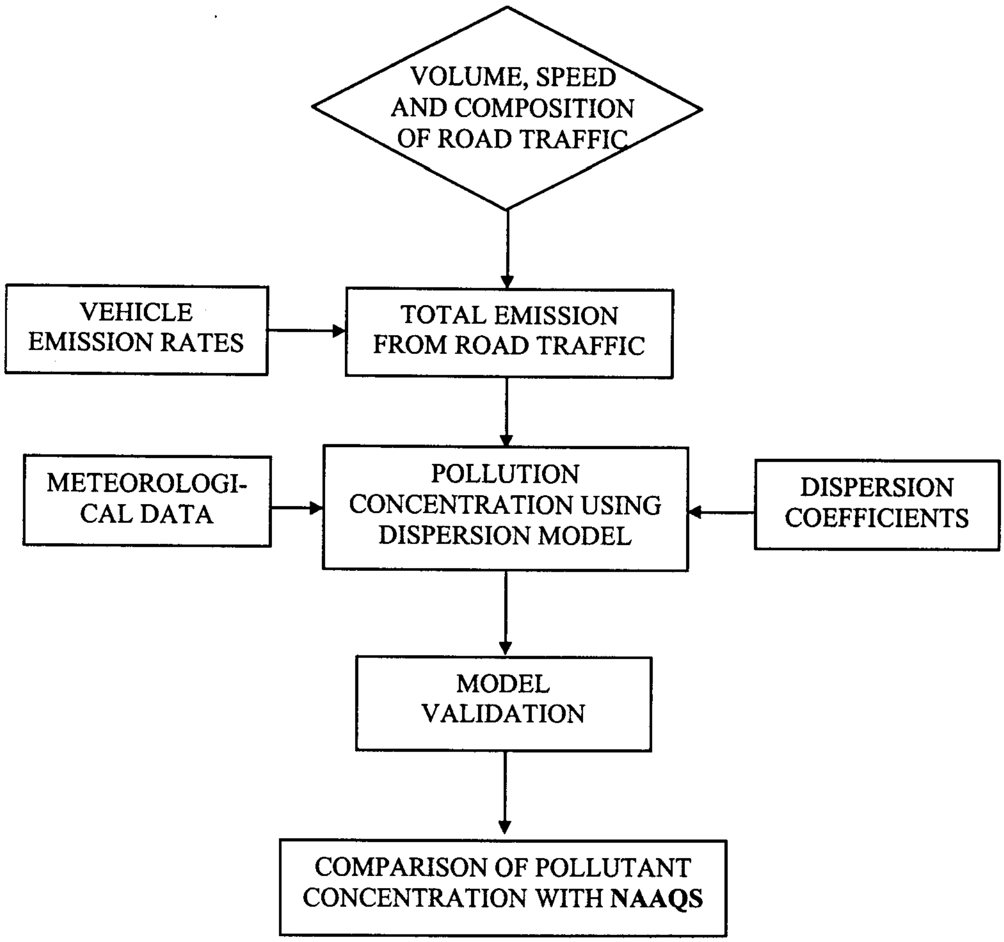

Fig. 3.2 FLOW CHART FOR THE ESTIMATION OF POLLUTANT CONCENTRATION DUE ROAD TRAFFIC

becomes:

$$C(x,y) = \frac{E(\exp(-1/2(y/\sigma_y)^2))}{\pi u \sigma_y \sigma_z} \qquad (3.3)$$

Gaussian theory assumes steady state, homogeneous meteorological conditions, which imply that wind characteristics and atmospheric turbulence are independent of time and space. These assumptions are not generally realistic and its steady state assumptions are violated near roadways. Vehicle movements produce complex air motion and introduce changes in the gas dispersion. Therefore, five different models were tested by using the modifications suggested by TRRL and U.S EPA. In all those models, the basic Gaussian Dispersion of Eqn.3.3 was used for the prediction of pollutant concentration due to road traffic. The models developed are briefly explained below:

3.5.1 MODEL – I

This model used normal Gaussian dispersion theory. In this model the major assumption is that wind speed and atmospheric turbulence are constant over time and space. The dispersion coefficients σ_y and σ_z are calculated by using Pasquill-Gifford equations $\sigma_y = a*x^p$ and $\sigma_z = b*x^p$. During the period of data collection, the atmosphere was moderately unstable. So **a**, **b**, and **p** were taken for that stability class from Pasquill and Gifford Curves (Rao(1990)).

3.5.2 MODEL - II

In this method, dispersion coefficients σ_y and σ_z as modified by TRRL were adopted for modelling (Matzoros (1992)). The dispersion coefficients were calculated by using the equations:

$$\sigma_z = 1.85[(1+\exp(0.39(\ln x)^3-4.76(\ln x)^2+ 20.95(\ln x)-32.67)] \quad (3.4)$$

$$\sigma_y = 12.5*\sigma_z \quad (3.5)$$

where:

x denotes downwind distance

3.5.3 MODEL - III

The dispersion coefficient σ_z of the Gaussian model, modified by US EPA (Petersen(1980)) was adopted in this model. According to it, the dispersion coefficient is composed of dispersion due to ambient turbulence plus the initial dispersion due to the turbulence generated by the vehicle. The dispersion parameter was computed as:

$$\sigma_z = (\sigma_{za}^2 + \sigma_{zo}^2)^{0.5} \quad (3.6)$$

where:

$\sigma_{za} = b*x^b$ (similar to that suggested by Pasquill)

$\sigma_{zo} = 3.57 - 0.53*u$ (initial turbulence generated by the vehicle)

where:

u = the wind speed in m/s

These empirically defined formulae are valid only for low wind speeds because at higher wind speeds, the dispersion due to turbulence generated by the vehicle is negligible when compared to the dispersion due to ambient turbulence.

3.5.4 MODEL - IV

Taking into account the turbulence generated by the vehicle movement, an empirical wind speed function was suggested by Hickman and Colwill(1982) as:

$$u^{*} = u/(0.59+ 0.11u) \quad (3.7)$$

where:

u^{*} denotes the modified wind speed

This modified wind speed was used for the dispersion modelling.

3.5.5 MODEL - V

In this model, the modified dispersion coefficient suggested by TRRL (as in model II) and the modified wind speed suggested by Hickman and Colwill (as in model IV) were used. Using the models explained in sections 3.5.1 to 3.5.5, the pollutant concentrations were estimated for selected locations within the urban area of Calicut city.

3.6 VALIDATION OF THE MODELS

The validation of the models was made by calculating the RMS percentage errors in the prediction of CO and HC concentrations. The estimated and observed values of pollutant concentrations and the corresponding RMS percentage errors are given in Tables 3.3 to 3.4. It was found that the differences between the predicted and the observed concentrations of pollutants were high, unlike the observation of Sistla et al.(1979) who had reported the close agreement between the predicted and the observed pollutant concentrations in nearly homogeneous traffic flow conditions.

3.7 NEED FOR CAUSAL MODELS

The analysis of the results obtained from dispersion models led to the suspicion that, the meteorological parameters were less significant in the prediction of ambient air quality near highways. For testing the significance of meteorological parameters, regression models were developed for the prediction of ambient air quality levels with the volume, the speed, the composition of traffic, the wind speed and the atmospheric temperature as causal variables. Table 3.5 gives the selected models based on R^2 and t-test values. From the analysis of t-test values of each variable, it was found that the meteorological parameters were less significant. That lead to the conclusion that the pollution levels near highways were more dependent on traffic variables than on meteorological parameters. Perhaps that explained the reason for the low RMS value for all Gaussian Dispersion models. It was for this reason, a statistical causal model was suspected to be more suitable for the prediction of ambient air quality levels near highways due to mixed traffic situations.

3.8 IDENTIFICATION OF CAUSAL VARIABLES

From the analysis of the above models it was suspected that, the relation between the concentration of pollutants and the influencing variables might not be linear at all. This was further corroborated from the literature as well. Figs. 2.1 and 2.2

Table 3.3 PREDICTED AND OBSERVED CONCENTRATIONS OF CARBON MONOXIDE (in ppm)

Location	Observed	Model I	Model II	Model III	Model IV	Model V
1	2.00	0.807	0.977	0.907	0.766	0.790
2	2.00	2.258	2.401	2.320	2.171	2.210
3	3.00	2.062	2.120	2.080	1.983	2.018
4	7.00	3.055	3.710	3.580	2.938	2.990
5	3.00	1.101	1.340	1.290	1.059	1.078
6	2.00	1.826	1.920	1.870	1.756	1.787
7	5.00	3.766	3.980	3.860	3.621	3.686
8	3.00	1.601	1.721	1.670	1.545	1.572
9	3.00	2.191	2.230	2.200	2.106	2.144
10	2.00	1.373	1.420	1.391	1.320	1.344
11	3.00	1.038	1.190	1.090	0.988	1.016
12	2.00	1.324	1.470	1.390	1.273	1.296
13	3.00	2.157	2.280	2.180	2.074	2.111
14	4.00	2.987	3.256	2.945	2.823	2.912
15	6.00	3.766	3.980	3.860	3.621	3.686
16	3.00	1.101	1.340	1.290	1.059	1.078
RMS %		48.00	41.78	45.96	49.30	49.12

Table 3.4 PREDICTED AND OBSERVED CONCENTRATIONS OF HYDRO CARBONS (in ppm)

Location	Observed	Model I	Model II	Model III	Model IV	Model V
1	2.00	0.543	0.591	0.578	0.541	0.566
2	2.00	2.142	2.420	2.291	2.098	2.123
3	1.00	1.754	1.873	1.810	1.717	1.741
4	2.00	2.778	2.901	2.823	2.717	2.739
5	1.00	0.844	1.321	1.097	0.826	0.835
6	1.00	1.631	1.824	1.725	1.596	1.617
7	2.00	3.293	3.421	3.378	3.233	3.269
8	1.00	1.328	1.528	1.393	1.300	1.319
9	2.00	1.801	2.146	1.901	1.832	1.857
10	2.00	1.110	1.321	1.271	1.086	1.090
11	1.00	0.730	1.090	0.978	0.714	0.726
12	1.00	1.093	1.267	1.126	1.070	1.080
13	1.00	1.562	1.720	1.601	1.529	1.540
14	2.00	1.632	1.824	1.726	1.596	1.617
15	1.00	1.720	1.836	1.791	1.677	1.711
16	1.00	1.110	1.321	1.271	1.086	1.090
RMS %		47.31	40.20	48.36	46.08	46.65

Table 3.5 REGRESSION MODEL WITH METEOROLOGICAL FACTORS

List of Variables	Beta weights	t-test	Intercept constant	Multiple R^2 value	RMS percentage
1	0.00278	2.8014			
2	-0.00932	-0.8839			
4	0.03752	2.0366	0.20376	0.2341	21.37
5	0.00646	0.9181			
6	0.54420	0.3021			
7	-0.06610	-0.2491			

Where:

1 - Traffic volume (veh/hr)
2 - Traffic speed (km/hr)
3 - Pollutant concentrations predicted by transfer function model (ppm)
4 - Percentage composition of auto-rickshaws
5 - Percentage composition of two-wheelers
6 - Wind speed (kmph)
7 - Atmospheric temperature
8 - Pollutant concentration in ppm (dependent variable)

show that the HC and NO concentrations are non-linear in relation to the traffic volume and the average vehicle speed.

In order to build good prediction models, it therefore became obvious that one single model applicable to the whole city would do a poor job and therefore it was necessary to divide the city into bands or rings in which one can expect more or less uniform pollutant concentrations.

The following were the variables identified for detailed study: i) traffic volume ii)traffic speed iii) percentage composition of auto-rickshaws and iv) percentage composition of two-wheelers. Further to this, it was decided to use distance as a classification variable to divide the city into bands of uniform pollutant concentrations.

3.9 CONCLUSIONS

In this chapter, the following points have been presented:

i) The details of the Pilot survey that was launched in the city of Calicut.

ii) The incapability of Gaussian model to effectively predict the pollutant concentrations due to moving traffic.

iii) The insignificance of meteorological parameters to explain the variations in pollutant concentrations due to road traffic.

iv) The need for dividing the city into bands or rings of uniform pollutant concentrations.

v) The importance of traffic stream variables in modelling the pollutant concentrations.

Chapter 4 presents the efforts put in for the collection of detailed data for modelling pollution due to road traffic.

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DATA COLLECTION AND ANALYSIS

Cini A. “Modelling and evaluation of ambient air quality levels due to mixed traffic on city roads” Thesis. Department of Civil Engineering ,Regional Engineering College, University of Calicut, 1999

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 GENERAL

For the development of models and the evaluation of air quality levels, the traffic stream variables and the ambient air quality data are required. From the Pilot survey it was established that the study area is necessary to be divided into bands of uniform pollutant concentrations. This chapter presents the detailed data collection procedures and analysis adopted for this research work. The procedure for obtaining the inputs to SATASS, the assignment model in SATURN package is also explained.

4.2 DESCRIPTION OF THE STUDY AREA

Calicut is one of the fast growing cities of Kerala State with a population of over 4.2 lakhs(1991,CENSUS), spread over an area of 82.4 sq.km. It is located on the West Coast of India at 11° 15' North latitude and 75° 40' East longitude. Fig. 4.1 presents the study area divided into zones for the purpose of estimation of travel demand.

From the pilot survey, it was established that the level of pollutant concentrations varied with the distance from the city center and to get the spatial distribution of pollutant concentrations, the study area is necessary to be divided into bands or rings. Accordingly, the city was divided into four bands. While, the first band was the area between 0.5 km and 1.0 km radii, the second was the area contained between 1.0 km and 2.0 km radii. The third and the fourth bands were the areas

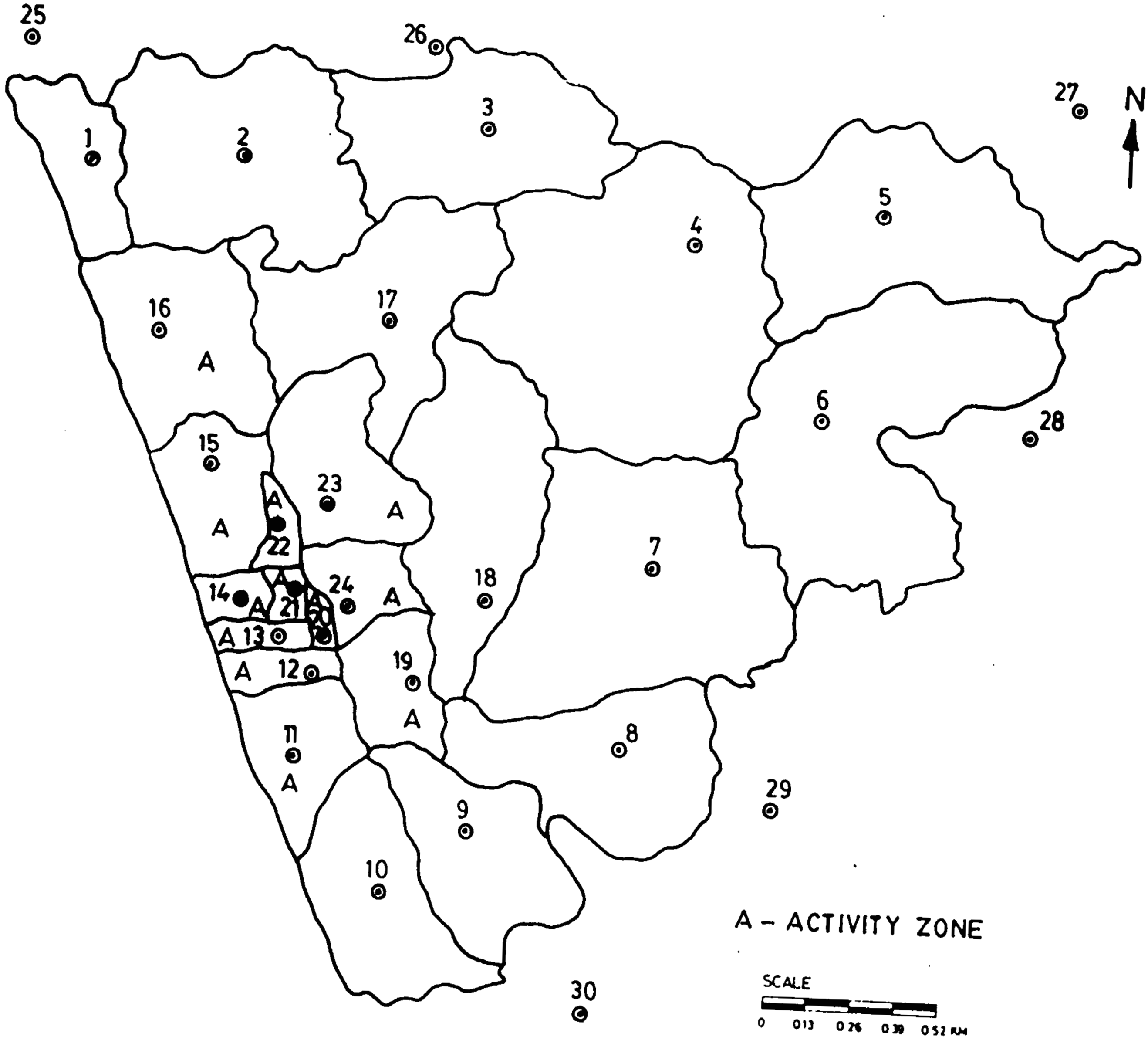

Fig. 4.1 ZONAL MAP OF STUDY AREA

formed between 2.0 and 4.0 km, and 4.0 and 8.0 km radii, respectively. Four major roads viz., Kallai road, Mavoor road, Wynad road and Kannur are the roads which enter the study area.

4.3 TRAFFIC STREAM AND AMBIENT AIR QUALITY DATA

For the purpose of data collection, 16 locations were selected on the four major roads distributed in four groups of bands as shown in Fig.4.2. Traffic stream variables like the volume, the composition and the speed were measured. Manual methods were used for the collection of the speed and the volume of the traffic. For the purpose of the study, the sections were chosen in such way that they were located on straight stretches of at least of 30m length.

Ambient concentrations of pollutants like the carbon monoxide, the hydrocarbons and the nitric oxide were measured with portable electronic sensors. Those instruments were calibrated to give the concentration of pollutants directly in ppm. Traffic and Air quality data were collected for a period of half an hour at each of those locations. Data were collected for every fifteen minutes. A sample of the data of the traffic volume, the speed and pollutant concentrations collected for half-an-hour on Trichur road are given in the Tables 4.1 to 4.3.

Key coverage surveys were also organised, one each, in the four bands of the study area. The objective of this Key coverage was to get comprehensive data on traffic volume, speed, and pollutant concentrations so that the surveys conducted at different time points in half an hour survey could be deduced to the required time frame. This can be worked out by the interrelationship between the data of the half-an-hour survey and the corresponding data observed in Key coverage surveys.

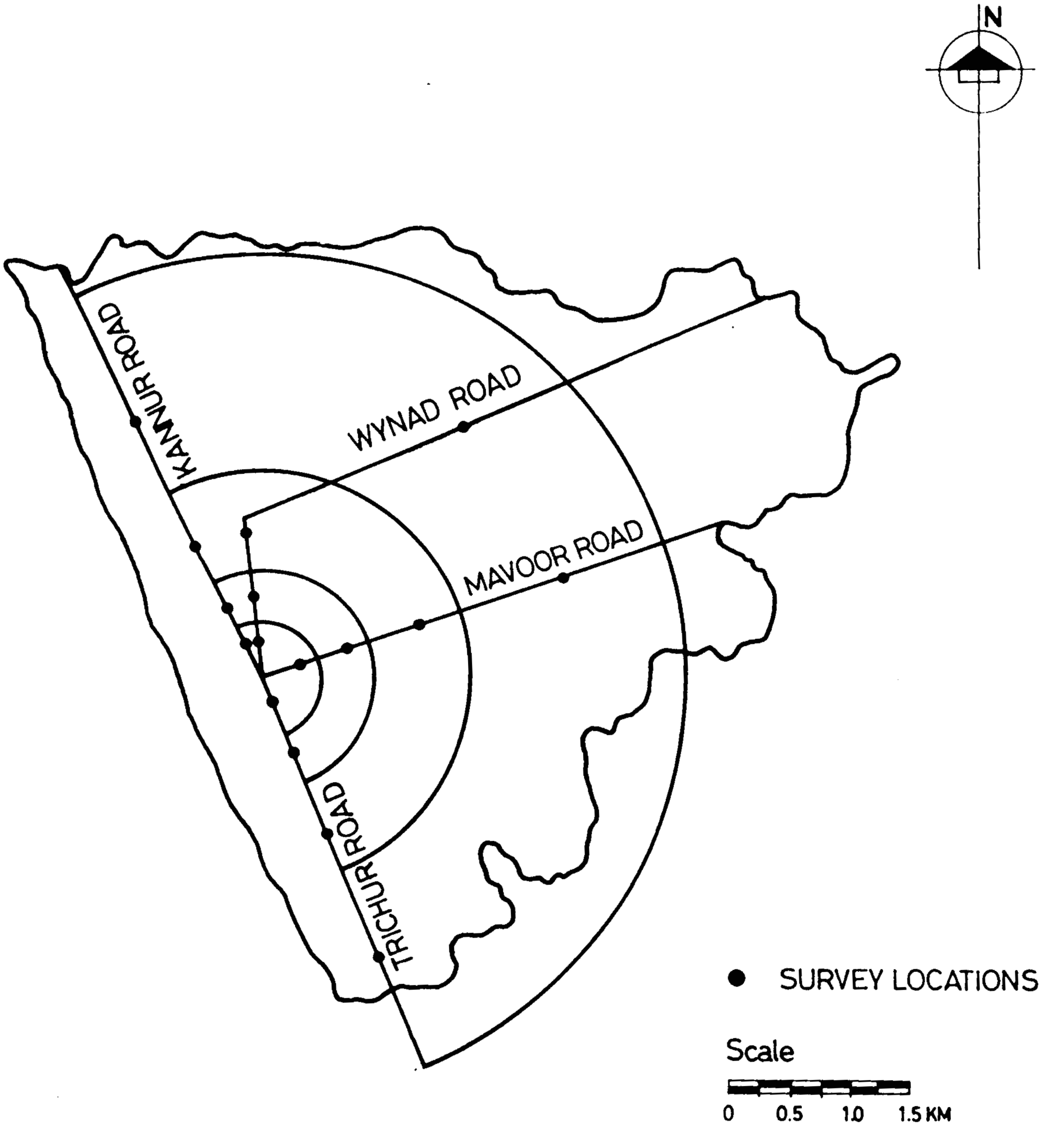

Fig. 4.2 SIMPLIFIED LAYOUT OF STUDY AREA WITH SURVEY LOCATIONS

Table 4.1 DETAILS OF VOLUME STUDY (HALF AN HOUR SURVEY)

TRICHUR ROAD

Distance from city center (km)	Duration (min)	AUTO	BUS	CAR	SCOOTER	VAN/ JEEP	MOTOR CYCLE	TRUCK	TOTAL VOLUME
0.5-1.0	0 - 15	172	0	16	43	12	18	0	261
	15 - 30	178	0	15	44	7	26	0	270
1.0-2.0	0 - 15	179	0	13	66	17	28	0	303
	15 - 30	177	0	15	63	15	39	0	306
2.0-4.0	0 - 15	46	29	17	50	25	14	14	197
	15 - 30	51	30	20	38	15	21	5	180
4.0-8.0	0 - 15	23	32	16	31	27	27	12	168
	15 - 30	29	33	16	38	18	19	7	160

Table 4.2 DETAILS OF SPEED STUDY (HALF AN HOUR SURVEY)

TRICHUR ROAD (in kmph)

Distance from city Center (km)	Duration (min)	AUTO	BUS	CAR	SCOOTER	VAN/ JEEP	MOTOR CYCLE	TRUCK	STREAM SPEED
0.5-1.0	0 - 15	27.1	0.0	29.7	27.7	22.7	30.0	0.0	25.51
	15 - 30	26.2	0.0	28.8	22.2	25.8	27.6	0.0	25.61
1.0-2.0	0 - 15	26.4	0.0	29.8	26.1	28.7	27.0	0.0	26.98
	15 - 30	27.2	0.0	28.7	27.2	29.1	23.2	0.0	26.19
2.0-4.0	0 - 15	23.1	25.4	22.5	25.3	28.9	24.0	23.2	24.56
	15 - 30	21.8	25.2	21.2	29.9	32.1	20.6	29.1	28.12
4.0-8.0	0 - 15	32.4	40.5	48.4	34.8	44.9	38.0	34.1	39.70
	15 - 30	30.4	40.1	48.3	31.2	45.9	39.9	39.2	42.10

Table 4.3 DETAILS OF POLLUTION STUDY(HALF AN HOUR SURVEY)

TRICHUR ROAD

Distance From city Center(km)	Duration in minutes	CONCENTRATIONS IN ppm		
		CO	HC	NO
0.5-1.0	0 - 15	6.0	2.0	1.0
	15 - 30	5.0	2.0	1.0
1.0-2.0	0 - 15	4.0	1.0	2.0
	15 - 30	4.0	1.0	2.0
2.0-4.0	0 - 15	3.0	1.0	2.0
	15 - 30	4.0	2.0	2.0
4.0-8.0	0 - 15	2.0	0.0	1.0
	15 - 30	2.0	1.0	1.0

Key coverage surveys were conducted for a period of 10 hours (from 7.30 AM to 5.30 PM). The daily variations of the pollutant concentration could also obtained from the Key coverage surveys. Tables 4.4 to 4.6 give the tabulated data for every 30 minutes for Wynad road. Along with the traffic and the air quality data, section details like the road width, shoulder widths, the wind speed and the atmospheric temperature were also measured.

4.4 CHARACTERISTICS DISTRIBUTION OF POLLUTANT CONCENTRATIONS

A comparison of observed data with NAAQS shows that at most of the locations in the Calicut city, the level of pollutant concentrations exceed the permissible values. Figs. 4.3 to 4.5 show the variation of concentration of CO, HC, and NO with distance from the city center for all the four trunk roads. It could be seen from these figures that, both the CO and HC concentrations show similar trend in relation to the distance from the city center, though the extent of variations were found to be different. In the city center, due to frequent STOP and GO situations, the speeds were less, and concentrations of both CO and HC were found to be high. Again on the highway sections, which were found to be critical due to bad road geometrics, such as steep vertical gradient, sharp horizontal curve, resulting in considerable reduction in speed, the concentration of both CO and HC were higher compared to sub-urban sections. But the extent of influence of those impediments was higher for HC compared to that of CO. On the other hand, the NO concentration was found to be low when the speeds were low and vice versa.

Table 4.4 DETAILS OF VOLUME STUDY (FULL SCALE SURVEY)

WYNAD ROAD (7.30 AM TO 5.30 PM)

CLOCK TIME	AUTO	BUS	CAR	SCOOTER	VAN/ JEEP	MOTOR CYCLE	TRUCK	TOTAL VOLUME
7.00-7.30	11	46	15	31	23	19	19	166
7.30-8.00	26	45	39	43	31	15	22	221
8.00-8.30	36	57	49	91	42	50	22	347
8.30-9.00	51	48	51	103	67	55	19	395
9.00-9.30	41	42	76	111	62	93	10	435
9.30-10.00	51	51	59	84	65	50	20	380
10.00-10.30	38	47	51	71	49	45	13	314
10.30-11.00	35	45	50	60	55	35	16	296
11.00-11.30	39	45	36	53	47	41	13	274
11.30-12.00	48	48	59	42	71	39	15	322
12.00-12.30	36	40	60	55	37	45	20	293
12.30-13.00	36	47	50	61	59	22	24	299
13.00-13.30	26	36	46	49	52	48	11	268
13.30-14.00	38	29	42	52	59	44	20	304
14.00-14.30	32	47	64	57	53	31	21	305
14.30-15.00	39	39	65	45	58	52	21	327
15.00-15.30	30	31	78	41	31	32	22	265
15.30-16.00	14	52	68	40	41	44	23	278
16.00-16.30	20	51	72	42	38	41	10	288
16.30-17.00	22	61	67	38	34	51	11	285

Table 4.5 DETAILS OF SPEED STUDY (FULL SCALE SURVEY)

WYNAD ROAD(7.30 AM TO 5.30 PM) (in kmph)

CLOCK TIME	AUTO	BUS	CAR	SCOOTER	VAN JEEP	MOTOR CYCLE	TRUCK	AVERAGE SPEED
7.00-7.30	38.0	50.8	52.1	35.2	57.8	53.0	52.2	52.86
7.30-8.00	29.6	38.1	46.3	51.9	55.0	54.0	51.1	44.87
8.00-8.30	31.2	41.2	42.1	47.8	49.3	51.5	53.1	45.17
8.30-9.00	39.4	43.6	58.9	50.0	53.8	48.0	43.7	49.05
9.00-9.30	35.3	46.8	60.9	48.2	51.2	48.0	37.7	48.76
9.30-10.00	36.2	44.5	57.8	38.5	50.7	45.1	38.8	49.18
10.00-10.30	29.8	44.4	46.1	37.9	55.1	39.0	58.3	44.44
10.30-11.00	35.6	44.2	49.1	37.5	48.9	39.0	43.2	42.84
11.00-11.30	37.6	37.7	48.6	36.1	46.3	35.0	37.6	40.01
11.30-12.00	32.6	59.4	46.1	40.0	53.4	46.0	66.9	49.63
12.00-12.30	41.3	44.1	56.3	38.8	47.5	44.2	51.8	46.53
12.30-13.00	46.0	42.1	45.2	53.6	40.1	41.6	00.0	44.50
13.00-13.30	32.4	46.2	50.1	36.2	51.4	44.3	39.6	44.84
13.30-14.00	41.5	50.2	49.3	47.2	50.1	42.3	40.1	45.81
14.00-14.30	46.7	49.8	44.3	39.1	47.5	41.6	37.6	43.80
14.30-15.00	43.7	57.0	58.1	40.5	53.1	43.2	59.2	50.68
15.00-15.30	47.5	61.2	55.4	54.4	67.1	45.1	59.2	57.73
15.30-16.00	48.6	57.8	53.2	51.2	55.1	54.5	54.4	54.18
16.00-16.30	31.5	41.2	50.2	32.6	36.9	40.7	37.3	39.18
16.30-17.00	41.3	43.2	49.2	34.2	37.5	34.9	41.2	41.21

Table 4.6 DETAILS OF POLLUTION STUDY (FULL SCALE SURVEY)

CLOCK TIME	WYNAD ROAD(7.30 AM TO 5.30 PM) CONCENTRATIONS IN ppm		
	CO	HC	NO
7.00-7.30	1.0	1.0	0.0
7.30-8.00	1.0	0.0	2.0
8.00-8.30	3.0	3.0	1.0
8.30-9.00	3.0	1.0	1.0
9.00-9.30	4.0	2.0	2.0
9.30-10.00	3.0	1.0	2.0
10.00-10.30	3.0	2.0	1.0
10.30-11.00	4.0	0.0	1.0
11.00-11.30	4.0	2.0	1.0
11.30-12.00	3.0	1.0	1.0
12.00-12.30	3.0	1.0	0.0
12.30-13.00	3.0	1.0	0.0
13.00-13.30	2.0	2.0	0.0
13.30-14.00	4.0	2.0	1.0
14.00-14.30	3.0	3.0	2.0
14.30-15.00	4.0	2.0	2.0
15.00-15.30	3.0	2.0	2.0
15.30-16.00	4.0	2.0	1.0
16.00-16.30	3.0	2.0	1.0
16.30-17.00	2.0	1.0	0.0

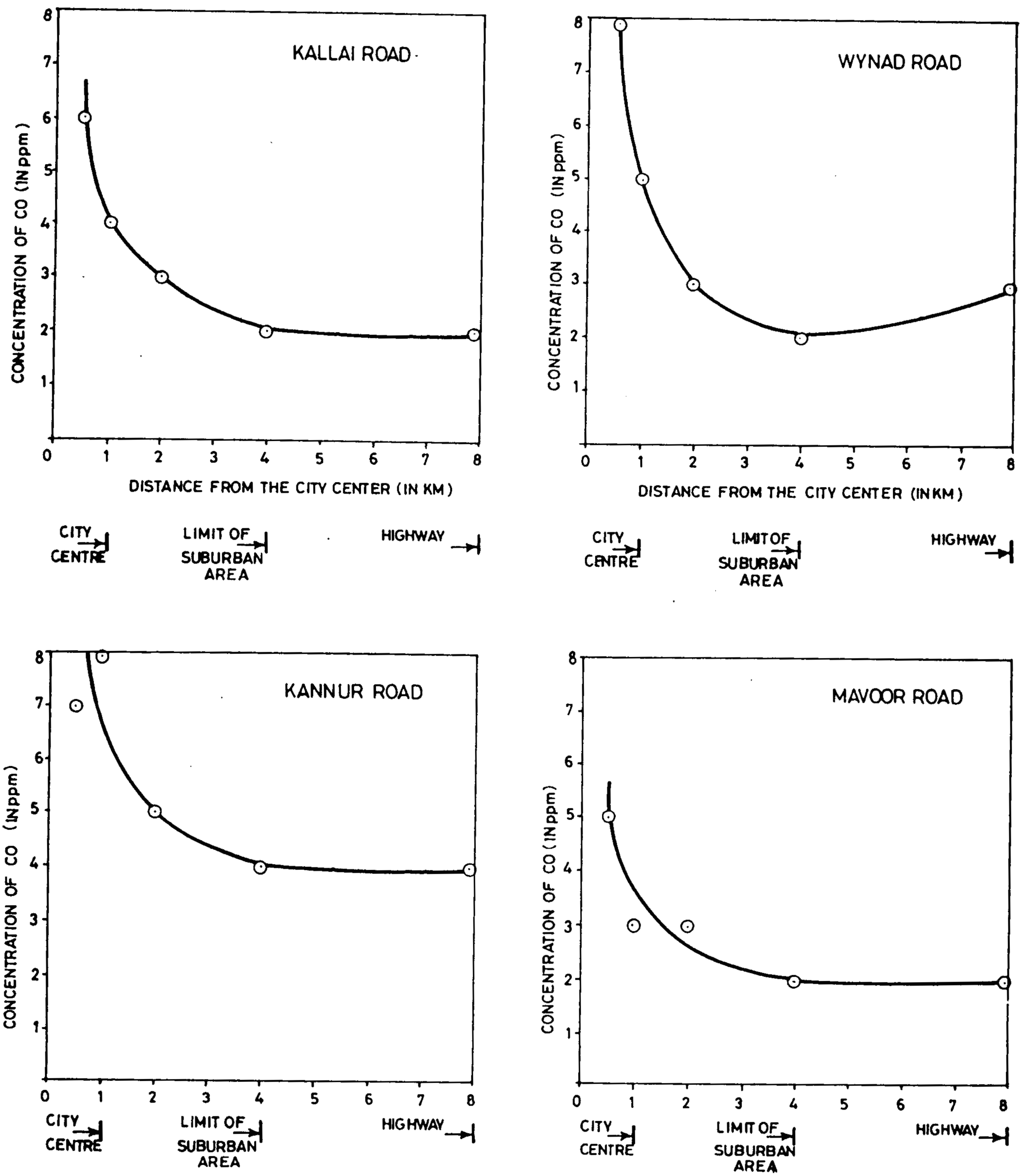

Fig. 4.3 VARIATION OF CONCENTRATION OF CO WITH DISTANCE FROM THE CITY CENTER

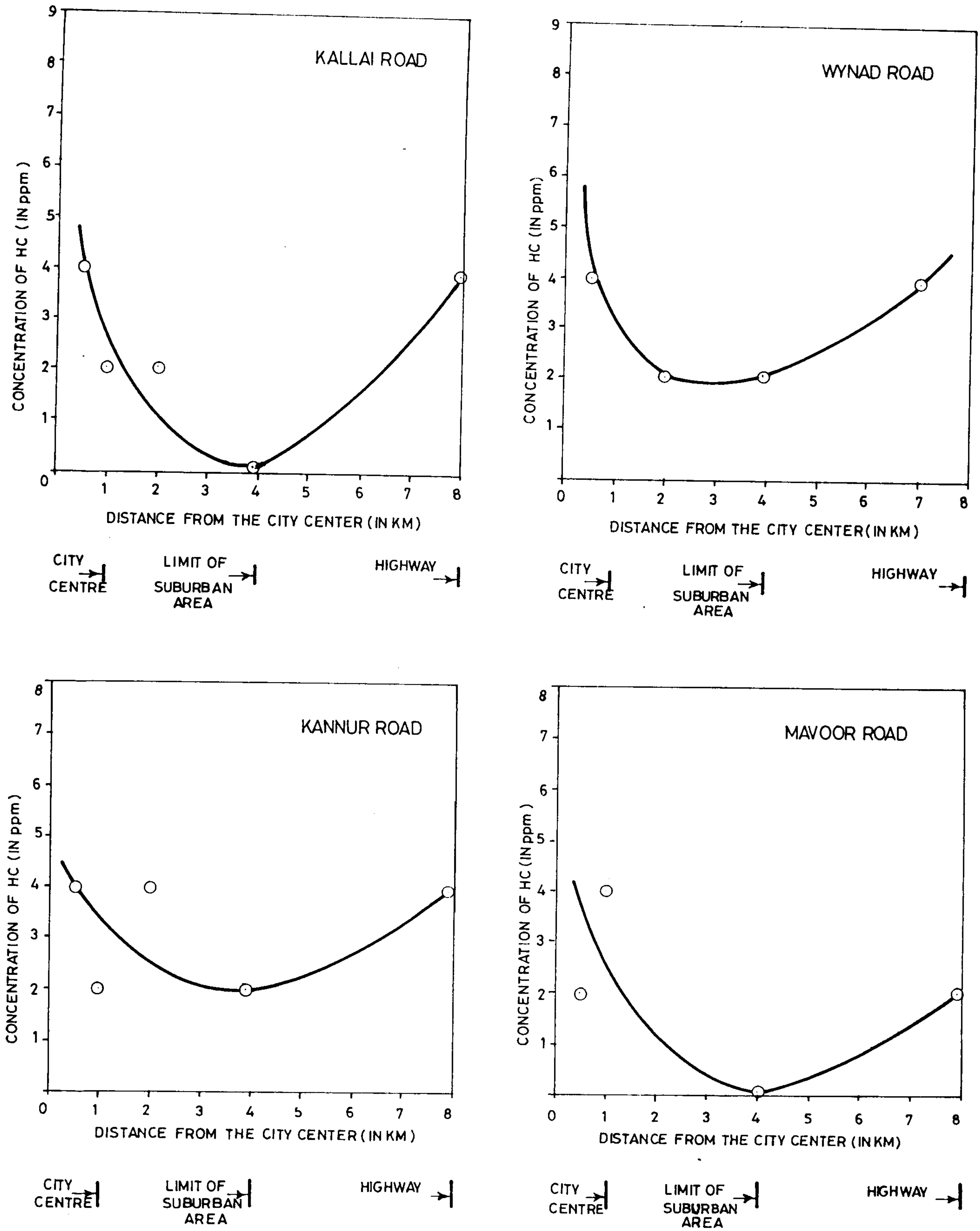

Fig.4.4 VARIATION OF CONCENTRATION OF HC WITH DISTANCE FROM THE CITY CENTER

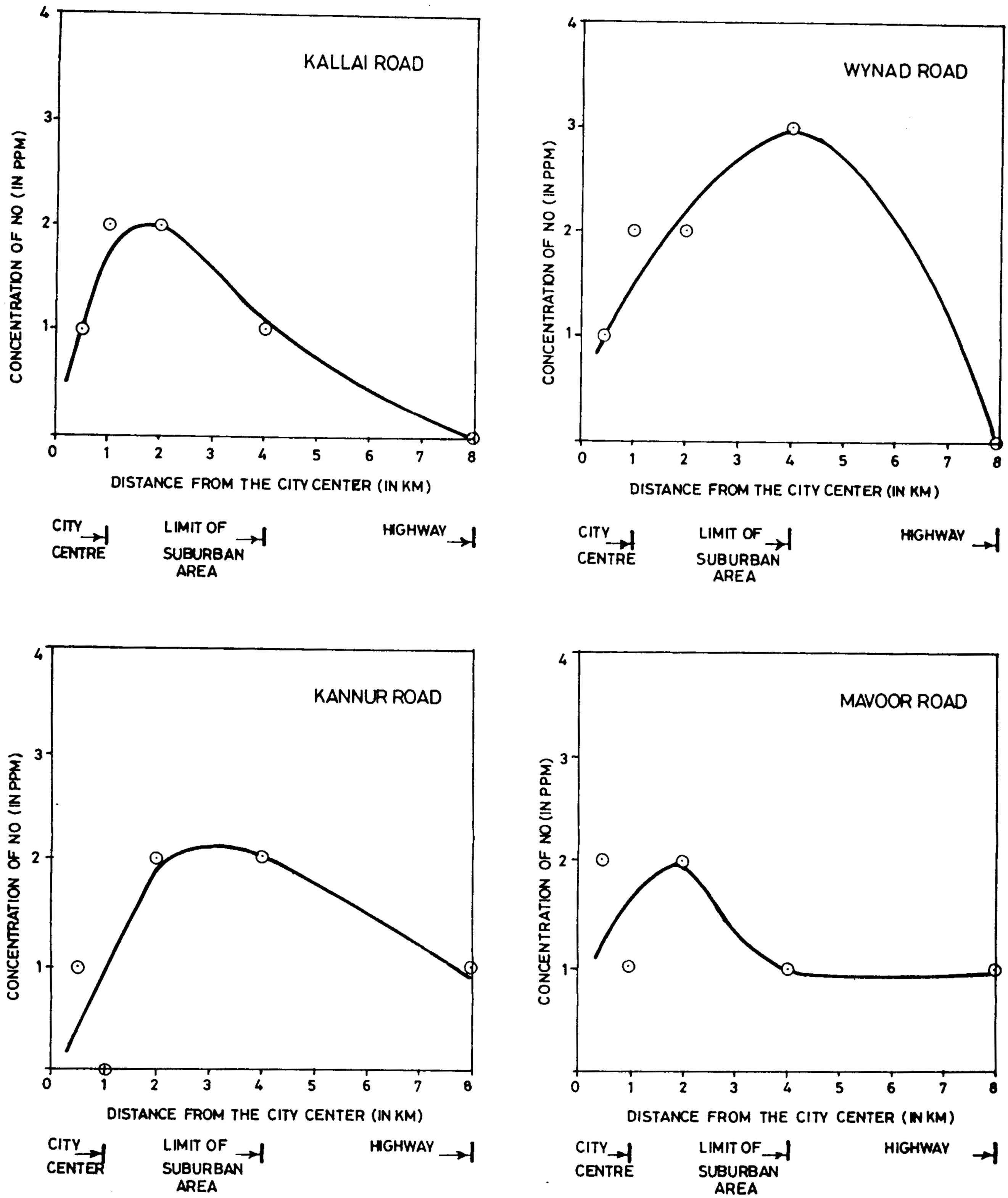

Fig. 4.5 VARIATION OF CONCENTRATION OF NO WITH DISTANCE FROM THE CITY CENTER

4.5 ESTIMATION OF LINK VOLUMES

The data required for the assignment model are:

i) Network data

ii) The O-D matrix data.

4.5.1 Network Data

The network data required for the assignment modelling are the link data and the turn data.

- Link data include the free flow travel times, link distances, the number of lanes and the travel time-flow relationships.
- Turn data include the junction delays to each specific turn, delay-turning flow relationship, separate lanes for turns and banned turns if any.

Link travel time-flow relationship was established from the data collected by a moving car observer survey conducted in Calicut city by the Transportation division of Regional Engineering College, Calicut. The study was conducted on the four major corridors of the city. The flow and travel times obtained after the analyses are presented in Table 4.7. The established travel time -flow relationship is shown in Fig. 4.6. Best fit curve to explain the relationship was found to be of exponential form, viz., $Y = A * e^{Bx}$, where; Y corresponds to travel time in min/km and x corresponds to traffic flow in veh/min.

A multiple regression analysis was performed between the variables, taking logarithm of travel time (min/km) as the dependent variable and traffic flow

Table 4.7 RESULTS FROM THE ANALYSIS OF MOVING CAR OBSERVER SURVEY

CORRIDOR	FLOW (in veh/min)	TRAVEL TIME (in min)
1 (a)	6.03	15.85
(b)	6.04	13.50
2 (a)	3.64	14.26
(b)	6.30	11.96
3 (a)	9.33	8.88
(b)	11.73	5.61
4 (a)	7.58	13.77
(b)	3.91	13.88

a : Journey up b : Journey down

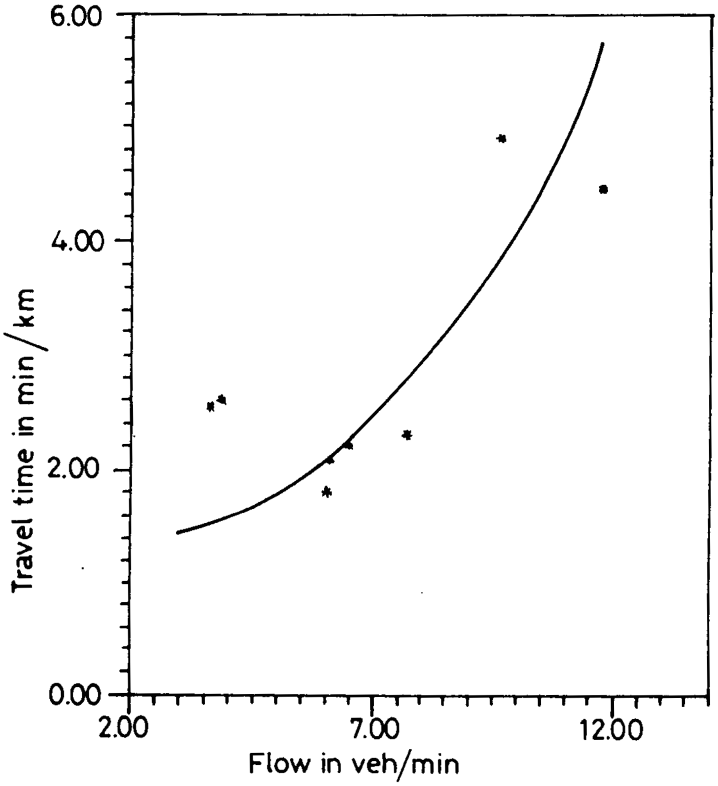

Fig.4.6 TRAVEL TIME-FLOW RELATIONSHIP →

(vehicles/min) as the independent variable and the resulting equation was:

$$Y = 1.2473 * \exp(0.094584 * X) \tag{4.1}$$

From this relationship, free flow travel time was obtained as 1.2473 min/km. Knowing the link distance, the free flow travel time for each link was obtained.

In this study, only the delays at junctions due to right turning volumes were considered. For this, delays due to right turning traffic at three flows, viz., i) zero flow ii) actual flow and iii) capacity-flow, were required. Delay at capacity, current flow and zero flow were calculated using Adam's formulae (Kadiyali(1991)). Thus delay- right turn flow relationship was established as:

$$Y = 0.0177804 * X^{1.34835} \tag{4.2}$$

where:

Y - junction delay to right turns in min/vehicles

X - right turning flow in vehicles/min

The above relationship is shown in Fig 4.7.

4.5.2 Generation of Seed O-D Matrix

For the assignment modelling, an O-D matrix is required. In this study this O-D matrix was generated using Internal Volume Forecasting (IVF) modelling philosophy based on Low's gravity formulation approach. The computer package NIPTAC-NODIAC developed by Nagaraj (1984) was used. The algorithm for the link-volume modelling philosophy can be represented as:

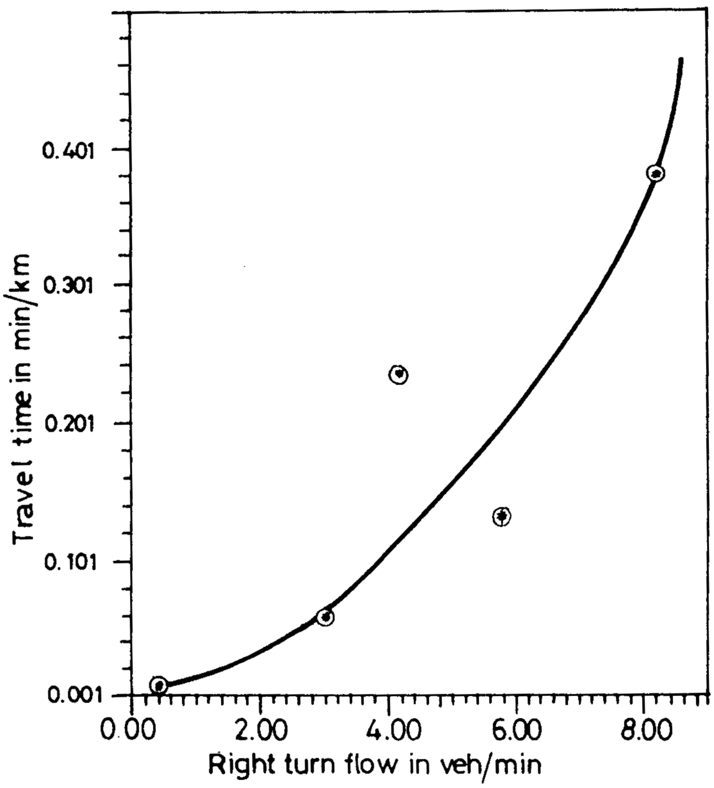

Fig. 4.7 DELAY-RIGHT TURN FLOW RELATIONSHIP

$$V_a = a_0 + a_1F_1 + a_2F_2 + \ldots \qquad (4.3)$$

Where F_1, F_2, ... are the trip probability factors. In general, these trip probability factors themselves can be represented as:

$$F = \sum_{ij} \left[\frac{O_i O_j f(d_{ij})}{\sum_j O_j f(d_{ij})} \right] P_{ij}^{a} \qquad (4.4)$$

Where:

O_i, O_j - are proxies for trip productions and trip attractions and $f(d_{ij})$ is the measure of deterrence.

P_{ij}^{a} - proportion of the traffic between **i** and **j** using link **a**

The usual proxies that are used for trip productions and trip attractions are the population and the employment of the zones of the study area.

The main inputs to the NIPTAC were:

i) Population and the employment particulars of each of the zones of the study area

ii) Node link table of the network

iii) Available link volume counts

Outputs from NIPTAC were:

i) The exponents of the deterrence function for different trip probability factors

ii) The estimated regression weights

The inputs for the NODIAC were:

i) The inputs used for NIPTAC

ii) The estimated forms of trip probability pairs

iii) The calibrated deterrence values

iv) The regression constants.

The output from the NODIAC were:

i) The simulated O-D matrix

ii) The link volume on all the links of the network

Following were the data required for IVF model calibration:

i) Zonal Description

ii) Network Description

iii) Socioeconomic characteristics of zones

iv) Traffic volumes on selected links

Zonal Description

The study area consisted of 39 revenue wards of Calicut Corporation. Combining the zones having similar economic activities, the total number of zones was reduced to 30 zones including six external zones. Those zones are shown in Fig.4.1. Fig.4.8 shows the study area with junction details and Table 4.8 gives the name of the important road junctions.

Network Description

Network coding and the preparation of node link diagram were done following

Table 4.8 NAME OF IMPORTANT ROAD JUNCTIONS

JUNCTION NO.	NAME OF THE JUNCTIONS
1	MAVOOR ROAD JUNCTION
2	ARAYADATHUPALAM
3	PALAYAM
4	FRANCIS ROAD
5	PATTALAMPALLI
6	CSI JUNCTION
7	STADIUM JUNCTION
8	MANORAMA JUNCTION
9	EAST NADAKKAVU
10	WEST NADAKKAVU

Potts and Oliver(1972). The zonal centroids were connected to the nearest highway system by means of dummy links. The network of Calicut city used for the work consisted of 118 nodes with centroids of 24 internal zones, 6 external zones, 6 gateways and 82 highway nodes. There were totally 340 links. Node link table was prepared with origin node, destination node and the free flow travel time for all the links in the network, except for the dummy connectors. Free flow travel time/km was obtained from the travel-time flow relationship. Free flow travel time on each link was obtained knowing the link distances.

Socio-Economic Characteristics of zones

Data regarding the population and the employment details of the zones of the study area were collected from the census of India office. These are given in Table 4.9 along with the area of zones in hectares.

Traffic Volumes on selected links

Traffic volumes on selected links, which were required for the calibration of IVF model, were supplied from the 1991 data files of the Consulting Engineering Services (CES). These are given in Table 4.10.

Calibrated models for different types of vehicles obtained from NIPTAC are presented in Table 4.11. Those models were accepted based on their statistical validity in terms of R^2 and t-test values. Link volumes were generated for each mode separately by NODIAC.

4.6 CONCLUSIONS

In this chapter, the procedure used for collection of traffic stream and air quality

Table 4.9 POPULATION, EMPLOYMENT AND ZONAL AREA
(AS PER 1991 CENSUS)

ZONE	POPULATION	EMPLOYMENT	AREA (in sq.km)
1	11618	711	1.81
2	18150	1066	6.23
3	10020	451	5.23
4	25261	1333	9.61
5	10576	651	6.55
6	16288	4230	8.73
7	28052	1800	8.12
8	21170	2206	4.09
9	26811	5447	3.77
10	30340	1998	3.56
11	45419	3879	1.74
12	7896	3563	0.64
13	2961	1607	0.23
14	3017	6500	0.41
15	34254	7297	2.02
16	25506	6073	3.70
17	20003	771	4.67
18	21006	2496	1.58
19	14788	9186	0.12
20	1690	11603	0.31
21	2762	1700	0.36
22	4165	1630	0.46
23	15512	4603	2.97
24	10398	3192	1.08

Table 4.10 TRAFFIC VOLUMES ON SELECTED LINKS (AS PER CENSUS (DATA DURING 9.00 AM - 11.00 AM)

ORIGIN	CAR	BUS	TRUCK	AUTO	TWO WHEELER	CYCLE
53-87	275	155	52	430	572	566
87-53	204	135	60	298	312	313
117-105	76	6	78	160	120	148
105-107	58	3	122	166	130	142
71-102	268	170	46	342	577	505
102-71	234	179	49	282	286	267
75-74	145	231	104	207	261	319
74-75	191	258	119	298	331	559
36-44	9	0	8	14	44	133
44-36	6	0	7	8	22	115
36-30	155	150	114	50	122	147
30-36	185	148	109	63	157	155
89-61	53	3	32	194	127	243
38-37	12	11	12	14	52	126
37-38	18	12	13	11	30	83
78-49	206	0	23	502	398	88
49-78	4	0	0	19	12	123
47-76	22	2	113	57	55	52
76-47	16	1	67	100	69	64
116-96	149	56	16	585	285	197
93-77	149	4	2	427	268	99
77-93	17	0	0	27	30	49
82-51	120	21	46	685	249	195
81-51	42	0	39	490	169	176
51-81	116	0	100	582	314	175
108-116	212	297	21	964	440	193
50-80	15	0	8	123	72	56
80-50	15	0	2	138	78	95
80-77	51	1	3	245	131	179
96-97	216	284	12	569	325	229
40-69	96	71	50	107	315	212
69-40	57	55	25	53	113	190

Table 4.11 CALIBRATED MODELS FOR DIFFERENT TYPES OF VEHICLE

Vehicle Type	Independent variables	Beta weights	t-test	Intercept	R^2 value
AUTO	10	2.8506	1.1188	68.6093	0.3124
	11	3.3970	7.7832		
	20	0.9168			
BUS	10	2.3733	1.3728	22.8395	0.3041
	11	5.3951	1.5487		
	16	2.5653	7.5299		
CAR	1	4.5187	2.4707	13.3955	0.4275
	6	4.4743	1.9747		
TWO WHEELER	1	4.0847	8.5170	39.4366	0.5107
	6	4.9095	1.2647		
	16	8.1947	1.6074		
TRUCK	1	1.2218	2.5971	17.2450	0.5441
	11	1.6473	2.2884		
	17	1.1273	1.5376		

where:

i for activity zone:

1 - $P_iP_jd_{ij}^{-0.5}/\Sigma P_jd_{ij}^{-0.5}$

6 - $P_iE_jd_{ij}^{-0.5}/\Sigma E_jd_{ij}^{-0.5}$

10 - $P_iE_jd_{ij}^{-2.5}/\Sigma E_jd_{ij}^{-2.5}$

ii for non-activity zone:

11 - $P_iP_jd_{ij}^{-0.5}/\Sigma P_jd_{ij}^{-0.5}$

16 - $P_iE_jd_{ij}^{-0.5}/\Sigma E_jd_{ij}^{-0.5}$

17 - $P_iE_jd_{ij}^{-1.5}/\Sigma E_jd_{ij}^{-1.5}$

has been described. Hand in hand with this, generation of O-D matrices for simulating the link volumes through IVF models has also been described. The presentation of the development and validation of pollutant concentration models are the subject matter of Chapter 5.

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DEVELOPMENT AND VALIDATION OF MODELS FOR PREDICTING CONCENTRATION OF AIR POLLUTANTS

Cini A. “Modelling and evaluation of ambient air quality levels due to mixed traffic on city roads” Thesis. Department of Civil Engineering ,Regional Engineering College, University of Calicut, 1999

CHAPTER 5

DEVELOPMENT AND VALIDATION OF MODELS FOR PREDICTING CONCENTRATION OF AIR POLLUTANTS

5.1 GENERAL

Even though Gaussian models are restricted by their simplifying assumptions, they are still used for the prediction of ambient air quality level. But to study the existing system or the effects of a system of moving vehicles on the ambient air quality levels near highways, regression and time series models should be developed. Such a study will be useful in transportation planning processes.

The objective of this Chapter is to explain the development of mathematical models to predict the pollutant concentrations due to road traffic at any instant, combining the effects of traffic stream variables at that instant and pollutant concentrations levels at a few past intervals of time, predicted by the time series based transfer function modelling approach.

5.2 DEVELOPMENT OF CAUSAL REGRESSION MODEL

Simple regression models were developed for the prediction of pollutant concentrations. The independent variables considered were the traffic volume, the speed, the percentage composition of auto-rickshaws, and the percentage composition of two-wheelers. Table 5.1 gives the selected models based on the

Table 5.1 MODELS FOR PREDICTING POLLUTANT CONCENTRATION

List of variables	Beta Weights	t-test values	Intercept constant	R^2 value
		CARBON MONOXIDE		
4	0.0369	4.6386	2.533	0.4176
1	0.0041	1.8839	4.838	0.2431
5	-0.0735	-2.6126		
2	-0.0191	-0.4666	3.445	0.4217
4	0.0308	2.8199		
2	-0.0623	-3.2740	7.709	0.3798
5	-0.0579	-2.3320		
2	-0.0335	-0.8227		
4	0.0187	1.8641	5.667	0.4481
5	-0.0443	-1.1544		
		HYDRO CARBONS		
1	0.0061	3.0964	1.698	0.2566
4	-0.0438	-2.8723		
1	0.0069	3.4390		
2	0.0430	1.5510	0.586	0.3155
4	-0.0303	-1.5930		
		NITRIC OXIDE		
2	0.0441	2.9643	0.105	0.2265
1	0.0034	2.6120		
2	0.0517	2.9409	0.961	0.3877
4	-0.0067	-1.0260		
5	-0.0002	-0.8230		

Where:
1 Traffic volume
2 Traffic speed
3 Pollutant concentration predicted by transfer function models
4 Percentage composition of auto-rickshaws
5 Percentage composition of two-wheelers
6 Ambient Air Quality level(dependent variable)

regression sum of square and the t-test values. The physical validation of the selected model was done by calculating the root mean square (RMS) error percentage obtained by comparing the predicted values with the observed values.

Figs. 5.1 to 5.4 show graphically the fluctuations in traffic volumes and the pollutant concentrations over time on the four trunk routes. High and low values of both the time series occur roughly at the same time. But at few instances, pollutant concentrations show peak values one or two time periods after the occurrence of peaks for traffic volume. This lagged relationship between traffic volume and pollutant concentrations, which when accounted along with causal variables might improve the explanatory power of the models. Therefore, it was thought that it might be necessary to incorporate pollution concentration levels by time series analysis using transfer function modelling approach.

5.3 DEVELOPMENT OF TRANSFER FUNCTION MODEL

There are three main stages and various sub stages in the complete process of transfer function model building. Different stages involved in the Transfer Function Modelling approach are:

STAGE I : IDENTIFICATION OF THE MODEL STRUCTURE

1. Preparation of the input and output series
2. Prewhitening of the input and output series
3. Computing cross and auto correlations for the prewhitened series
4. Estimation of the impulse response weights
5. Specifying the order (r,s,b) for the transfer function model
6. Estimation of the noise series

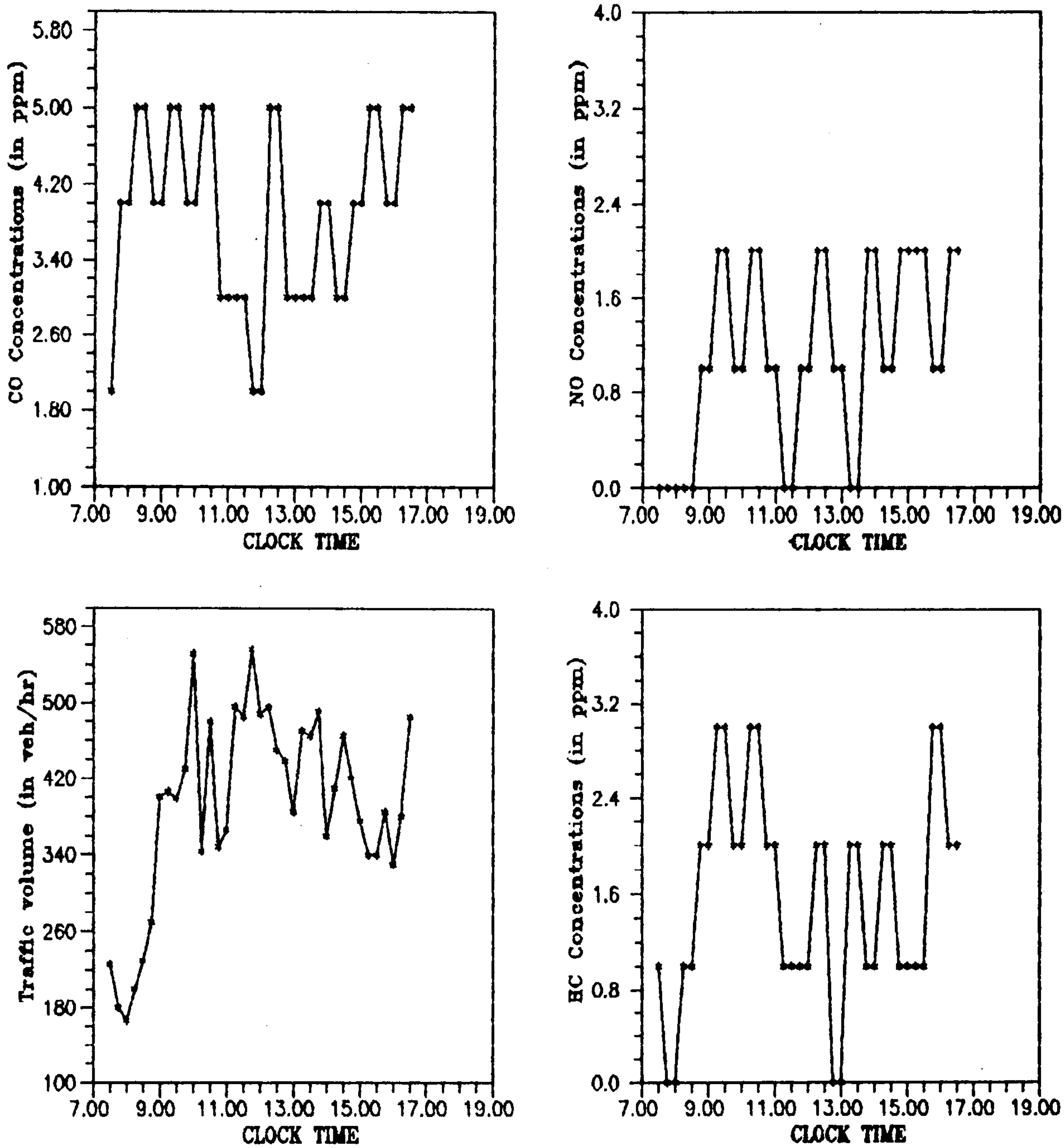


Fig. 5.1 Fluctuations of Traffic Volume , Hydrocarbons, Carbon monoxide and Nitric oxide concentrations with clock time (Trichur Road)

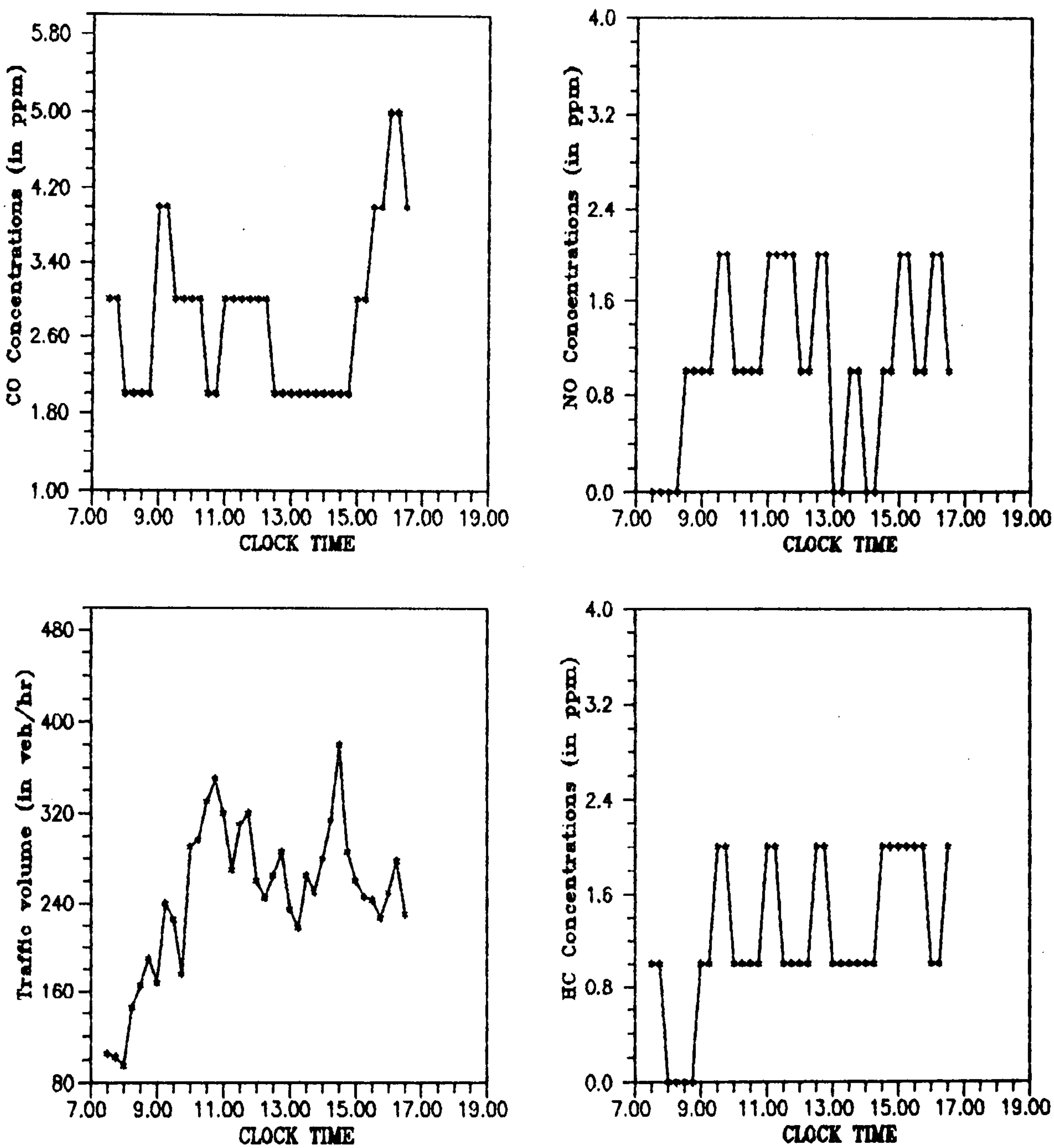


Fig. 5.2 Fluctuations of Traffic Volume , Hydrocarbons, Carbon monoxide and Nitric oxide concentrations with clock time (Kannur Road)

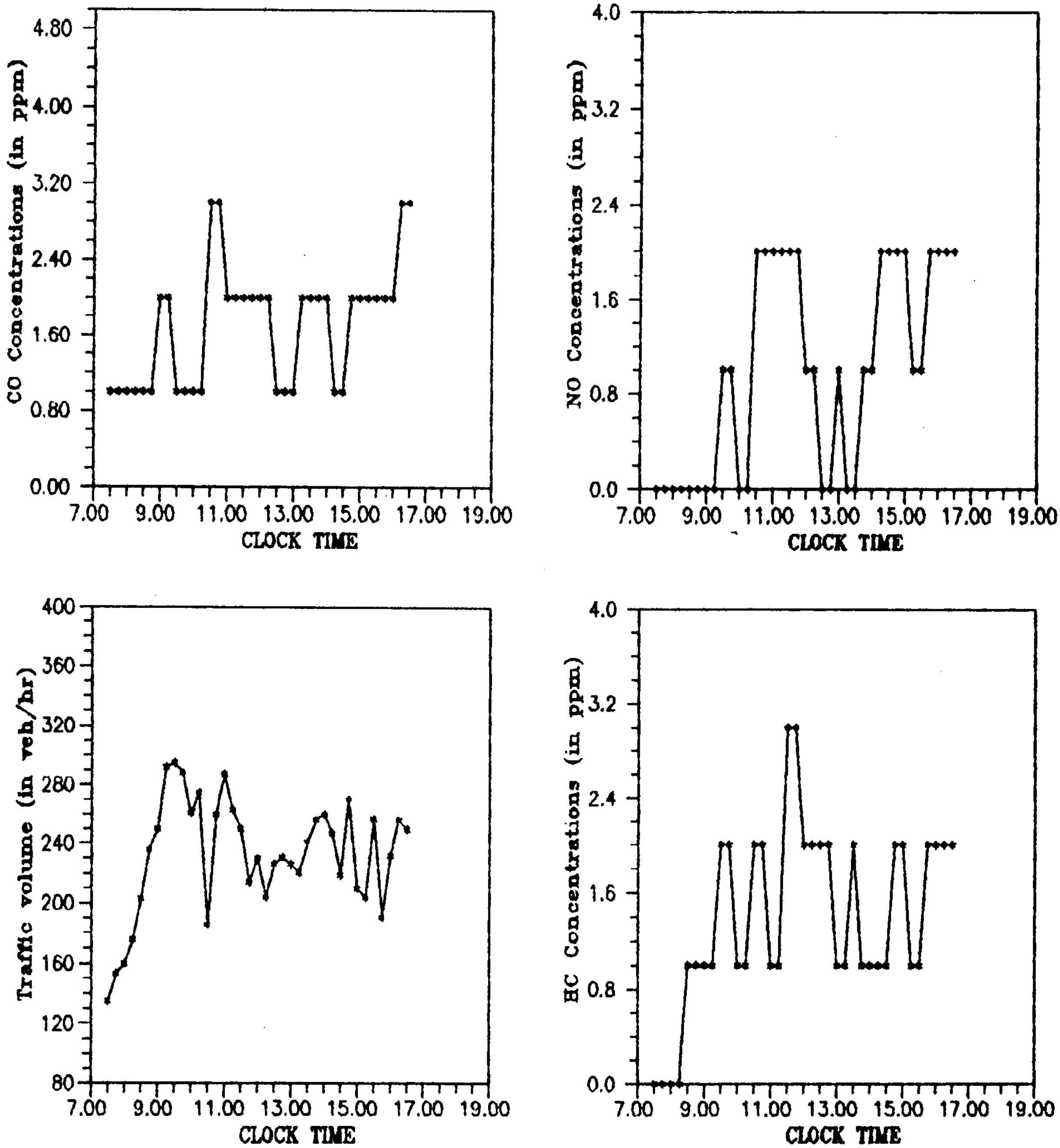


Fig. 5.3 Fluctuations of Traffic Volume , Hydrocarbons, Carbon monoxide and Nitric oxide concentrations with clock time (Mavoor Road)

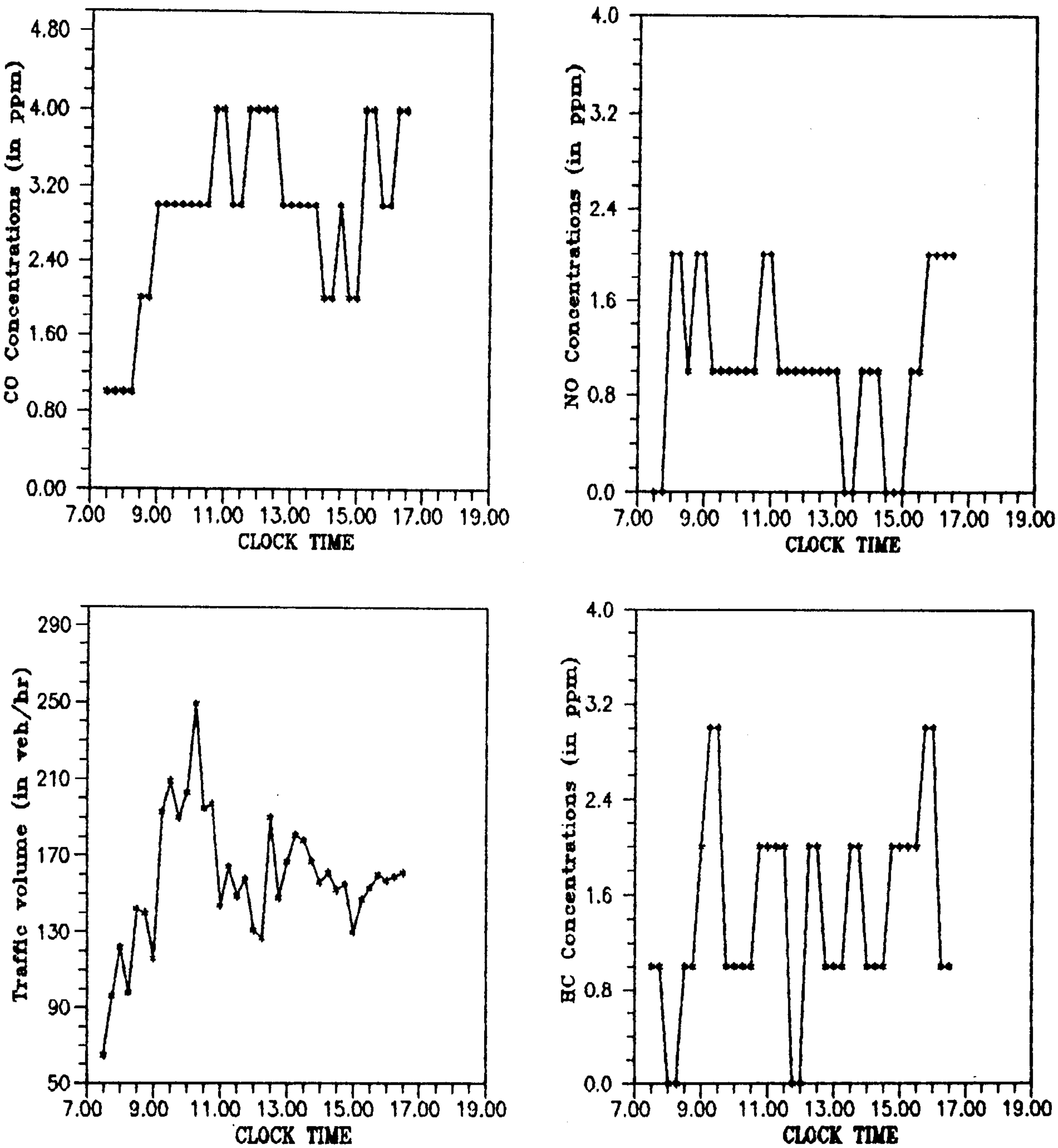


Fig. 5.4 Fluctuations of Traffic Volume , Hydrocarbons, Carbon monoxide and Nitric oxide concentrations with clock time (Wynad Road)

7. Specifying the ARMA model of the noise series

STAGE II : ESTIMATION OF THE PARAMETERS OF TRANSFER FUNCTION MODEL

1. Preliminary estimates of the parameters
2. Final estimates of the parameters

STAGE III : DIAGNOSTIC TESTING OF TRANSFER FUNCTION MODEL

1. Computation of autocorrelations for the residuals
2. Computation of cross correlation between the residuals and the prewhitened series

Fig. 5.5 shows the various steps in transfer function modelling (Makridakis(1978)). Each step involved in this modelling approach is explained for a set of data.

5.3.1 Identification of the Model Structure

If the data show seasonality, non-stationarity or a definite trend, they must be differenced before starting transfer function modelling. Plots of both input and output series before and after taking difference are shown in Figs. 5.6 and 5.7 respectively. Autocorrelation for the original and differenced series are given in Table 5.2. Autocorrelation values for the differenced series were almost equal to zero. This showed that there was no trend or stationarity in the differenced data.

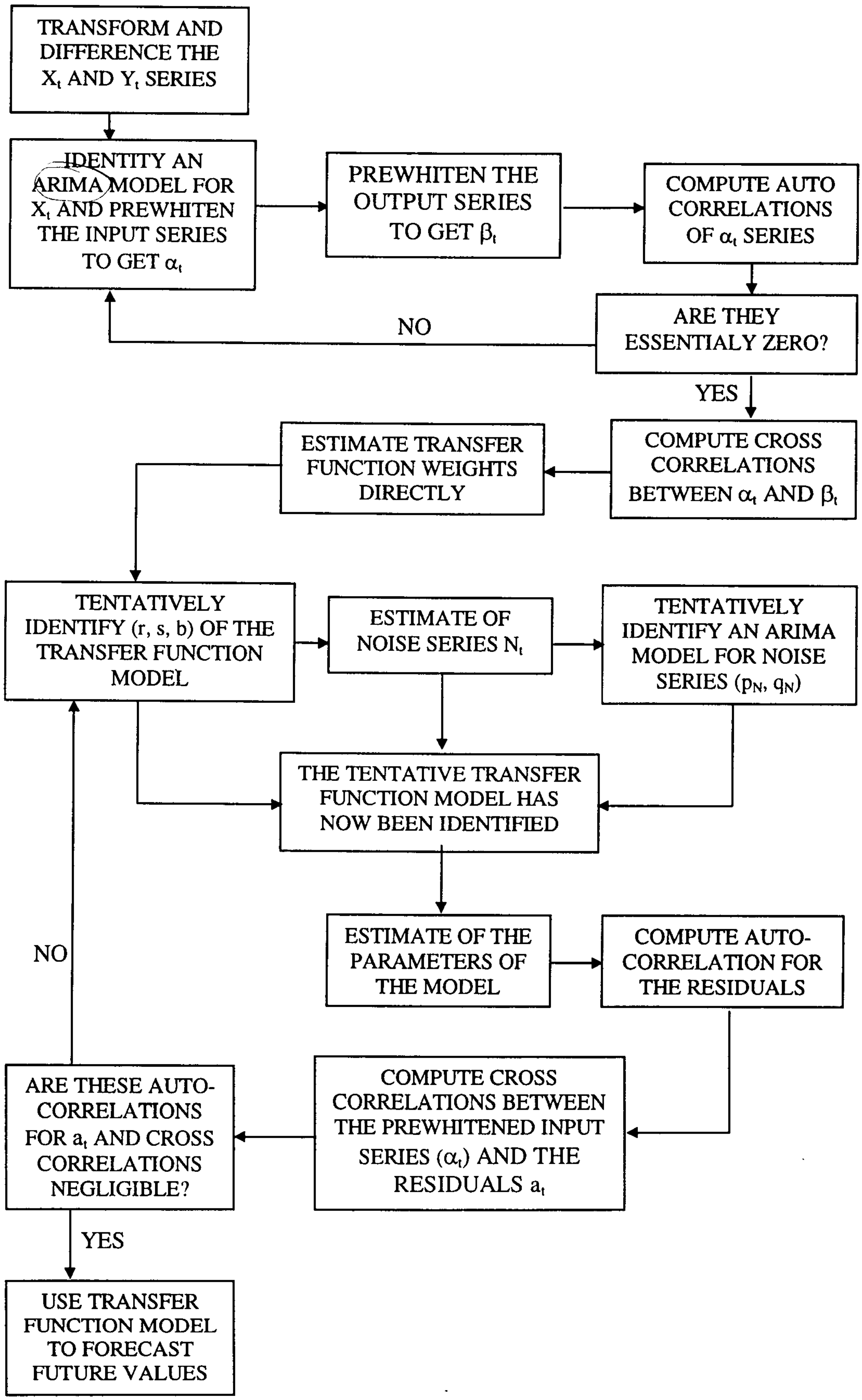


Fig. 5.5 FLOW CHART FOR IDENTIFICATION AND FORECASTING USING TRANSFER FUNCTION MODELLING

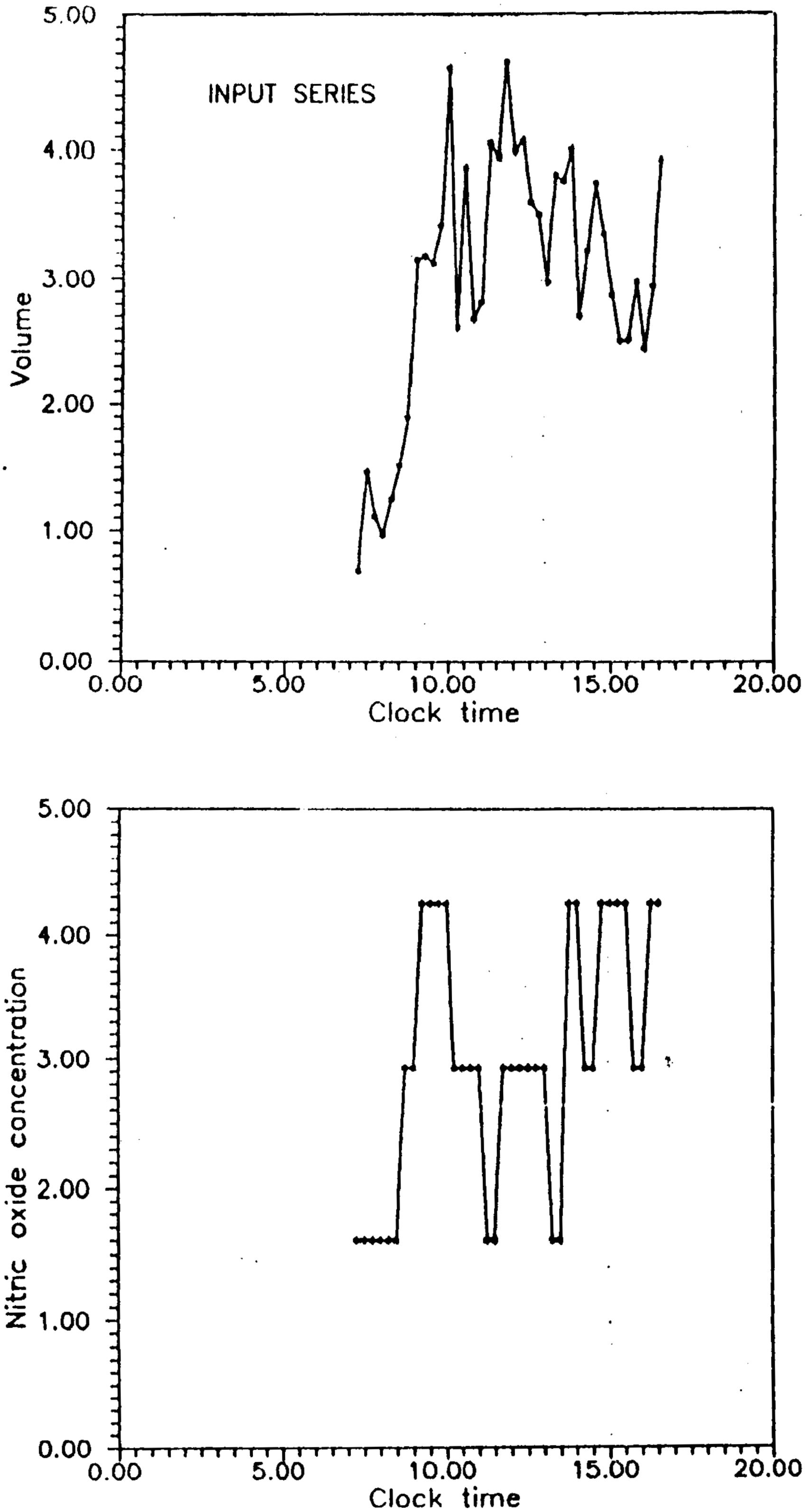
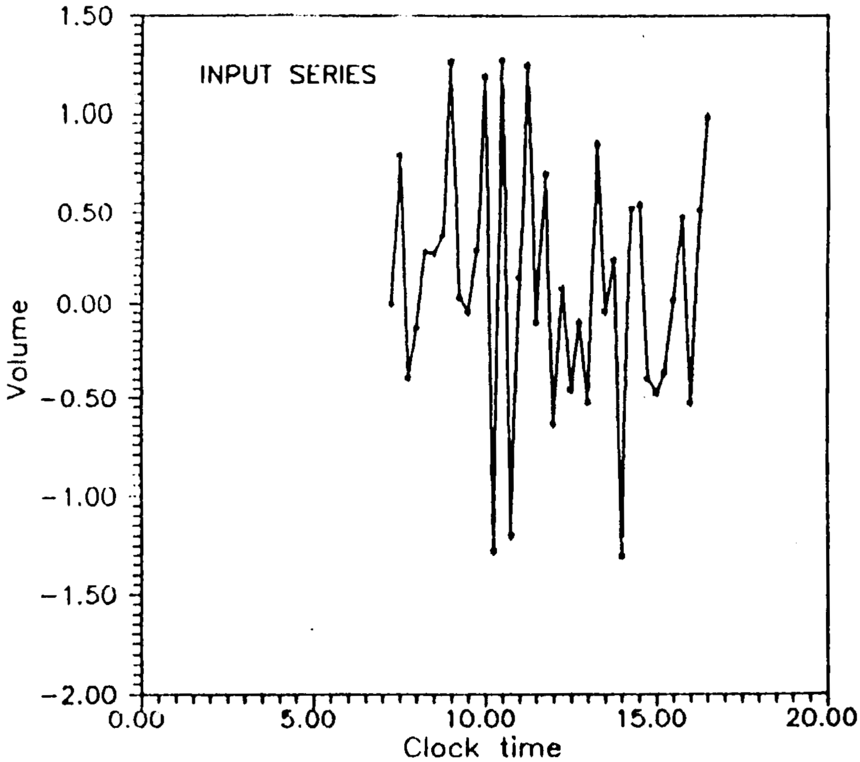


Fig. 5.6 INPUT AND OUTPUT SERIES BEFORE DIFFERENCING



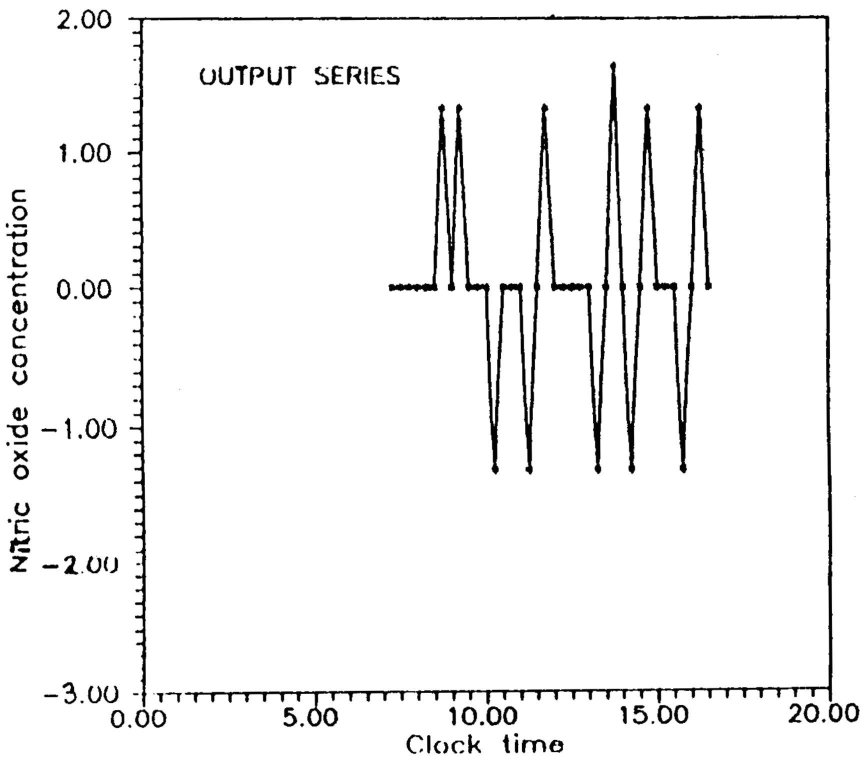


Fig. 5.7 INPUT AND OUTPUT SERIES AFTER DIFFERENCING

Table 5.2 AUTOCORRELATION VALUES OF STANDARDISED AND DIFFERENCED SERIES

	Standardised series			Differenced series	
lag (k)	x_t	y_t	lag (k)	x_t	y_t
1	0.663	0.634	1	-0.392	-0.008
2	0.592	0.269	2	-0.119	-0.436
3	0.447	0.221	3	-0.048	-0.005
4	0.300	0.173	4	-0.034	-0.135
5	0.195	-0.010	5	-0.009	-0.009
6	-0.264	-0.045	6	-0.019	-0.149
7	0.022	-0.236	7	-0.061	-0.005
8	0.039	-0.280	8	0.069	-0.070
9	0.010	-0.186	9	0.099	-0.002
10	-0.059	-0.093	10	-0.028	-0.001

In transfer function modelling approach, identification of the model form is easier if the input system is as simple as possible. The input series can be made more manageable by prewhitening. That means removing all known patterns to leave just white noise. This can be done by modelling as an ARMA(p,q) process. For the given set of data, ARMA(1,1) model was identified for prewhitening of the input series and this can be written as:

$$(1 - \phi_1 B)\ x_t = (1 - \theta_1)\alpha_t \qquad (5.1)$$

$$\alpha_t = x_t - \phi_1\ x_{t-1} + \theta_1\ \alpha_{t-1} \qquad (5.2)$$

where:

ϕ_1 and θ_1	are the autoregressive and moving average operators
α_t	is the white noise term
x_t	is the input series
B	the differential operators

The values of the parameters ϕ_1 and θ_1 were calculated by solving the Yule-Walker equations (Box and ~~Junkins~~(1976)). The estimated values of ϕ_1 and θ_1 were –0.008 and 0.07 respectively. The prewhitened output series was:

$$\beta_t = y_t - \phi_{1y t-1} + \theta_1 \beta_{t-1} \qquad (5.3)$$

The prewhitened input and output series are given in Table 5.3. The next step was to check the autocorrelations of the input and output series. By

Table 5.3 THE COMPLETE SET OF PREWHITENED SERIES

Sl.No.	Input Series(α_t)	Output Series(β_t)
1	0.000	0.000
2	-0.358	0.000
3	-0.140	0.000
4	0.276	0.000
5	0.273	0.000
6	0.378	1.317
7	1.263	0.020
8	0.048	1.318
9	-0.047	0.020
10	0.287	0.000
11	1.185	0.000
12	-1.969	-1.317
13	1.237	-0.020
14	-1.181	0.000
15	0.116	0.000
16	1.240	-1.317
17	-0.087	-0.020
18	0.689	1.317
19	-0.633	0.020
20	0.067	0.000
21	-0.460	0.000
22	-0.112	0.000
23	-0.629	0.000
24	0.837	-1.317
25	-0.037	-0.020
26	0.230	2.635
27	-1.302	0.040
28	0.499	-1.317
29	0.545	-0.020
30	-0.395	1.317
31	-0.486	0.020
32	-0.381	0.000
33	0.004	0.000
34	0.470	-1.317
35	-0.530	-0.020
36	0.501	1.817
37	0.986	0.020

prewhitening, all known patterns of the input and output series were removed. Therefore autocorrelations were expected to be small. The autocorrelation values and their corresponding plot for the prewhitened input and output series are given in Table 5.4 and Fig. 5.8. Most of the values appear to be very nearly equal to zero.

Cross correlation values have important role in transfer function modelling. It is a measure of the relationship between two series and can be calculated as:

$$\tau_{\alpha\beta}^{(k)} = \frac{C_{\alpha\beta}^{(k)}}{S_{\alpha}\ S_{\beta}} \qquad (5.4)$$

Where:

$C_{\alpha\beta}$ - the co-variance between α and β

S_{α} - standard deviation of input series

S_{β} - standard deviation of output series

k - time lag considered

The cross correlations between prewhitened input and output series and their corresponding plot are given in Table 5.5 and Fig. 5.9, respectively. The highest value of cross correlation was for time lag 2, which meant that the pollution level after two time periods would depend on the volume at the present time period. For identifying the order or transfer function and for the estimation of noise series, the impulse response weights or transfer function weights are necessary. The impulse response weights $v_1, v_2, \ldots, v_k$ etc. as given in equation 5.5 are the values which measure the responses of output series with input series. The values of transfer function weights are calculated from the cross correlation

Table 5.4 AUTOCORRELATION VALUES OF PREWHITENED SERIES

Lag	Input series	Output series
1	-0.378	0.001
2	0.119	-0.440
3	-0.059	-0.013
4	-0.050	0.136
5	-0.008	-0.004
6	-0.070	-0.148
7	-0.063	-0.003
8	0.078	0.072
9	0.092	-0.001
10	-0.074	0.000

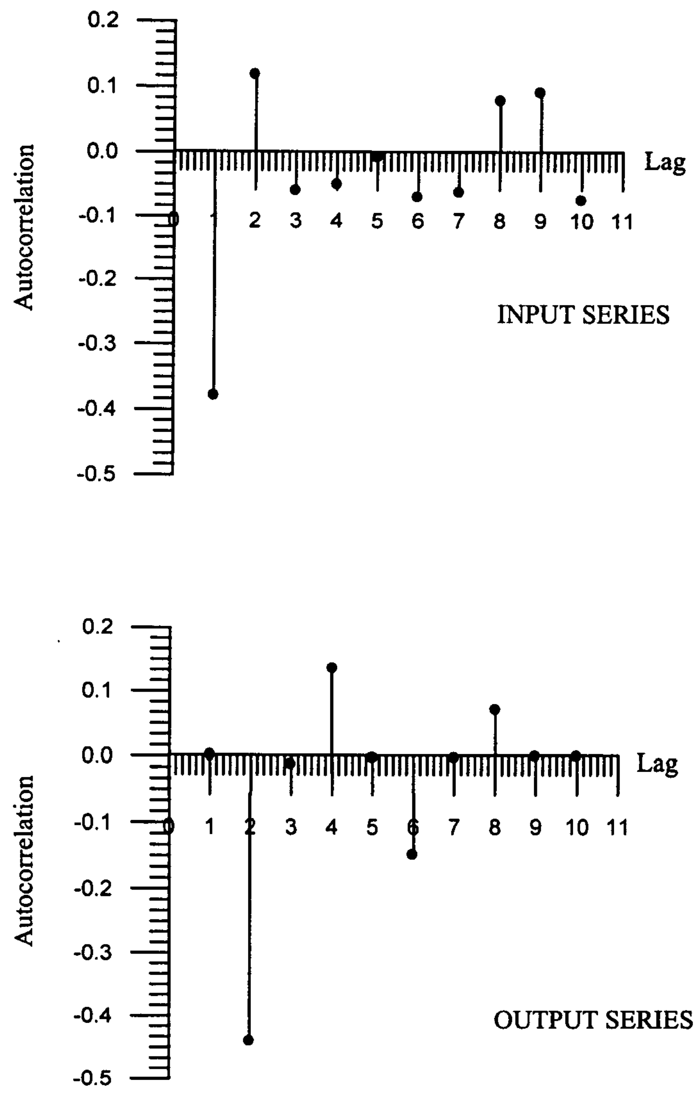


Fig. 5.8 AUTOCORRELATION VALUES PREWHITENED SERIES

Table 5.5 CROSS-CORRELATION BETWEEN PREWHITENED INPUT AND OUTPUT SERIES

Lag	Cross correlation
-6	-0.001
-5	0.014
-4	-0.130
-3	0.181
-2	0.066
-1	-0.175
0	0.027
1	0.112
2	0.350
3	-0.148
4	-0.025
5	-0.141
6	-0.225
7	-0.002

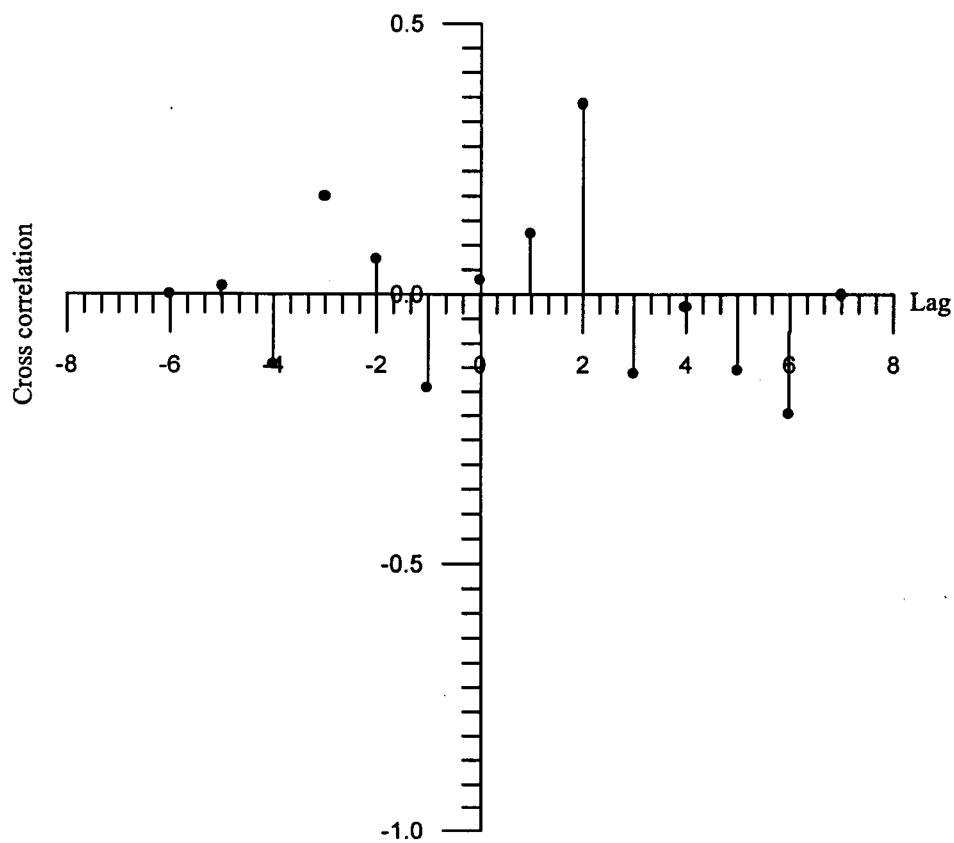


Fig. 5.9 CROSS-CORRELATION BETWEEN PREWHITENED INPUT AND OUTPUT SERIES

between the input and the output series and standard deviations of the prewhitened input and output series as:

$$V_k = \frac{\tau_{\alpha\beta}^{(k)} S_\beta}{S_\alpha} \qquad (5.5)$$

The calculated values of transfer function weights are given in Table 5.6. The highest value of impulse response weights is for k = 2, which means that the output series after two time periods is highly responsive to the input series at present time periods.

The next stage of transfer function modelling was to identify (r,s,b), the order of the transfer function model connecting x_t and y_t. The parameter b is the delay or lag parameter. From the analysis of cross correlations and transfer function weights, the lag parameter b was identified as 2. By testing different models for the given set of data, r and s were identified as 1,1 respectively.

In order to specify the complete transfer function model, it was necessary to estimate the noise series and to choose an ARMA model for the same. By rearranging the terms in equation ~~5.1~~ 2.4, the noise series can be calculated as:

$$n_t = y_t - v_0 x_t - v_1 x_{t-1} - \ldots - v_g x_{t-g} \qquad (5.6)$$

Where, 'g' is a practical value chosen by the forecaster. Here g was taken as 6. The calculated values of noise series is given in Table 5.7, and the autocorrelation values and their plot of noise series are shown in Table 5.8 and Fig.5.10, respectively. The autocorrelation values show a second order

Table 5.6 TRANSFER FUNCTION WEIGHTS

Lag (k)	Transfer function weights
0	0.0309
1	0.1283
2	0.4010
3	-0.1695
4	-0.0286
5	-0.1615
6	-0.2578
7	-0.0022

Table 5.7 CALCULATED VALUES OF NOISE SERIES

Sl.No.	Noise series
1	1.253
2	-0.007
3	0.643
4	-0.425
5	0.324
6	0.116
7	-1.230
8	0.110
9	0.870
10	-0.627
11	-0.469
12	-0.393
13	0.494
14	0.320
15	-0.500
16	-0.416
17	0.178
18	-0.046
19	1.501
20	0.551
21	0.328
22	-1.184
23	0.582
24	1.107
25	-0.103
26	-0.266
27	0.030
28	0.347
29	1.074
30	0.023
31	0.727
32	1.229

Table 5.8 AUTOCORRELATION VALUES OF NOISE SERIES

Lag	Autocorrelation
1	-0.081
2	-0.025
3	-0.018
4	-0.153
5	-0.061
6	-0.042
7	-0.076
8	0.155
9	0.015
10	-0.091

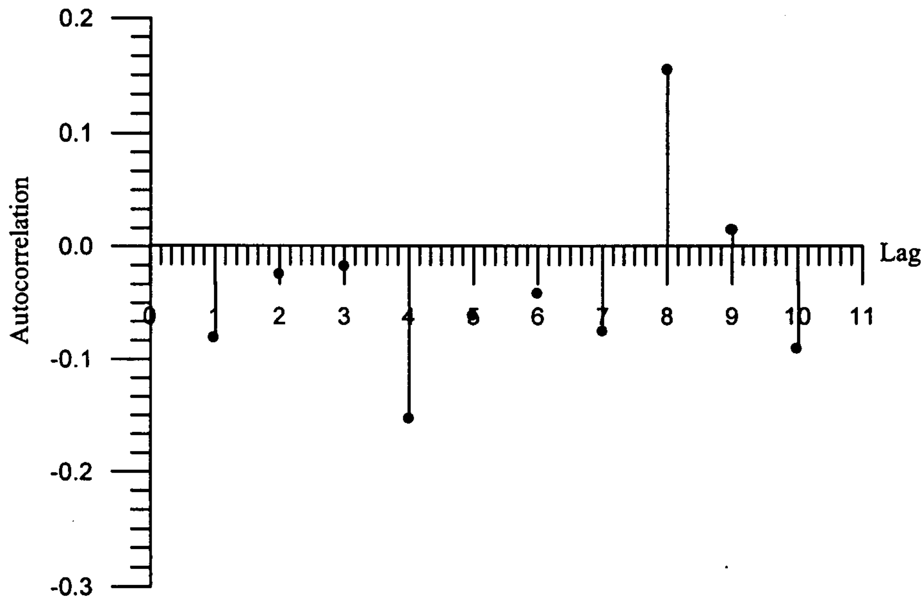


Fig. 5.10 AUTOCORRELATION VALUES OF NOISE SERIES

autoregressive aspect ie., damped sine wave shape. Therefore ARMA (2,1) was identified for modelling noise series and can be written as:

$$n_t = \frac{(1 - \theta_1 B)}{(1 - \phi_1 B - \phi_2 B^2)} a_t \tag{5.7}$$

where:

ϕ_1 and ϕ_2 – the autoregressive parameters

θ_1 - moving average parameter

a_t - a random noise

By using the above explained procedures, the transfer function model was identified as:

$$y_t = \frac{(w_0 - w_1 B)}{(1 - \delta_1 B)} x_{t-2} + \frac{(1 - \theta_1 B)}{(1 - \phi_1 B - \phi_2 B^2)} a_t \tag{5.8}$$

5.3.2 Estimation of Parameters

The parameters to be estimated are w_0, w_1, δ_1, θ_1, ϕ_1 and ϕ_2. The parameters w_0, w_1 and δ_1 of the input series were calculated from the transfer function weights and the θ_1, ϕ_1 and ϕ_2 of ARMA(2,1) model for the noise series were calculated from the autocorrelation values of noise series. The estimated value of parameters w_0, w_1, δ_1, θ_1, ϕ_1 and ϕ_2 for the given set of data were:

$$w_0 = 0.4010 \quad w_1 = 0.2370$$

$$\delta_1 = 0.1687 \quad \theta_1 = 0.0815$$

$$\phi_1 = -0.0835 \quad \phi_2 = -0.0317$$

Thus the final transfer function model was identified as:

$$y_t = \frac{(0.401 - 0.237B)}{(1 - 0.1687B)} x_{t-2} + \frac{(1- 0.8158B)}{(1 + 0.8538B+ 0.0317B^2)} a_t \qquad (5.9)$$

Table 5.9 gives the identified models for three pollutants, viz., carbon monoxide, hydrocarbons and nitric oxide, respectively for all the four rings.

5.3.3 Diagnostic Testing of the Model

The testing of the model was done by analysing the residual series of the transfer function model. The residual series a_t was obtained from the equation Eqn. (5.9). Two types of testing were done for the statistical validation. In the first test, the Box-Pierce chi-square test was used to check whether the set of autocorrelations was significantly different from zero. Chi-square value obtained from the table at 5 percent significance level was 14.007, which was higher than the calculated value of 8.001, which only meant that the values of residuals were not correlated. The autocorrelation values of the residual series and their corresponding plot are shown in Table 5.10 and Fig.5.11, respectively.

The prewhitened input series α_t was independent of the random noise component a_t. So it was obvious that there would not be any significant cross correlation between α_t and a_t. Calculated values of cross correlation between

Table 5.9 IDENTIFIED MODELS FOR THE FOUR BANDS/RINGS

Ring No.	w_0	w_1	δ_1	θ_1	ϕ_1	ϕ_2	b
			CARBON MONOXIDE				
I	0.1132	0.2212	0.638	0.007	-0.0097	-0.397	2
II	0.0218	0.0924	1.170	0.120	0.8830	0.000	2
III	0.2287	-0.1590	-0.778	0.570	0.6960	0.000	1
IV	0.2890	-0.0407	0.513	0.300	0.7250	0.000	2
			HYDRO CARBONS				
I	0.1570	-0.7730	0.110	0.300	0.6150	0.000	1
II	0.4150	-0.4750	0.590	-0.179	-0.2578	-0.482	1
III	0.0260	0.0014	0.633	-0.531	0.5700	-0.377	3
IV	0.0760	0.1713	0.776	0.250	0.6899	-0.352	1
			NITRIC OXIDE				
I	0.4010	0.2370	0.169	0.082	-0.0835	-0.032	2
II	0.2090	-1.0080	0.664	0.470	0.7010	0.000	2
III	0.2406	-1.9180	-0.066	-0.094	0.0946	0.000	1
IV	0.1860	0.7380	-0.727	0.180	0.6540	0.000	1

Table 5.10 AUTOCORRELATION VALUES OF RESIDUAL SERIES

Lag	Autocorrelation
1	0.145
2	-0.298
3	-0.086
4	0.082
5	0.006
6	-0.133
7	-0.056
8	-0.900
9	-0.048
10	0.037

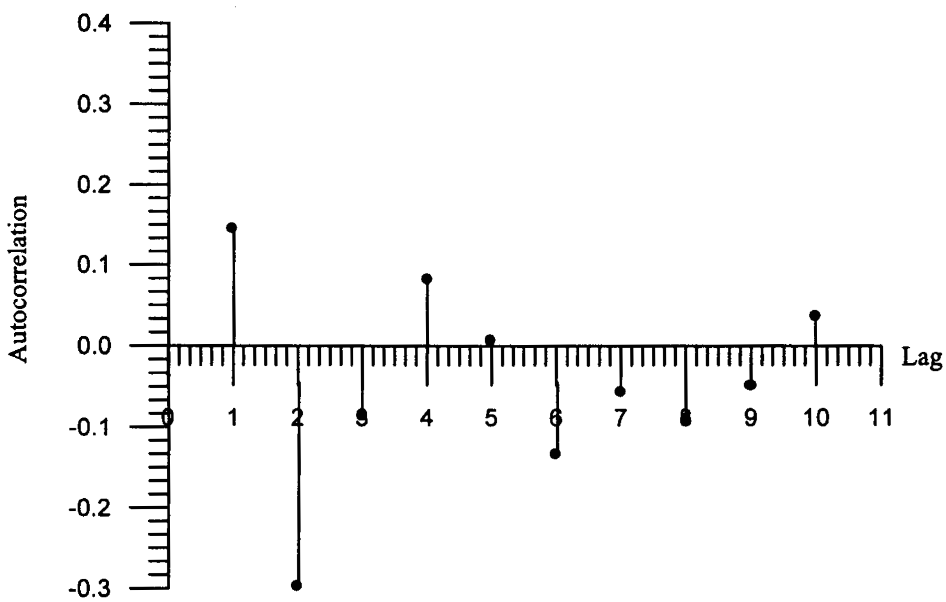


Fig. 5.11 AUTOCORRELATION VALUES OF RESIDUAL SERIES

α_t and a_t are given in Table 5.11 and their plot is shown in Fig. 5.12. In the second test, Box – Pierce chi- square test was used to check whether the cross correlation between α_t and a_t were significantly different from zero. The value obtained from the table at 5 percent significance level was 15.507, which was higher than the calculated value of 7.375. That only confirmed that the prewhitened input series was independent of random noise component.

Physical validation of the models was done by analysing the RMS percentage errors, obtained from the predicted and observed concentration of pollutants. The observed and estimated values for pollutants CO, HC and NO on each trunk road and their corresponding RMS percentage errors are given in Table 5.12. For checking the validity, one more set of data were collected from the same study area. The observed and estimated values of pollutant concentrations and their corresponding RMS percentage errors for the second set of data was given in Table 5.13. The RMS percentage obtained were observed to be on the higher side, which only confirmed that the influence of other traffic parameters should be included in model building. In transfer function modelling, only an overall effect of volume is taken into account for the model building, and hence the need for inclusion of direct causal effect.

5.4 COMPOSITE MODELS FOR PREDICTING POLLUTANT CONCENTRATION LEVELS

Regression models were then developed, by combining both the traffic stream parameters and the pollution levels predicted by the transfer function models. Table 5.14 gives the details of the selected models based on root mean square and t-test values. From those models, it was observed that inclusion of the

Table 5.11 CROSS-CORRELATION BETWEEN PREWHITENED INPUT AND RESIDUALS SERIES

Lag	Cross-correlation
1	-0.081
2	-0.025
3	-0.018
4	-0.153
5	-0.061
6	-0.042
7	-0.076
8	0.155
9	0.015
10	-0.091

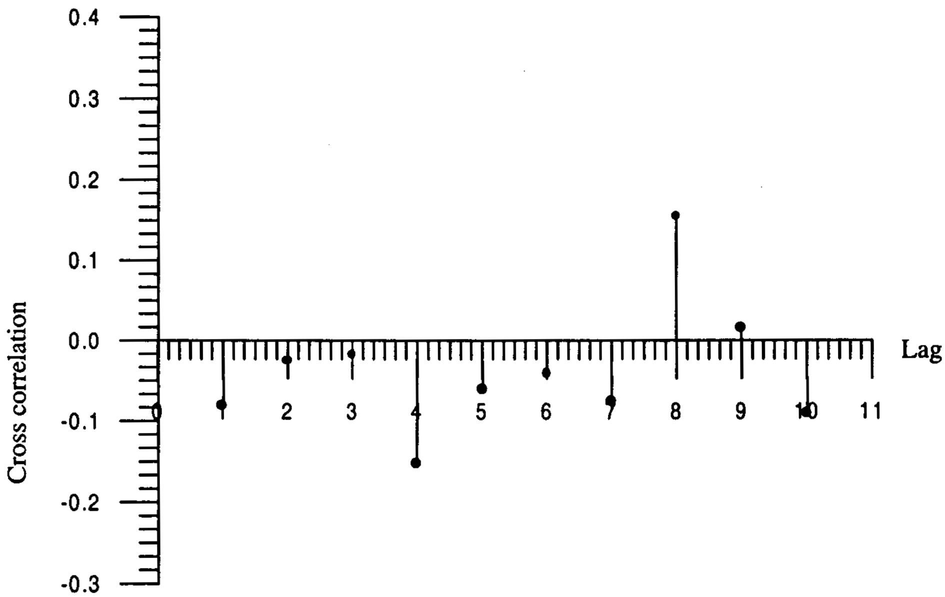


Fig. 5.12 CROSS-CORRELATION BETWEEN PREWHITENED INPUT AND RESIDUAL SERIES

Table 5.12 OBSERVED AND ESTIMATED VALUES OF POLLUTANTS

Sl.No.	First Zone		Second zone		Third zone		Fourth zone	
	Obs.	Est.	Obs.	Est.	Obs.	Est.	Obs.	Est.
CARBON MONOXIDE								
1	3	2.91	3	2.12	1	0.92	4	2.91
2	4	4.45	4	3.26	1	0.82	4	4.55
3	4	5.10	4	2.32	1	1.21	1	1.11
4	5	3.68	3	2.12	1	0.78	1	1.86
5	6	4.17	3	1.91	1	1.01	2	3.11
6	4	4.51	3	2.82	1	1.12	4	4.13
7	4	3.80	3	2.81	2	2.54	5	4.16
8	5	4.11	3	1.99	2	2.88	2	1.62
RMS %	22.281		29.169		31.110		25.635	
HYDRO CARBONS								
1	1	1.34	0	1.26	0	0.98	2	1.81
2	0	0.91	1	1.39	1	1.33	2	2.40
3	1	1.62	1	2.01	0	0.01	1	0.61
4	1	0.91	2	1.56	1	1.51	1	0.82
5	1	0.65	2	2.12	1	1.12	2	2.69
6	2	2.06	1	0.38	1	0.63	2	1.71
7	2	2.57	1	1.68	1	0.89	1	1.98
8	3	2.26	2	1.90	1	1.42	1	1.50
RMS %	31.041		39.571		34.372		34.573	
NITRIC OXIDE								
1	0	0.81	2	1.58	0	1.11	1	1.58
2	0	0.79	1	1.71	0	0.21	2	1.55
3	2	1.66	1	1.48	1	1.38	1	1.41
4	0	1.11	2	1.66	1	0.73	1	0.49
5	0	0.95	2	2.11	2	2.18	2	2.54
6	1	1.51	1	0.74	1	1.10	2	1.61
7	1	1.06	1	1.50	1	1.71	1	1.30
8	2	1.68	1	1.44	1	1.64	1	0.72
RMS %	22.134		32.010		37.874		32.312	

Table 5.13 OBSERVED AND ESTIMATED VALUES OF POLLUTANTS (SECOND SET OF DATA)

CARBON MONOXIDE

Sl.No.	First Zone		Second zone		Third zone		Fourth zone	
	Obs.	Est.	Obs.	Est.	Obs.	Est.	Obs.	Est
1	6	4.11	5	3.98	3	3.21	4	2.78
2	5	3.98	4	3.26	3	2.76	3	3.31
3	5	4.08	4	4.28	4	3.38	3	2.82
4	4	2.36	6	3.65	4	2.98	2	1.87
5	6	4.98	3	2.82	3	2.56	2	2.32
6	4	2.43	4	3.47	3	1.98	1	1.42
7	3	2.19	3	3.17	2	1.02	1	1.01
8	4	2.96	3	2.83	2	2.12	1	1.78
RMS %	27.97		24.30		22.77		26.42	

HYDRO CARBONS

Sl.No.	First Zone		Second zone		Third zone		Fourth zone	
	Obs.	Est.	Obs.	Est.	Obs.	Est.	Obs.	Est
1	4	3.53	2	1.31	2	2.98	4	3.42
2	3	3.56	3	1.98	2	2.54	2	1.72
3	2	1.72	2	2.31	1	1.07	2	1.56
4	2	2.12	1	1.47	1	1.78	2	2.23
5	4	4.42	2	1.83	4	4.13	1	1.21
6	3	1.86	2	2.33	3	2.76	4	3.16
7	2	2.33	4	3.53	1	1.36	2	2.24
8	2	2.41	3	3.21	0	0.42	1	0.56
RMS %	20.18		22.26		29.96		20.26	

NITRIC OXIDE

Sl.No.	First Zone		Second zone		Third zone		Fourth zone	
	Obs.	Est.	Obs.	Est.	Obs.	Est.	Obs.	Est
1	2	2.44	1	1.42	2	1.98	1	0.49
2	2	1.31	2	1.56	1	2.01	1	1.55
3	1	0.74	2	1.72	0	0.11	2	1.38
4	1	1.55	1	0.63	0	0.73	1	1.24
5	2	1.38	2	2.54	1	1.10	2	1.78
6	1	1.48	2	2.41	1	0.83	2	2.32
7	2	1.55	1	2.10	2	1.88	0	0.21
8	1	1.63	1	1.33	1	1.63	1	0.33
RMS %	35.38		36.24		37.23		36.31	

Table 5.14 COMPOSITE MODELS FOR PREDICTING POLLUTANT CONCENTRATIONS

List of variables	Beta Weights	t-test values	Intercept constant	R^2 value
		CARBON MONOXIDE		
3	0.3506	4.3055	0.487	0.6447
4	0.0514	6.9805		
1	0.0008	3.1790		
3	0.3160	2.6610	2.086	0.3959
5	0.0044	2.6210		
2	-0.1180	-3.5009		
3	0.6041	6.1232	4.635	0.7528
4	0.0240	3.6572		
2	-0.1492	-6.5641		
3	0.5831	5.0634	7.769	0.6766
5	-0.0385	-1.8924		
2	-0.1224	-3.4542		
3	0.5791	5.7992	5.900	0.7544
4	0.0170	2.9282		
5	-0.0262	-0.3854		
1	0.0075	0.4593		
2	-0.1190	-3.2563	4.880	0.7548
3	0.5930	5.8520		
4	0.0290	3.4314		
		HYDRO CARBONS		
1	0.0005	0.2534		
3	0.5660	7.0126	0.8007	0.7303
4	-0.0071	-0.5131		
1	0.0001	0.1621		
2	-0.0140	-0.1669	1.497	0.7306
3	0.5950	6.4505		
4	-0.0096	-0.5316		

cont....

NITRIC OXIDE				
2	0.0404	2.7227	0.078	0.3462
3	0.2501	0.9701		
1	0.0036	3.1310		
2	0.0380	1.7880	0.430	0.4645
3	0.0710	2.1549		
4	-0.0153	-1.8319		
1	0.0054	3.4761		
2	0.0170	1.7458		
3	0.1729	2.4573	0.046	0.5233
4	-0.0320	-2.3461		
5	-0.0235	-1.4218		

Where:

1 Traffic volume
2 Traffic speed
3 Pollutant concentration predicted by transfer function models
4 Percentage composition of auto-rickshaws
5 Percentage composition of two-wheelers
6 Ambient Air Quality level (dependent variable)

concentrations predicted using transfer function models, the explanatory power of regression models improve considerably.

It has been reported in the literature that the pollution concentration levels generally increase with the increase in traffic volume and decrease with speed, particularly in the case of pollutants like CO and HC, but in the case of NO, the concentration increases with increase in the average speed upto a certain volume and then decreases.

To check whether it was necessary to divide the study area into bands for the study of air pollution, grouping of the zones was attempted by combining some of the bands. These were:

i) Grouping of rings 1 and 2 and of rings 3 and 4

ii) Retaining 1 and 4 as it is and grouping the remaining rings

iii) Combining all the rings into one and only one group

Separate regression models were run for each of these combinations. Out of those, models obtained by grouping all the rings together gave models with logical signs. It was thus concluded that not much purpose will be served by dividing the study area into different rings and the composite models developed by combining all the rings into one group would serve as the final models. Table 5.15 gives the final models, which were selected in this study for the prediction of concentration of CO, HC and NO respectively, in the city of Calicut, based on statistical tests such as regression sum of squares, t-test and the logical signs for the regression coefficients.

Table 5.15 FINAL MODELS FOR PREDICTING POLLUTANT CONCENTRATIONS

List of variables	Beta Weights	t-test values	Intercept constant	R^2 value
		CARBON MONOXIDE		
1	0.0075	0.4593		
2	-0.1190	-3.2563	4.880	0.7548
3	0.5930	5.8520		
4	0.0290	3.4314		
		HYDRO CARBONS		
1	0.0001	0.1621		
2	-0.0140	-0.1669	1.497	0.7306
3	0.5950	6.4505		
4	-0.0096	-0.5316		
		NITRIC OXIDE		
1	0.0036	3.1310		
2	0.0380	1.7880	0.430	0.4645
3	0.0710	2.1549		
4	-0.0153	-1.8319		

Where:

1 Traffic volume
2 Traffic speed
3 Pollutant concentration predicted by transfer function models
4 Percentage composition of auto-rickshaws
5 Percentage composition of two-wheelers
6 Ambient Air Quality level(dependent variable)

5.5 EVALUATION OF AIR QUALITY LEVELS IN CALICUT CITY USING COMPOSITE MODEL

For the evaluation of ambient air quality, the pollutant concentrations were predicted using the composite models for 16 locations within the study area. These concentrations are shown schematically in Figs. 5.13, 5.14 and 5.15 for CO, HC, NO respectively.

It could be seen from these figures that the concentrations of pollutants like CO and HC were generally higher on stretches in the city center compared to their concentrations in the suburban locations. This trend may be due to frequent STOP and GO situations to which vehicles are subjected. Added to this may be the problems created by the road geometrics like the gradients, the horizontal and vertical curves etc. The individual effect due to many such contributory factors, which would not been possible to be explained in this study because of their meagre contributions might have been accounted by the noise term of the transfer function model. Perhaps, this may be one of the advantages gained from the transfer function modelling approach.

The Central Pollution Control Board Notification (CPCB(1991)) has recommended ambient air quality standards in India for the pollutants CO and NO as 5ppm and 0.06ppm respectively. According to California Standards, the standard limit for HC concentration is 0.24ppm. From the concentration of these pollutants presented in Figs. 5.13 to 5.14, it could be noticed that, at all except a few locations, CO concentration was below 5ppm level. However, in all the locations, the HC and NO concentrations were above the permissible limit.

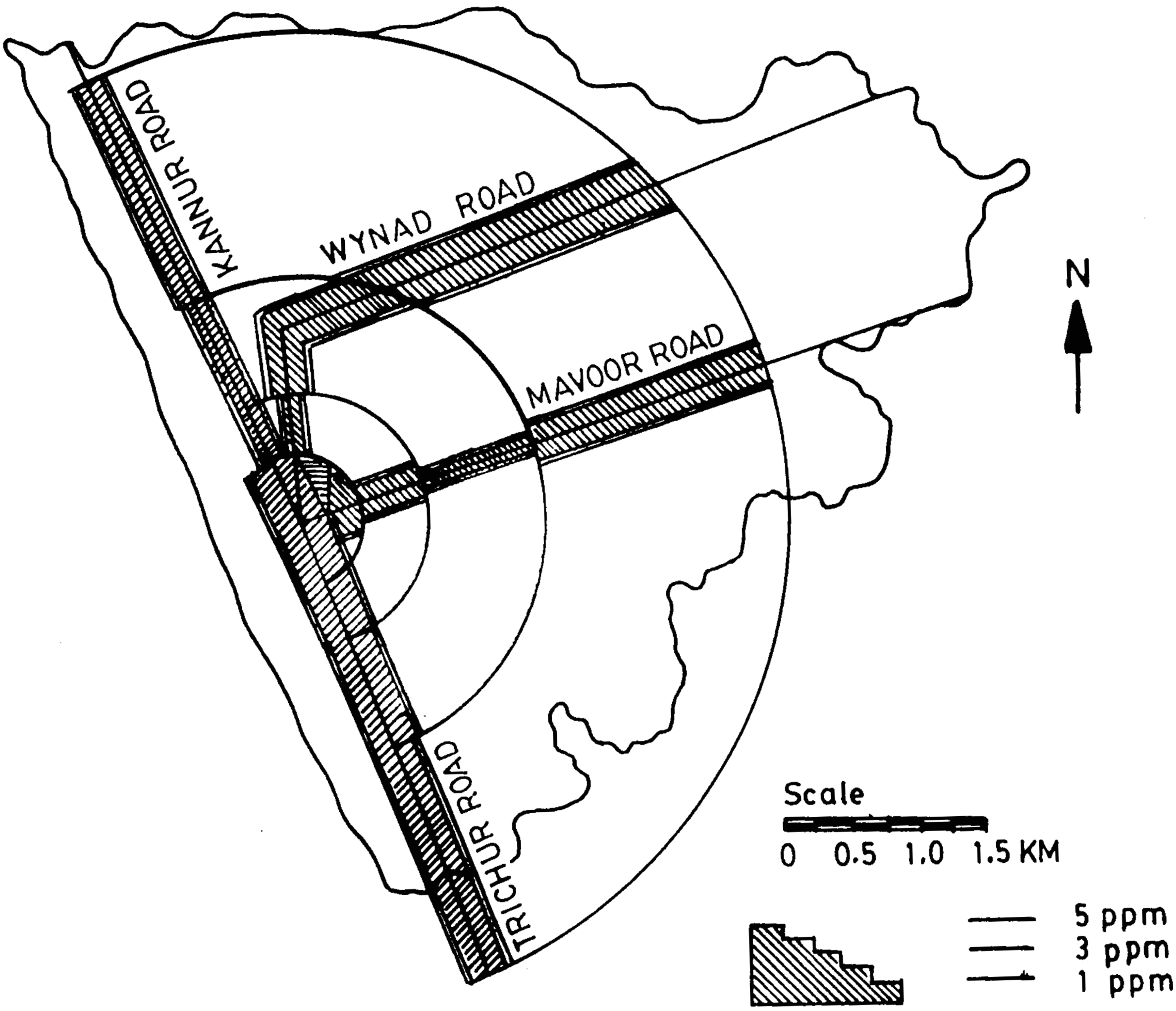


Fig. 5.13 VARIATION OF CO WITH DISTANCE FROM THE CITY CENTRE

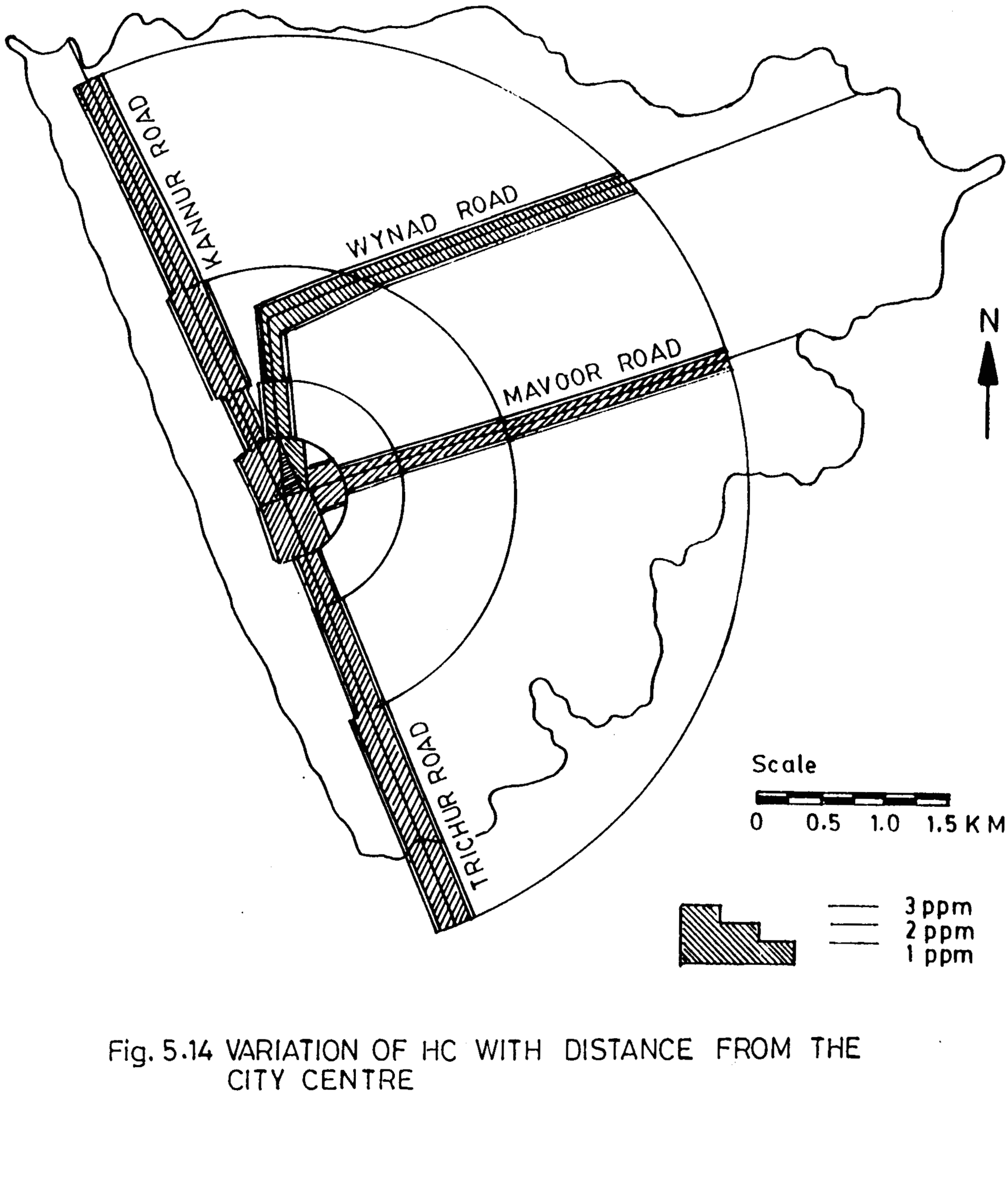


Fig. 5.14 VARIATION OF HC WITH DISTANCE FROM THE CITY CENTRE

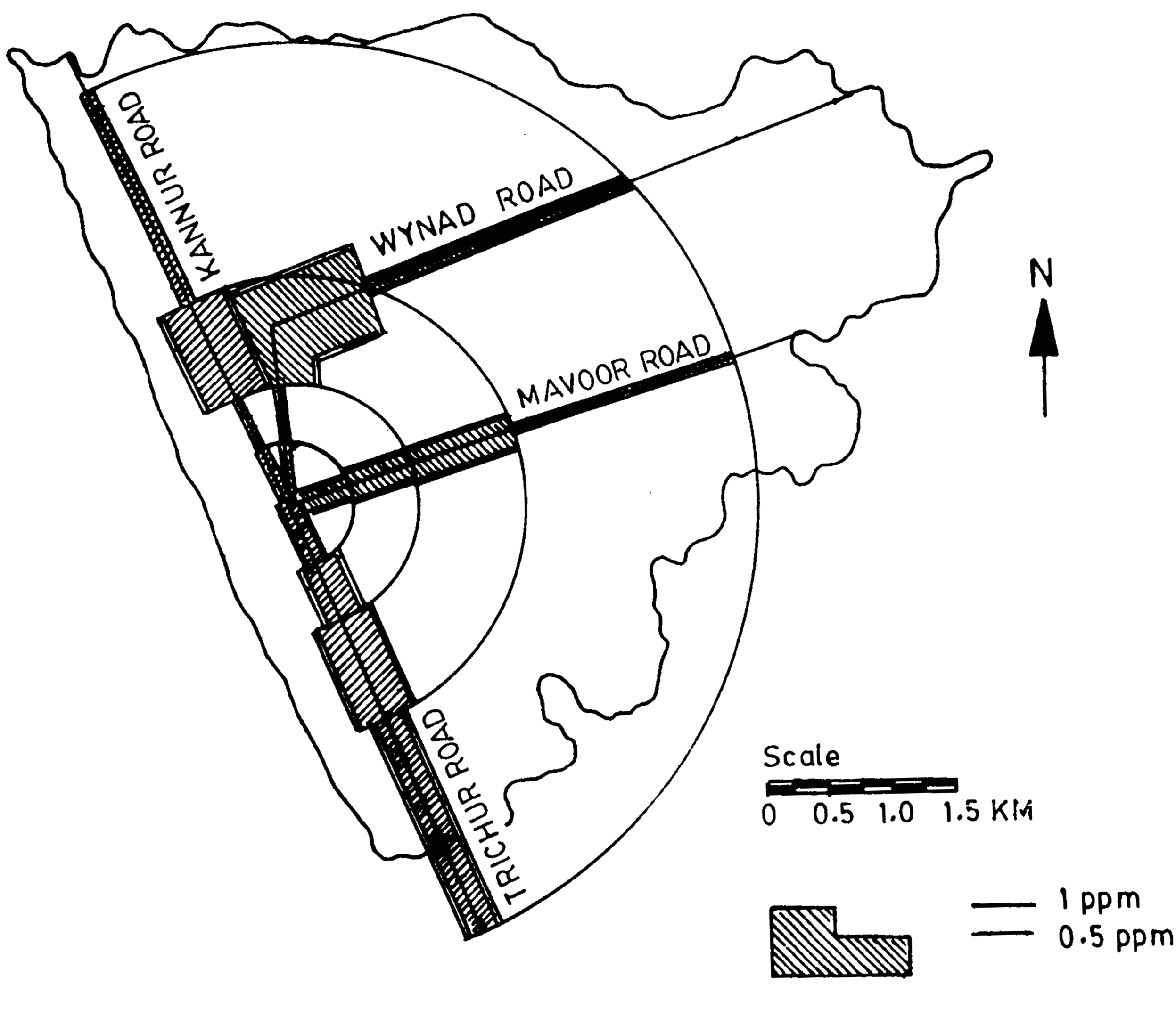


Fig. 5.15 VARIATION OF NO WITH DISTANCE FROM THE CITY CENTRE

5.6 CONCLUSIONS

In this Chapter, the procedure adopted for the development and validation of models for predicting the ambient air quality levels has been presented. It has been established in this chapter, that the ability of a simple regression type model for predicting ambient air quality near highways from traffic flow variables, could be very much improved by incorporating the time series based transfer function variables as an additional input into the model structure. Chapter 6 presents the operational scheme that has been developed for integrating traffic and air quality models for the prediction of ambient air quality levels near highways. It also presents the procedure used for the evaluation of existing road network for ambient air quality levels.

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MODELLING AND EVALUATION OF AMBIENT AIR QUALITY LEVELS DUE TO MIXED TRAFFIC ON CITY ROADS

Cini A. “Modelling and evaluation of ambient air quality levels due to mixed traffic on city roads” Thesis. Department of Civil Engineering ,Regional Engineering College, University of Calicut, 1999

CHAPTER 6

MODELLING AND EVALUATION OF AMBIENT AIR QUALITY LEVELS DUE TO MIXED TRAFFIC ON CITY ROADS

6.1 GENERAL

To limit the pollutant concentration within the acceptable limits in the city, it is essential that appropriate steps are taken to ensure the smooth flow of traffic on the city road network using suitable traffic management measures. For the design and evaluation of traffic control measures to limit the air quality within the permissible limits, we require models which integrate both the traffic prediction and air quality modelling approaches. However, such types of modelling approaches are generally lacking in the literature. The objective of this chapter is to explain the procedure for the development of integrated models for the prediction of ambient air quality levels due to mixed traffic conditions near city roads on one hand and to evaluate the city road network by the use of the integrated models on the other.

Traffic volumes on the road network for the management measures can be obtained only when it is possible to estimate an O-D matrix and load it on the network using an appropriate assignment technique. The procedure adopted for the assignment of traffic is also presented in this chapter.

6.2 PREDICTION OF LINK VOLUMES ON THE NETWORK

For the prediction of air quality levels near highways, we require prediction of traffic stream variables on all the links of the study area. However, conduct of physical surveys for obtaining those variable values on all the links of the network is prohibitively costly. One has no other choice but to estimate the Origin-Destination flows for all vehicles by indirect approach such as the link volume forecasting modelling (IVF) philosophy and then use a suitable assignment model for obtaining the link flows.

6.2.1 Traffic Assignment Through SATURN Package

Trip matrices are normally required for the design and evaluation of traffic assignment schemes and other transport project. In this context, the application of the computer package such as SATURN becomes relevant. SATURN (Simulation and Assignment of Traffic in Urban Road Networks) is a computer model for the analysis and evaluation of traffic management schemes. The structure of the model is shown in Fig. 6.1. SATASS, the traffic assignment model in SATURN is used in this work for the estimation of travel demand matrix.

6.2.2 The Assignment Model

The objective of the assignment model is to achieve a pattern of route choice satisfying Wardrop's first principle according to which " Traffic arranges itself on congested networks in such a way that all routes used for any O - D movement have equal and minimum costs/times, while, all unused routes have equal or greater cost".

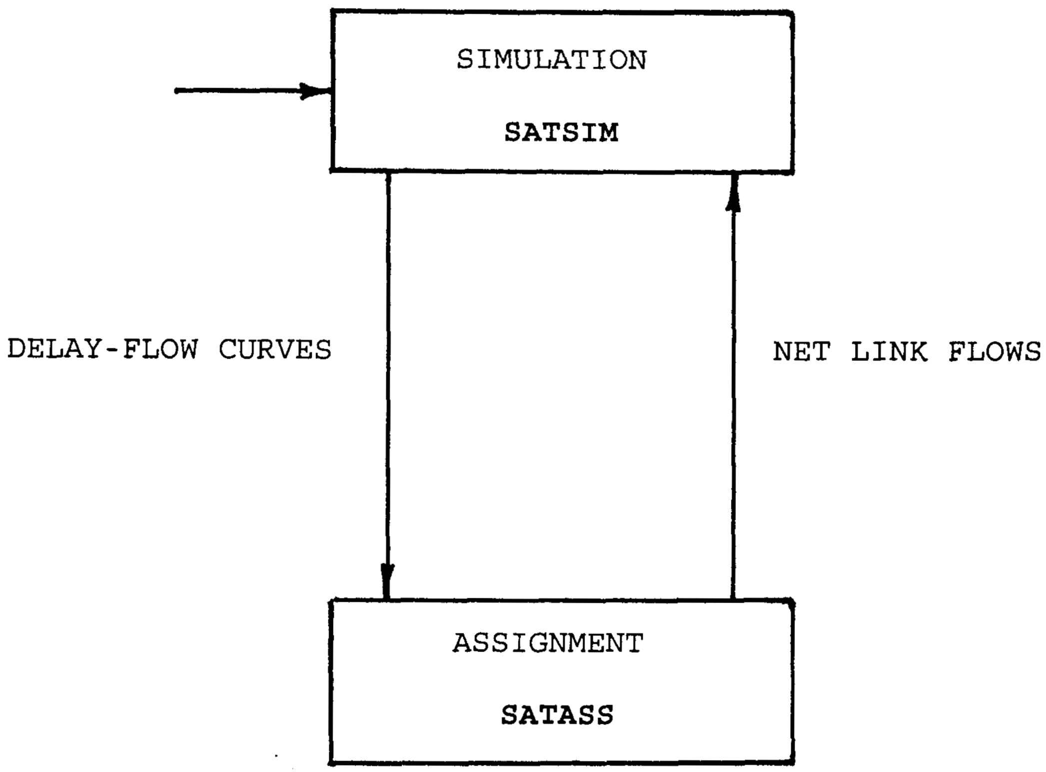

Fig. 6.1 THE SIMULATION AND ASSIGNMENT PHASES IN **SATURN**

The model uses an "equilibrium technique" which optimally combines a succession of all or nothing assignments such that the ultimate flow pattern satisfies the above criterion (Dow and Van Vliet (1979)).

6.2.3 Algorithm for SATASS

Let:

T_{ij} = number of trips from zone i to zone j

p_{ij} = a route or path from i to j

V_a = the total flow on link 'a'

C_a = the time of travel on link 'a' which is related to the flow on link by "Travel time-flow curve"

$C_a = C(V_a)$

Cp_{ij} = time of travel on route p_{ij}

I_a = the area under the travel time-flow curve from zero up to the assigned volume V_a

$= \int C_a \ (V_a) \ V_a \, dv_a$

Z = summation over all links of integrals I_a

$$Z = \sum \int_{0}^{V} C_a \ (V_a) \ V_a \ dv_a \qquad (6.1)$$

The algorithm employed by SATASS uses the following iterative sequence ('Frank-Wolfe Algorithm'):

1. All trips are assigned to O-D paths to produce an initial set of link flows $V_a(n)$, where n=1. Conventionally, the first assignment is an all -or- nothing assignment, with the link times set to their free-flow values.

2. The link times are altered in accordance with the current flows $V_a(n)$; i.e. $C_a(n) = C_a(V_a(n))$.

3. A few set of shortest paths are built based on $C_a(n)$ and all T_{ij}'s are assigned to them to produce a set of "auxiliary" all -or -nothing flows $F_a(n)$.

4. An improved set of link flows $V_a(n+1)$ are generated as a combination of the old and the auxiliary flows.

$$V_a(n+1) = (1-\lambda) * V_a(n) + \lambda * F_a(n) \tag{6.2}$$

5. Where λ (lambda) is chosen so that the new flows $V_a(n+1)$ minimize the objective function. The value of λ (lambda) varies between 0 and 1. λ is taken as 1/n, in which 'n' is the number of iterations at the end of which the value of Z is the minimum.

6. The control is passed on to step (2) unless convergence criterion is satisfied. The "gap function or delta is used as the convergence level. It is defined by:

$$\text{delta} = \frac{\text{sum}(T_{pij}\ (C_{pij} - C_{ij}^*))}{\text{sum}(T_{ij}\ C_{ij}^*)} \tag{6.3}$$

where:

C_{ij}^{*} = the minimum travel time from i to j

Cp_{ij} = time of travel on route p_{ij}

Thus, if the traffic uses a particular route p_{ij} (so that $T_{pij} > 0$), then $(C_{pij} - C_{ij}^{*})$ is the 'excess cost' of travel on that route relative to the minimum cost of travel for that ij pair. Hence delta measures the total cost of excess travel in relative terms rather than in absolute terms. Delta should be less than 5% and this could be taken as the convergence level. A schematic representation of the assignment model is shown in Fig.6.2.

6.2.4 Inputs And Outputs Of The Assignment Model

Inputs required for the assignment model are:

a) Network data

i) Link data : Link distance, travel time, number of lanes, volume counts on selected links

ii) Turn data : Saturation flow, lanes available

b) Trip matrix : Traffic flow between O-D pairs. The O-D matrix obtained from NIPTAC- NODIAC package is used as the seed trip matrix for the assignment modelling.

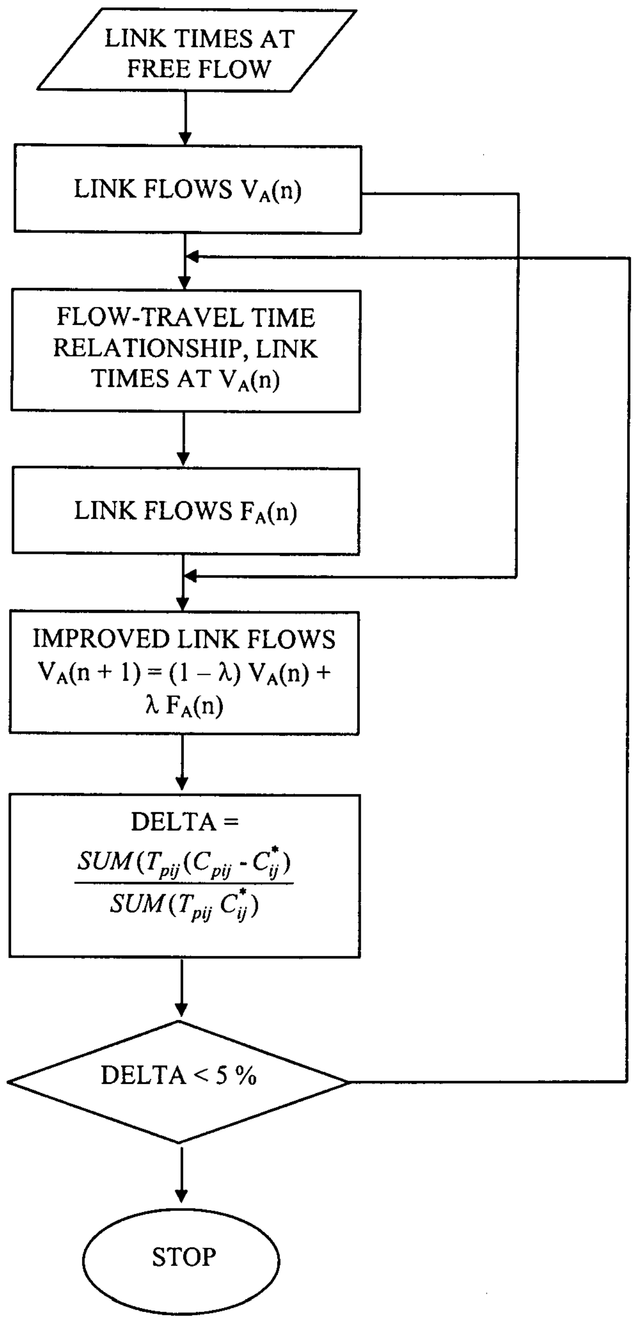

FIG. 6.2 THE SCHEMATIC REPRESENTATION OF THE ASSIGNMENT MODEL

Outputs obtained from assignment model, SATASS, include: estimated O-D matrix, flows and travel time for all the links and right turns, average speeds and total vehicle kilometers. The estimated and observed volumes are given in Table 6.1.

6.3 PREDICTION OF SPEED ON THE LINKS OF THE NETWORK

The traffic speed is an identified causal variable for the prediction of pollutant concentrations. Hence it is necessary to predict the traffic speeds on all the links of the network. For this purpose, speed-flow relationship is used. From the link volumes obtained through the assignment process and the speed-flow relationship, the traffic speeds on all the links of the network were calculated.

6.4 PREDICTION OF PERCENTAGE COMPOSITION OF AUTO-RICKSHAWS AND TWO WHEELERS

The percentage composition of auto-rickshaws and two-wheelers were identified as the significant variables for the prediction of pollutant concentrations. For obtaining the values of these variables, the assignment model was run for different types of vehicles and also for total traffic. From these outputs from the assignment model, the percentage composition of auto-rickshaws and two-wheelers were calculated.

6.5 PREDICTION OF POLLUTANT CONCENTRATIONS ON THE LINKS OF THE NETWORK

Conventional Urban Transportation Planning System (UTPS) type models use a standard four stage process consists of trip generation, trip distribution, mode split and route split. However, those models alone are not sufficient to give forecast of pollution

Table 6.1 COMPARISON OF OBSERVED AND PREDICTED LINK VOLUMES (BUS TRAFFIC)

Link No.	Observed link Volumes	Link volumes from the model
238	17	18
110	155	150
232	135	141
178	170	172
186	258	255
46	150	153
33	148	144
239	3	2
54	11	10
51	12	12
89	2	2
61	71	70
168	55	55
114	16	21
102	18	6
215	21	8

levels on the links of the network for air quality monitoring. For that purpose, we require models, which integrate both the air quality prediction and traffic assignment models. Hence, there is a need for improvement of conventional UTPS type models for monitoring the air quality levels.

Fig. 6.3 shows the Flow Chart for the integrated models developed for the prediction of ambient air quality levels near highways due to mixed traffic conditions. Such types of models are useful for the design and evaluation of different Traffic Control Measures(TSMs) with respect to air quality levels. This type of study will be useful in determining the effect of a system of moving vehicles on ambient air quality near roadways.

6.6 EVALUATION OF THE EXISTING TRAFFIC MANAGEMENT MEASURE WITH RESPECT TO AIR QUALITY

A computer model was developed by linking the pollutant concentration prediction model and the traffic assignment model. By using the developed model, the existing road network of the city was evaluated. Since the public transport vehicles are confined to move along present routes and other vehicles have route choice, only the latter were allowed to be dictated by the route assignment.

6.6.1 Existing Routing Patterns in Calicut City

There are various type of buses being operated, which are broadly classified into, those operated by the Government (KSRTC buses) and those by the private

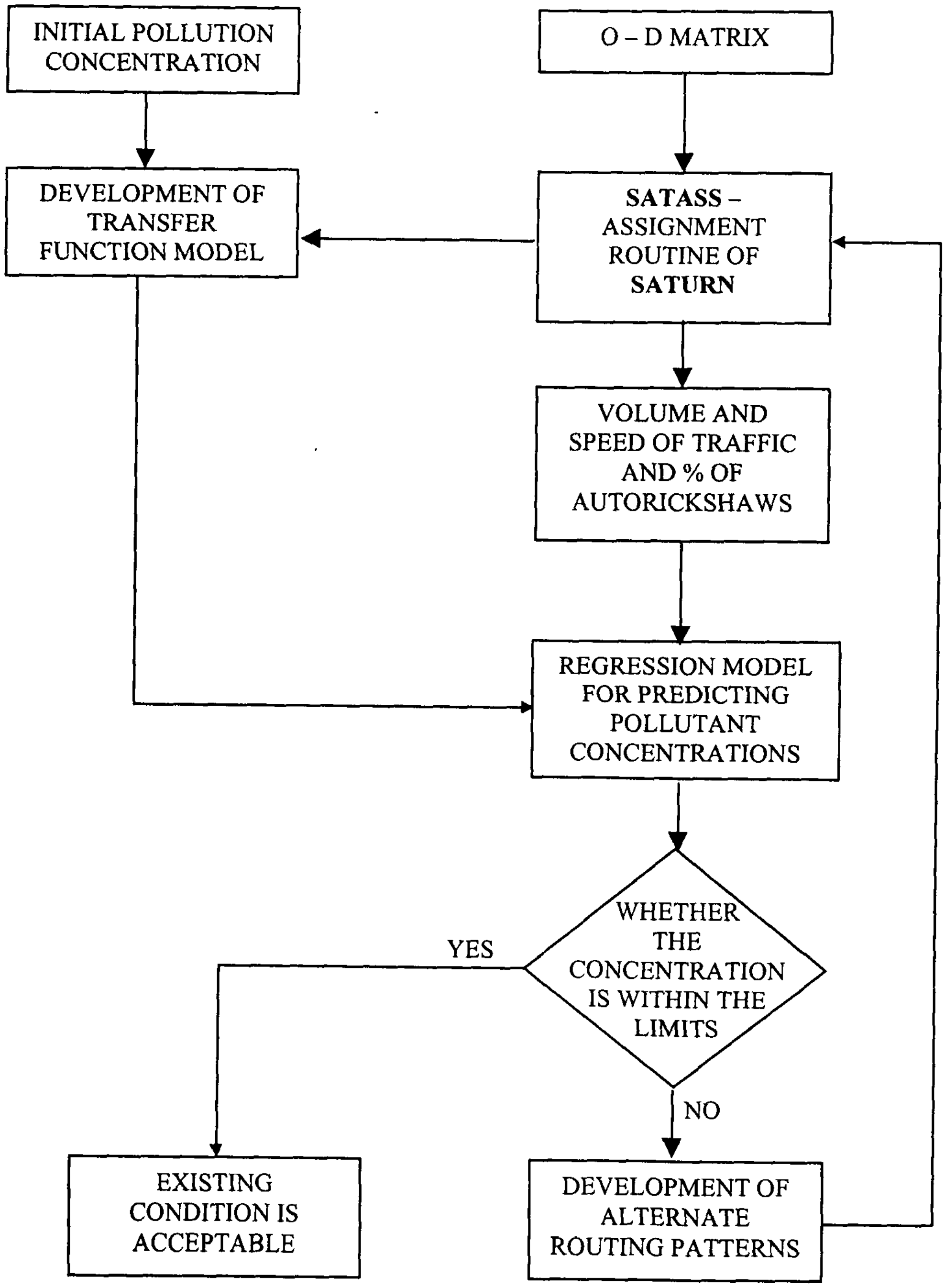

FIG. 6.3 FLOW CHART FOR TRAFFIC MANAGEMENT MEASURES FOR MONITORING POLLUTANT CONCENTRATIONS

operators (private buses). These are further split into regional bus operation and city bus operation.

The Government owned KSRTC buses are stationed in the KSRTC depot located on the Mavoor road near Mavoor road junction. On the other hand, the private buses operated for regional services are being parked in Mofussil bus stand or Palayam stand, depending on the length of the routes of those buses, shorter route length buses being parked in Palayam stand. Fig.6.4 shows the existing routing patterns for buses in Calicut city.

6.6.2 Route Structure of the Existing Pattern

Regional Buses

i) From North and East (KSRTC BUSES)

Eranhipalam junction – East Nadakavu junction – Kottaram road- Mavoor road junction – Bank road – Pavamani road – Rajaji road – Mavoor road KSRTC stand.

ii) To North and East(KSRTC buses)

KSRTC stand – Mavoor road – Rajaji road – Pavamani road – Pattalapalli junction – Common Wealth road – Town Hall road – Kannur road – West Nadakavu junction – East Nadakavu junction- Eranhipalam junction – to North and East.

iii) From South (KSRTC buses)

Francis road junction – Francis road – Railway station road – Oyitty road – Town hall road – CSI junction – Pavamani junction – Pavamani road – Rajaji road – Mavoor road – KSRTC bus stand.

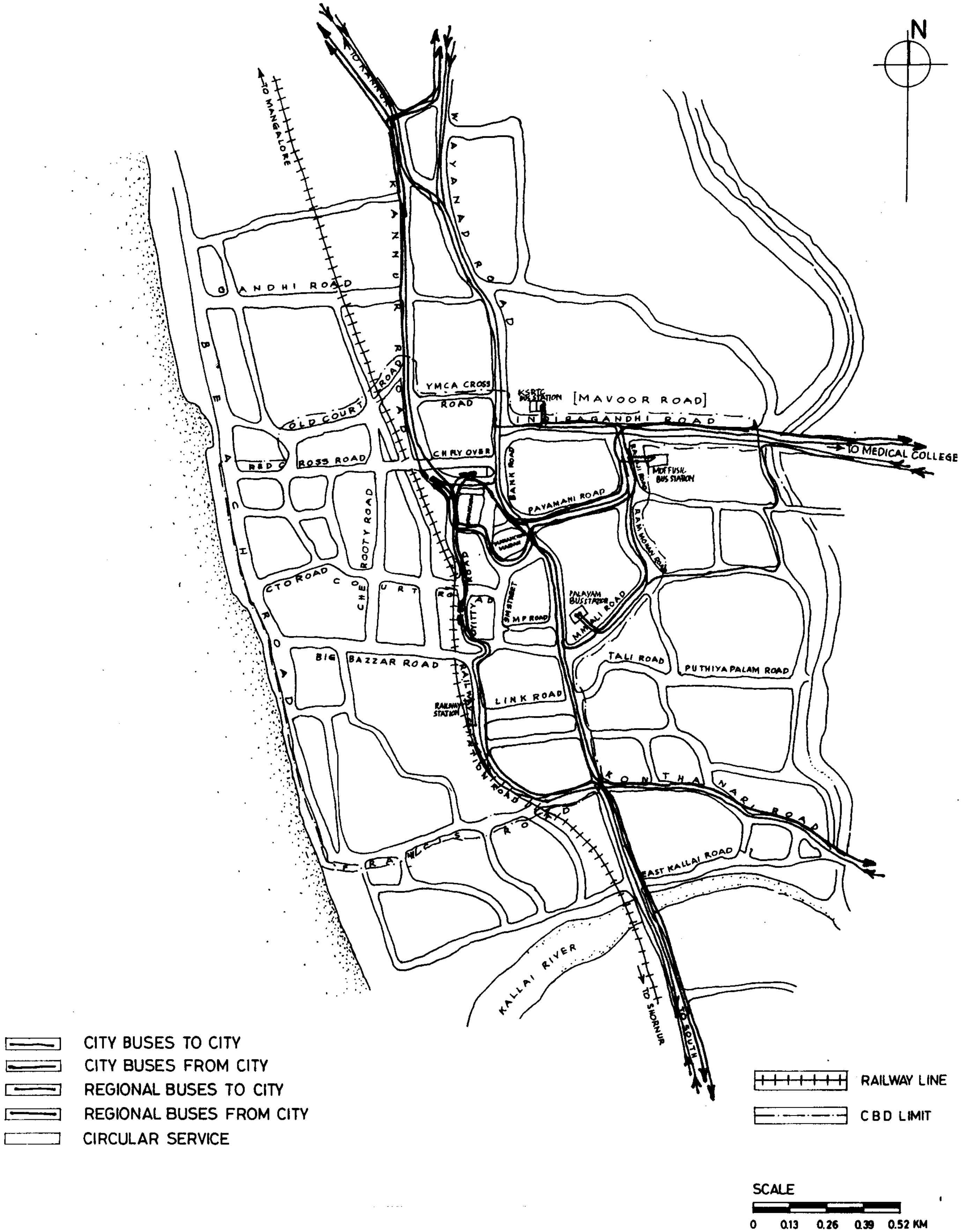

Fig. 6.4 EXISTING ROUTING PATTERN OF CALICUT CITY

iv) To South (KSRTC buses)

KSRTC stand – Mavoor road – Rajaji road – Pavamani road – NH – Francis junction – To South.

v) From North (Private buses)

West Nadakavu junction– Manorama junction– Mavoor road junction – Mavoor road – Rajaji road – Mofussil bus stand.

vi) To North (Private buses)

Mofussil bus stand – Rajaji road – Pavamani road – Pattalampalli junction – Common Wealth road – Town Hall road – Kannur road – West Nadakavu junction – to North.

vii) From East (Private buses)

Arayadathupalam junction – Jail road – M.M. Ali road – Palayam stand.

viii) To East (Private buses)

Palayam stand – M.M. Ali road – Rammohan road – Rajaji road – Mavoor road – Arayadathupalam- To East.

ix) From South (Private buses)

Francis road junction – Francis road – Railway station road – Oyitty road – Town Hall road – C.S.I. junction – Pavamani road- M.M. Ali road – Palayam stand.

x) To South (Private buses)

Palayam stand – Kallai road – Francis road junction – to South.

City Buses

i) From West Hill

West Nadakavu junction – Manorama junction – Mavoor road junction – Bank road – CSI junction - NH – Pattalapalli junction – Common Wealth road – Town Hall road – City bus stop.

ii) To West Hill

City bus stop – Kannur road – West Nadakavu junction – To West hill.

iii) From Vellimadukunnu

East Nadakavu junction – Kottaram road – Mavoor road junction- Bank road – CSI junction – NH – Pattalampalli junction – Common Wealth road – Town Hall road – City bus stop.

iv) To Vellimadukunnu

City bus stop – Kannur road – West Nadakavu junction – East Nadakavu junction – To Vellimadukunnu.

iv) From Medical College

Arayadathupalam junction – Mavoor road – Mavoor road junction- Bank road – Pattalampalli junction – Common Wealth road – Town Hall road – City bus stop (on North Mananchira road).

v) To Medical College

City bus stop – CSI junction – Pavamani junction – Pavamani road – Rajaji road – Mavoor road – Arayadathupalam – Medical College.

vi) From Kallai

Francis road junction – Francis road – Railway station road – Oyitty road – City bus stop (Oyitty road).

vii) To Kallai

City bus stop – Town Hall road – North Mananchira road CSI junction – Pattalapalli junction – palayam junction – Kallai road – Francis junction – To Kallai.

viii) From Mankavu

Same as that of vii

ix) To Mankavu

Same as that of viii

6.6.3 Problems Associated with the Existing Routing Pattern

The major problem of the existing road network of the city is that the bus terminii are widely scattered and transfer from one to the other is extremely difficult. People have to hire auto-rickshaws to make this transfer and hence a rise in the auto-rickshaw traffic in the city center. Another problem is the excessive number of right turns at junctions in the city center. No separate lane for right turns have been provided and

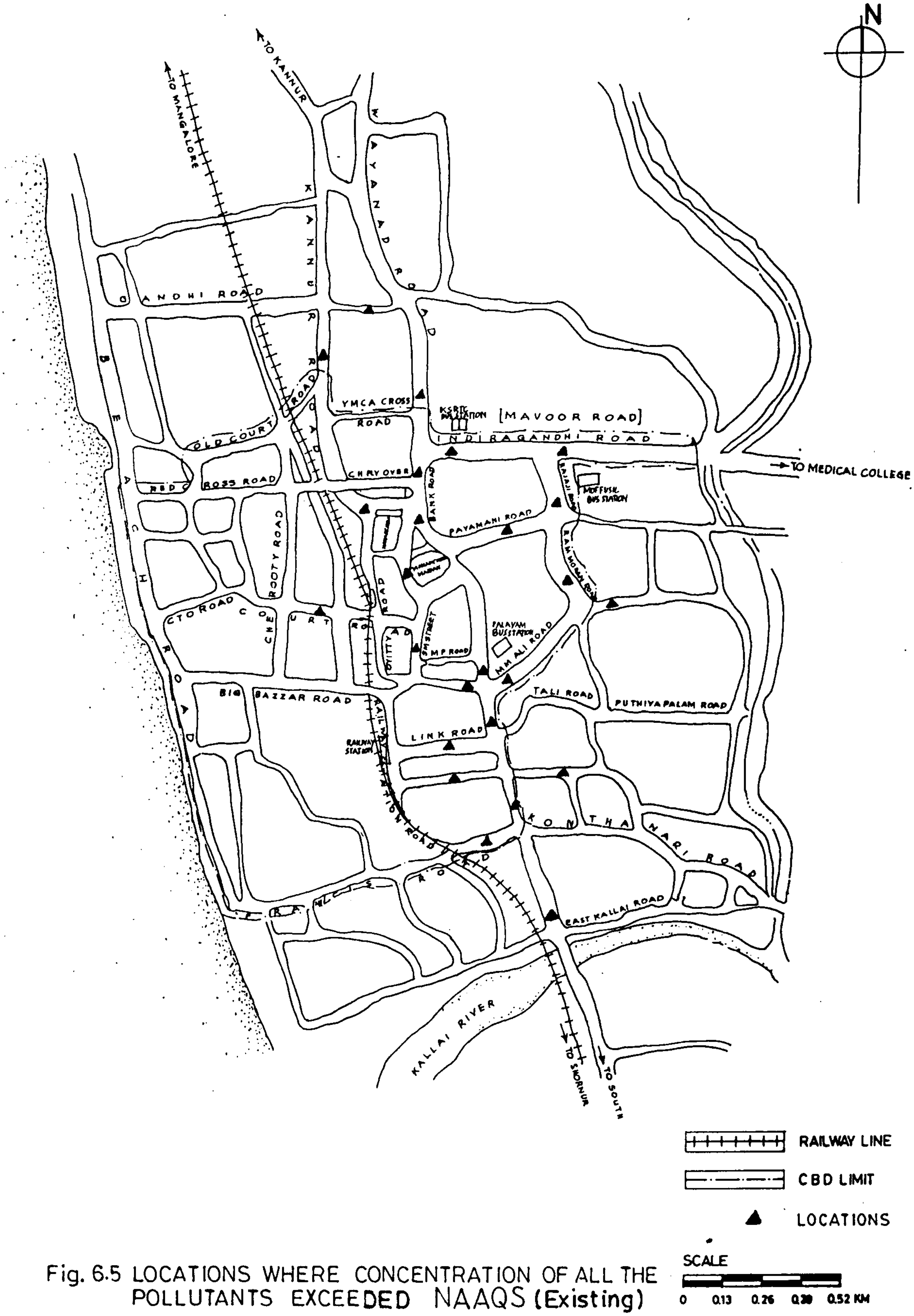

Fig. 6.5 LOCATIONS WHERE CONCENTRATION OF ALL THE POLLUTANTS EXCEEDED NAAQS (Existing)

bottleneck situations during the peak hours are quite common. Parking of vehicles on the carriage way, high pedestrian traffic during peak hours and location of bus stops on National Highways or on other major roads result in a jammed condition most of the time.

6.6.4 Evaluation of Existing Route Pattern of the City for Air Quality

By using the developed model, the concentrations of CO, HC, and NO were predicted for all the links within the study area. Existing road network is evaluated by comparing the predicted concentrations with National Ambient Air Quality Standards. From the comparison, it has been observed that at 41 locations CO concentrations exceed the permissible levels, at 62 locations concentration of HC is above the permissible limit and at 24 locations NO concentration is above the limit of 0.06ppm. Fig.6.5 shows the locations where concentration of all the pollutants exceed the NAAQS.

6.7 CONCLUSIONS

The procedure adopted for the development of models linking pollutant concentration prediction model and traffic assignment model has been presented in this Chapter. In this Chapter, the procedure adopted for the estimation of link volume counts through SATURN package has been presented. The procedure used for the evaluation of the existing road network for the air quality levels has also been presented in this Chapter. Chapter 7 presents the procedure for the development and evaluation of alternate routing patterns for the city with respect to air quality levels.

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GENERATION AND EVALUATION OF ALTERNATIVE ROUTING PATTERNS OF VEHICLES

Cini A. “Modelling and evaluation of ambient air quality levels due to mixed traffic on city roads” Thesis. Department of Civil Engineering ,Regional Engineering College, University of Calicut, 1999

CHAPTER 7

GENERATION AND EVALUATION OF ALTERNATIVE ROUTING PATTERNS OF VEHICLES

7.1 GENERAL

There are very many Traffic Management Measures that are usually adopted in cities to ensure the smooth flow of traffic on the road network. Many of these Traffic System Management strategies are implemented without examining the environmental implications. This chapter presents the procedure used for the development and evaluation of alternate routing patterns of vehicles for Calicut city.

7.2 GENERATION OF DIFFERENT ROUTING PATTERNS

The main objective behind the generation of alternate traffic management measures is to minimise the problems of existing traffic management measures for satisfying the traffic and air quality standards. In this study, four alternatives to the present day routing patterns of buses in Calicut city were developed. Alternate routing patterns along with their route structure are described in the following articles.

7.2.1 Alternative 1

In this alternative, city bus terminii for buses from South and East are shifted on to the link road, without disturbing the other terminii. Regional buses from South are diverted through Francis over-bridge, Beach road and C.H. over-bridge. An advantage of this alternative is that the Link road, which is sufficiently wide without much traffic is utilised effectively. City buses from the East follow the route via M.M.Ali road, Kallai road, Annie Hall road, Railway station road and then turn to Link road. To get an easy exit from link road to Kallai road, section of Kallai road between Annie Hall road and Link road is made one way.

Route Structure as per Alternative 1

Regional buses

i) From North and East(KSRTC buses)

Eranhipalam junction – East Nadakavu junction – Kottaram road – Mavoor road junction – Mavoor road – KSRTC stand.

ii) To North and East (KSRTC buses)

KSRTC stand – Mavoor road – Arayadathupalam junction– Mini bye-pass road – Eranhipalam junction – to North and East.

iii) From South (KSRTC buses)

Francis road junction – Francis over-bridge – Beach road- C.H. Fly-over – Bank road – NH – Pavamani road – Rajaji road – Mavoor road – KSRTC stand.

iv) To South (KSRTC buses)

KSRTC stand – Mavoor road – Rajaji road – Pavamani road – NH – Kallai road – Francis road junction.

v) From North (Private buses)

West Nadakkavu junction – Manorama junction – Mavoor road junction – Mavoor road – Rajaji road – Mofussil bus stand.

vi) To North (Private buses)

Mofussil bus stand – Mavoor road – Arayadathupalam – Mini bye-pass road – Eranhipalam.

vii) From East (Private buses)

Arayadathupalam junction – Mavoor road – Mofussil bus stand.

viii) To East (Private buses)

Mofussil bus stand – Mavoor road – Arayadathupalam junction – To East.

ix) From South (Private buses)

Francis road junction – Francis over-bridge – Beach road – C.H. fly-over – Bank road – Pavamani road – Rammohan road- M.M.Ali road – Palayam stand.

x) To South (Private buses)

Palayam stand – Kallai road – Francis road junction– To South.

City Buses

i) From West Hill

West Nadakavu junction – Manorama junction – Mavoor road junction – Bank road – CSI junction – NH – Pattalampalli junction – Common Wealth road – Town Hall road – City stand.

ii) To West Hill

City stand – Kannur road – West Nadakkavu junction – To West Hill.

iii) From Vellimadukunnu

East Nadakkkavu junction – Kottaram road – Mavoor road junction – Bank road – CSI junction – NH – Pattalampalli junction – Common Wealth road – Town Hall road – City stand.

iv) To Vellimadukunnu

City stand – Kannur road – West Nadakkavu junction – East Nadakkavu junction – Vellimadukunnu.

v) From Medical College

Arayadathupalam junction – Mavoor road – Rajaji road – Rammohan road – M.M.Ali road – Kallai road –Anni Hall road– Railway station road – city stand (Link road).

vi) To Medical College

City stand – Kallai road – Anni Hall road – Railway station road – Oyitty road – Kannur road – YMCA cross road – Mavoor road junction – Mavoor road – Arayadathupalam junction – To Medical college.

vii) From Kallai

Francis road junction – Francis road – Railway station road – City stand(Link road).

viii) To Kallai

City stand – Kallai road – Francis road junction – To Kallai.

ix) From Mankavu

Same as that of vii.

x) To Mankavu

Same as that of viii.

Fig. 7.1 shows the routing pattern of vehicles in Calicut city as per Alternative 1.

7.2.2 Alternative 2

In this alternative present Palayam and Mofussil stands are utilised as bus terminii. Both regional and city buses from the North and East are terminated in Mofussil stand and city buses from the South are terminated in Palayam stand. The main advantage gained from this alternative is that, the major corridors are made free from the city bus terminii.

Route Structure as per Alternative 2

Regional Buses

i) From the North and East (KSRTC buses)

Eranhipalam junction – East Nadakkavu junction – Kottaram road – Mavoor road junction – Mavoor road – KSRTC stand.

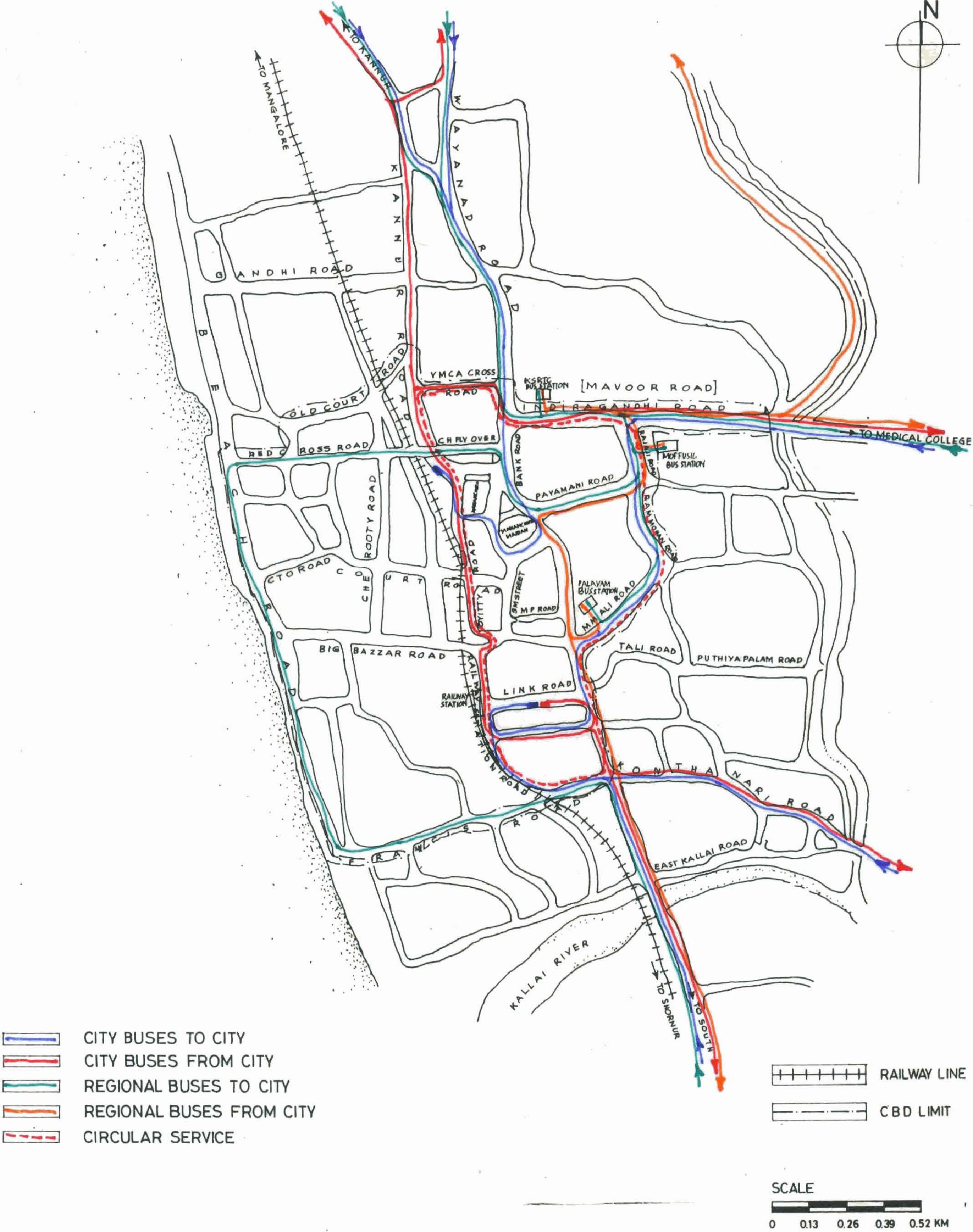

Fig. 7.1 ROUTING PATTERN AS PER ALTERNATIVE _ 1

ii) To North and East (KSRTC buses)

KSRTC stand – Mavoor road – Mini bye-pass road – Eranhipalam junction – To North and East.

iii) From South (KSRTC buses)

Francis road junction – Railway station road – Oyitty road – Town Hall road – CSI junction – Pavamani road – Rajaji road – Mavoor road – KSRTC stand.

iv) To South (KSRTC buses)

KSRTC stand – Mavoor road – Rajaji road – Pavamani road – NH – Pattalapalli junction – Palayam junction – Kallai road – Francis road junction – To South.

v) From North (Private buses)

West Nadakkavu junction – Manorama junction – Mavoor road – Rajaji road – Mofussil bus stand.

vi) To North (Private buses)

Mofussil bus stand – Mavoor road – Mini bye-pass road – Eranhipalam junction – to North.

vii) From East (Private buses)

Arayadathupalam – Mavoor road – Rajaji road – Mofussil bus stand.

viii) To East (Private buses)

Mofussil bus stand – Mavoor road – Arayadathupalam junction – to East.

ix) From South (Private buses)

Francis road junction – Francis road – Railway station road – Oyitty road – Town Hall road – CSI junction – Pavamani road – Rammohan road – M.M.Ali road – Palayam stand.

x) To South (Private buses)

Palayam stand – Kallai road – Francis road junction – to South.

City Buses

i) From West Hill

West Nadakkavu junction – Manorama junction – Mavoor road junction – Mavoor road – Rajaji road – Mofussil bus stand.

ii) To West Hill

Mofussil bus stand – Rajaji road – Pavamani road – Pattalapalli junction – Common Wealth road – Town Hall road – Kannur road – West Nadakkavu junction – To West Hill.

iii) From Vellimadukunnu

East Nadakkavu junction – Kottaram road – Mavoor road junction – Mavoor road – Mofussil bus stand.

iv) To Vellimadukunnu

Mofussil bus stand – Rajaji road – Pavamani road – Pattalapalli junction – Common Wealth road – Town Hall road – Kannur road – West Nadakkavu junction – East Nadakkavu junction – To Vellimadukunnu.

v) From Medical College

Arayadathupalam junction – Mavoor road – Rajaji road – Mofussil stand.

vi) To Medical College

Mofussil bus stand – Mavoor road – Arayadathupalam junction – To Medical College.

vii) From Kallai

Franacis road junction – Francis road – Railway station road – Oyitty road – Town Hall road – North Mananchira road – CSI junction – Pavamani road – Rammohan road – M.M.Ali road – Palayam stand.

viii) To Kallai

Palayam stand – Kallai road – Francis road junction – To Kallai.

ix) From Mankavu

Same as that of vii

x) To mankavu

Same as that of viii

Fig 7.2 shows the routing pattern of vehicles in Calicut city as per Alternative 2.

7.2.3 Alternative 3

Two existing regional bus terminii are kept as such in this case. Only difference is that buses from East are terminated in Mofussil bus stand. All city bus terminii at the city center are removed. Instead of terminating at the city center

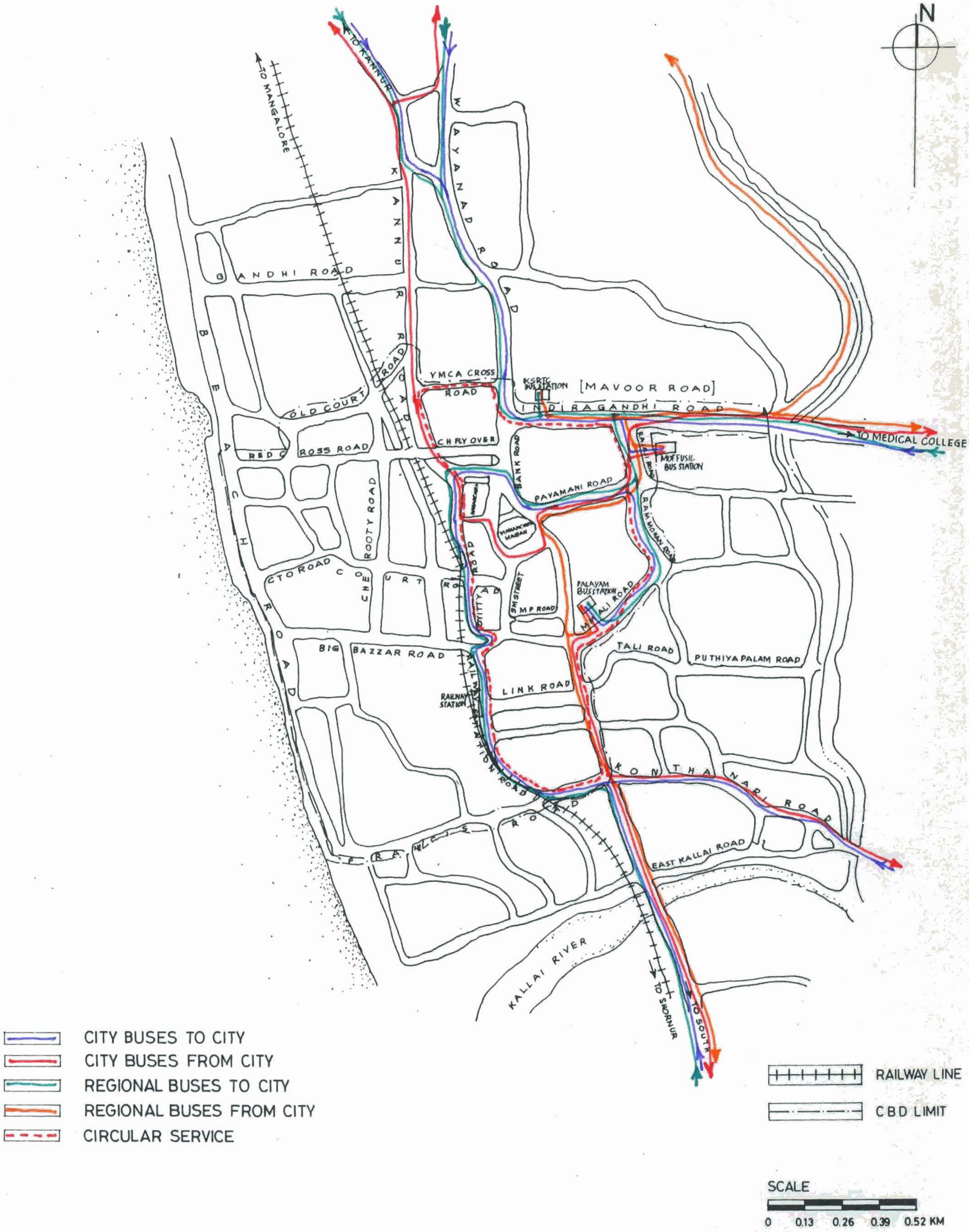

Fig. 7.2 ROUTING PATTERN AS PER ALTERNATIVE_2

these buses are extended towards the opposite directions of their entry, i.e., buses from the East are extended to West and those from North to South. Another feature of this alternative is that along the NH, two directional flow is allowed, thus restoring the function for which National Highways are constructed. Circulation of vehicles around the Mananchira square is prohibited and is opened to pedestrian movement only. City buses from the East are allowed to take left turn at Mavoor road junction and then take right turn at C.H. Fly-over junction and extended to beach. In order to make right turns at C.H.Over-bridge junction easy, the Bank road from Mavoor road junction to C.H.Fly-over junction is made one way.

Route Structure as per Alternative 3

Regional buses

i) From North and East (KSRTC buses)

Eranhipalam junction – East Nadakkavu junction – Kottaram road – Mavoor road junction – Mavoor road – KSRTC stand.

ii) To North and East (KSRTC buses)

KSRTC stand – Mavoor road – Arayadathupalam junction – Mini bye-pass road – Eranhipalam junction – To North and East.

iii) From South (KSRTC buses)

Francis road junction – Francis road – Railway station road – Oyitty road – Town Hall road – Kannur road – YMCA cross road – Wynad road – Mavoor road – KSRTC stand.

iv) To South (KSRTC buses)

KSRTC stand – Mavoor road – Rajaji road – M.M.Ali road – Palayam junction – Kallai road – Francis road junction – To South.

v) From North (Private buses)

West Nadakkavu junction – Manorama junction – Mavoor road junction – Mavoor road – Rajaji road – Mofussil bus stand.

vi) To North (Private Buses)

Mofussil bus stand – Mavoor road – Mini bye-pass road – Eranhipalam junction – to North.

vii) From East (Private buses)

Arayadathupalam junction – Mavoor road – Rajaji road – Mofussil bus stand.

viii) To East (Private buses)

Mofussil bus stand – Mavoor road – Arayadathupalam junction road – To East.

ix) From South(Private buses)

Francis road junction – Francis road – Railway station road – Oyitty road – Town Hall road – Kannur road – YMCA cross road – Wynad road – Mavoor road – Rajaji road – Rammohan road – M.M.Ali road – Palayam stand.

x) To South (Private buses)

Palayam stand – Kallai road – Francis road junction – To South.

City Buses

i) From West Hill to Mankavu

West Nadakkavu junction – Manorama junction – Mavoor road junction – NH – Palayam junction – Francis road Junction – To Mankavu.

ii) From Mankavu to West Hill

Francis road junction – Francis road – Railway station road – Oyitty road – Town Hall road- Kannur road – West Nadakkavu junction – To West Hill.

iii) From Vellimadukunnu to Kallai

East Nadakkavu junction – Kottaram road – Mavoor road junction – Bank road – NH – Kallai road – Francis road junction – To Kallai.

iv) From Kallai to Vellimadukunnu

Francis road junction – Francis road – Railway station road – Oyitty road – Town Hall road – Kannur road – West Nadakkavu junction – East Nadakkavu junction – To Vellimadukunnu.

v) From Medical College to Beach

Arayadathupalam junction – Mavoor road – Mavoor road junction – C.H.Fly-over – To Beach.

vi) From Beach to Medical College

Beach – C.H.Fly-over – Bank road – Pavamani road – Rajaji road – Mavoor road – Arayadathupalam junction – To Medical College.

Fig.7.3 shows the routing pattern of vehicles as per Alternative 3.

7.2.4 ALTERNATIVE 4

In this alternative, all private regional buses are brought to a common terminal (Mofussil bus stand) and city buses to another. All city buses are terminated at Palayam stand. Regional buses from the South are diverted through Francis over-bridge, Beach road, C.H.Fly-over, Mavoor road junction and then to Mofussil stand, thus utilizing the existing over-bridges. Regional buses from the North take a left turn at Mavoor road junction and then to Mofussil bus stand and the city buses go straight via Bank road to Palayam stand. Section between Mavoor road junction and C.H.over-bridge junction is made one way with traffic flow in the direction, Mavoor road junction to C.H.over-bridge junction.

Main advantage of this alternative is that all regional buses are brought to a common terminal and City buses to another, thus minimising the transfer. Transfer from one station to other is served by City buses from the East. Right turn at C.H.Fly-over junction is avoided in this alternative.

Route Structure as per Alternative 4

Regional buses

i) From North and East (KSRTC buses)

Ernahipalam junction – East Nadakkavu junction – Kottaram road – Mavoor road junction – Mavoor road – KSRTC stand.

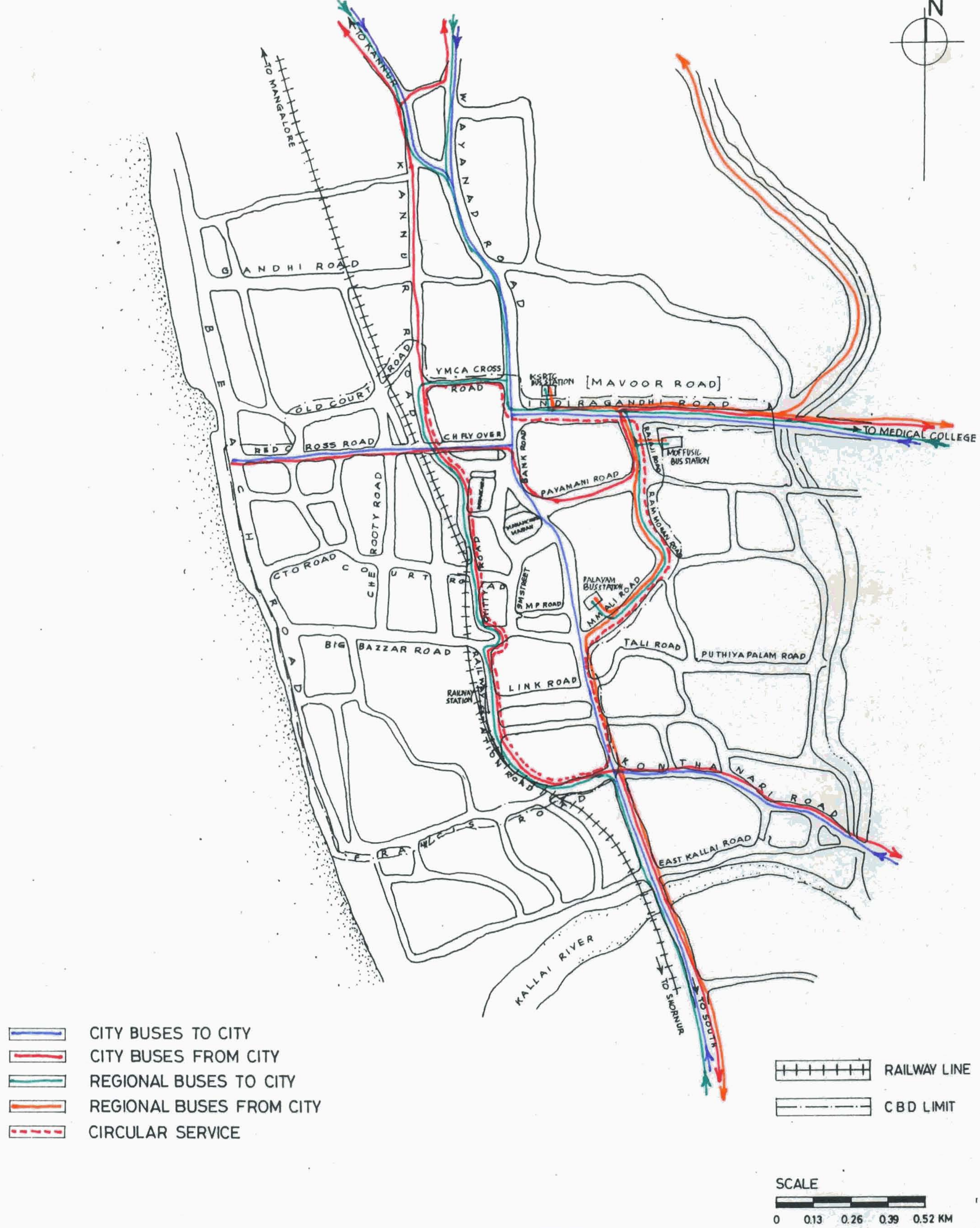

Fig. 7.3 ROUTING PATTERN AS PER ALTERNATIVE_3

ii) To North and East (KSRTC buses)

KSRTC stand – Mavoor road – Arayadathupalam junction – Mini bye-pass road – Eranhipalam junction – To North and East.

iii) From South (KSRTC buses)

Francis road junction – Francis over-bridge – Beach road - Red Cross road – C.H.Fly-over – Mavoor road junction – Mavoor road – KSRTC stand.

iv) To South (KSRTC buses)

KSRTC stand – Rajaji road – Pavamani road – NH – Palayam junction – Kallai road – Francis road junction – To South.

v) From North (Private buses)

West Nadakkavu junction – Manorama junction – Mavoor road junction – Mavoor road – Rajaji road – Mofussil bus stand.

vi) To North (Private buses)

Mofussil bus stand – Mavoor road – Arayadathupalam junction – Mini bye-pass road – Eranhipalam junction – To North.

vii) From East (Private buses)

Arayadathupalam junction – Mavoor road – Rajaji road– Mofussil bus stand.

viii) To East (Private buses)

Mofussil bus stand – Mavoor road – Arayadathupalam junction road – To East.

ix) From South (Private buses)

Francis road junction – Francis over-bridge – Beach road – Red cross road – C.H.Fly-over – Mavoor road junction – Mavoor road – Rajaji road – Mofussil bus stand.

x) To South (Private buses)

Mofussil bus stand – Rajaji road – Pavamani road – palayam junction – Kallai road – Francis road junction – To South.

City Buses

i) From West Hill

West Nadakkavu junction – Manorama junction – Mavoor road junction – Bank road – Pavamani road - Rammohan road – M.M.Ali – Palayam stand.

ii) To West Hill

Palayam stand – M.M.Ali road – Rammohan road -Pavamani road – Pattalapalli junction – Common Wealth road – Town Hall road – Kannur road – West Nadakkavu junction – To West Hill.

iii) From Vellimadukunnu

East Nadakkavu junction – Kottaram road – Mavoor road junction – Bank road – Pavamani road – Rammohan road – M.M.Ali road - Palayam stand.

iv) To Vellimadukunnu

Palayam stand – M.M. Ali road – Rammohan road - Pavamani road –

Pattalapalli junction – Common Wealth road – Town Hall road – Kannur road – West Nadakkavu junction – East Nadakkavu junction – To Vellimadukunnu.

v) From Medical College

Arayadathupalam junction – Mavoor road – Rajaji road – Rammohan road – M.M.Ali road – Palayam stand.

vi) To Medical College

Palayam stand – M.M.Ali road – Rammohan road – Rajaji road - Mavoor road – Arayadathupalam junction – To Medical College.

vii) From Kallai

Francis road junction – Francis road – Railway station road – Oyitty road – Town Hall road – CSI junction – NH - Pavamani road – Rammohan road – M.M.Ali road – Palayam stand.

viii) To Kallai

Palayam stand – Kallai road – Francis road junction – To Kallai.

ix) From Mankavu

Same as that of vii

xi) To mankavu

Same as that of viii

Fig.7.4 shows the routing pattern of vehicles in Calicut city as per Alternative 4.

Fig. 7.4 ROUTING PATTERN AS PER ALTERNATIVE_4

7.3 CRITERIA CHOSEN FOR EVALUATION

To compare the generated alternatives and to select the best among them, three criteria were been selected.

These were:

i) Number of right turns at junctions

ii) Total junction delay due to right turns (Vehicle-min)

iii) Number of locations in which ambient air quality exceeded National Ambient Air Quality Standards

7.4 COMPARISON OF VARIOUS ALTERNATIVES

The developed alternatives were evaluated with respect to the chosen criteria for the traffic flows during the peak hour. The calculated values corresponding to all the criteria are given in Table 7.1. From the evaluation, the fourth alternative is considered to be better with respect to all the criteria chosen. Fig.7.5 shows the locations where concentration of all the pollutants exceed the NAAQS. In this alternative, the private regional buses in Calicut city are brought to a single terminal at the newly built bus stand. While, K.S.R.T.C. buses are proposed to be terminated at the K.S.R.T.C. bus stand, all the city buses on the other hand are proposed to be terminated at a common bus terminal, namely Palayam stand. Salient feature of this alternative is that the two-way movement is permitted on the National Highway, the main arterial of the city.

7.5 CONCLUSIONS

The procedure used for the development and evaluation of alternate road networks for vehicles in Calicut city has been presented in this chapter. Four

Table 7.1 COMPARISON OF DIFFERENT ALTERNATIVES

Alternative Routing Patterns	Number of Right Turns	Junction Delays (veh-min)	Number of locations Where Concentrations Exceeding NAAQS		
			CO	HC	NO
Existing	829	508.32	41	62	24
1	943	687.91	43	59	31
2	896	610.13	51	63	21
3	945	691.39	47	68	18
4	804	473.07	28	39	26

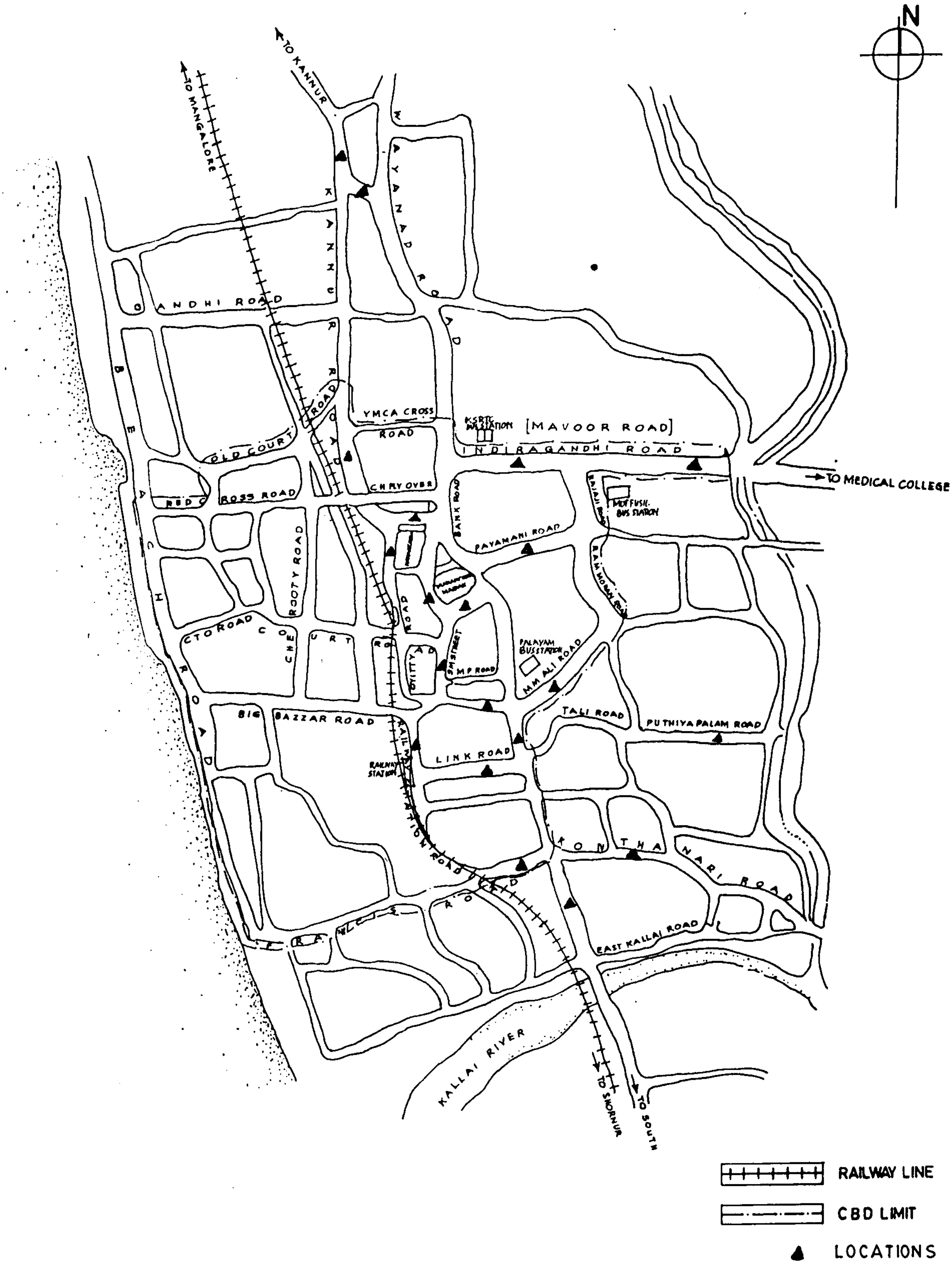

Fig. 7.5 LOCATIONS WHERE CONCENTRATION OF ALL THE POLLUTANTS EXCEEDED NAAQS

SCALE
0 0.13 0.26 0.39 0.52 KM

alternatives were generated and evaluated with respect to different criteria. From the comparison of different criteria, Alternative IV has been considered the best with respect to all the criteria chosen. Chapter 8 presents the procedure used for the development of Environmental Capacity Standards for the four trunk roads of the Calicut city.

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FURTHER EXTENSION TOWARDS THE DEVELOPMENT OF ENVIRONMENTAL CAPACITY STANDARDS

Cini A. "Modelling and evaluation of ambient air quality levels due to mixed traffic on city roads" Thesis. Department of Civil Engineering ,Regional Engineering College, University of Calicut, 1999

CHAPTER 8

FURTHER EXTENSION TOWARDS THE DEVELOPMENT OF ENVIRONMENTAL CAPACITY STANDARDS

8.1 GENERAL

From the literature survey it could be seen that there are not many attempts made in the development of models which are aimed at development of Environmental Capacity Standards and most of those models have been found to be limited to the prediction of concentration of pollutants only. But such types of models are necessary for the evaluation of different traffic control measures and for the development of environmental capacity to limit the concentration of pollutants within the acceptable limits. The objective of this chapter is to discuss possible extension towards the development of Environmental Capacity Standards for highway and its scope is limited to examine what can be achieved within the integrated ambient air quality models developed in the earlier chapter.

Development of capacity standards in mixed traffic flow environment, particularly in urban and sub-urban conditions is far from complete. Many researchers are still continuing the research work on this topic. The objective of this work is not to enter into this heavily researched area but only to derive reasonable values for environmental capacity as a ratio of the possible traffic capacity of the road sections.

To that extent, the procedure for the development of speed-flow relationship is primitive and should not be taken as a yardstick to determine the highway capacity.

8.2 DEVELOPMENT OF SPEED - FLOW RELATIONSHIP

It is necessary to develop speed - flow relationships for the determination of highway capacity of roads. From the field data collected by Key Coverage surveys, the average stream speed and the total traffic volumes were calculated. Fig. 8.1 represents the fitted second order speed –flow curves for the four major roads of Calicut city.

8.3 DETERMINATION OF CAPACITY OF ROADS

The capacities of the four trunk roads were determined based on the speed-flow curves of the corresponding roads. The flow corresponding to half the free speed was selected as the capacity of the road at that particular survey location. It is seen from the relationship established, the capacities of the roads differ widely from 1250 veh/hr to 2400 veh/hr. The variations can be predominantly attributed to the composition of the traffic stream on those roads. While, on Kannur and Kallai roads the predominant mode of vehicle is auto-rickshaws, on Mavoor and Wynad roads the predominant mode of vehicle is city and regional buses.

8.4 DEVELOPMENT OF ENVIRONMENTAL CAPACITY STANDARDS

Environmental capacity is defined as the minimum of the capacities of a road section, selected, to satisfy the ambient air quality levels for various pollutants.

The independent variables selected for the modelling process are the average stream speed, the concentrations predicted from the transfer function models, percentage composition of two-wheelers, percentage composition of auto-

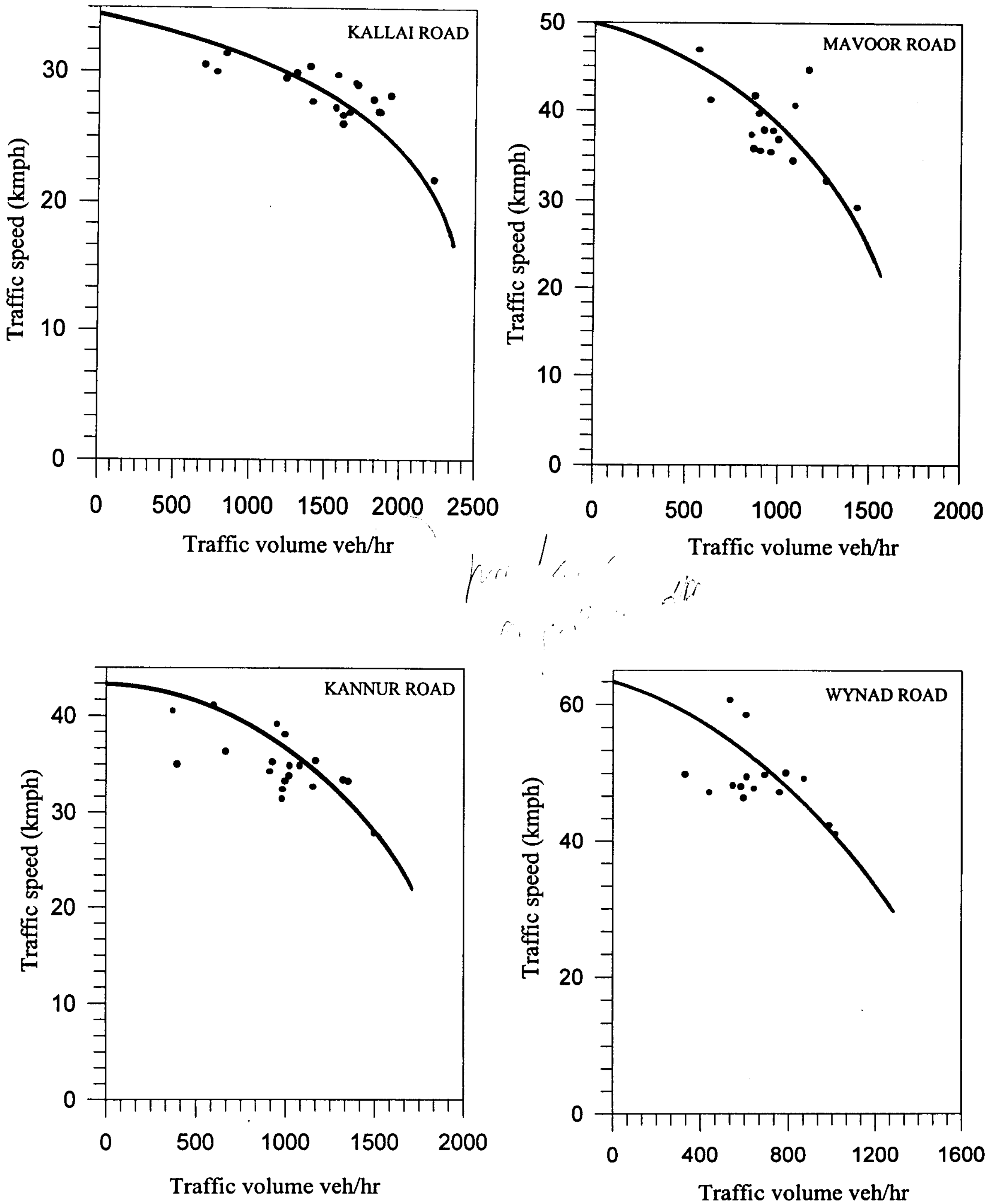

Fig. 8.1 SPEED-FLOW RELATIONSHIP

Table 8.1 MODELS FOR PREDICTING ENVIRONMENTAL CAPACITY STANDARDS (KANNUR ROAD)

List of variables	Beta Weights	t-test values	Intercept constant	Multiple square value
		CARBON MONOXIDE		
2	-0.153	-3.454		
3	36.671	2.287		
4	3.656	1.908	493.240	0.918
5	13.275	5.644		
6	-32.164	-1.755		
		HYDRO CARBONS		
2	-9.389	-1.711		
3	51.050	2.219		
4	5.473	2.370	242.018	0.903
5	11.181	4.051		
6	-26.122	-0.893		
		NITRIC OXIDE		
2	-5.091	-0.961		
3	105.947	4.606	137.07	0.893
4	9.344	5.430		
5	483.804	2.576		

Where:

1 Environmental capacity
2 Traffic speed (km/hr)
3 Pollutant concentration predicted by time series based transfer function models(ppm)
4 Percentage composition of auto-rickshaws
5 Percentage composition of two-wheelers
6 Ambient Air Quality Standards (ppm)

Table 8.2 MODELS FOR PREDICTING ENVIRONMENTAL CAPACITY STANDARDS (KALLAI ROAD)

List of variables	Beta Weights	t-test values	Intercept constant	Multiple R square value
		CARBON MONOXIDE		
2	82.076	-3.454		
3	24.635	0.463		
4	11.458	1.732	2239.734	0.612
5	16.367	1.511		
6	-59.058	-1.506		
		HYDRO CARBONS		
2	-41.138	-2.061		
3	-52.194	-1.231		
4	7.767	1.586	1553.412	0.778
5	159.722	1.859		
6	-134.846	-3.244		
		NITRIC OXIDE		
2	-85.941	-3.464		
3	-33.216	-0.497		
4	8.348	1.679	2684.738	0.688
5	7.315	0.751		
6	-15.724	-1.256		

Where:
1 Environmental Capacity
2 Traffic speed (km/hr)
3 Pollutant concentration predicted by time series based transfer function models (ppm)
4 Percentage composition of auto-rickshaws
5 Percentage composition of two-wheelers
6 Ambient Air Quality Standards (ppm)

Table 8.3 MODELS FOR PREDICTING ENVIRONMENTAL CAPACITY STANDARDS (WYNAD ROAD)

List of variables	Beta Weights	t-test values	Intercept constant	Multiple R square value
		CARBON MONOXIDE		
2	-1.197	-0.522		
3	33.245	1.837		
4	128.239	2.598	-108.832	0.808
5	6.613	3.283		
6	3.743	1.228		
		HYDRO CARBONS		
2	-1.544	-0.515		
3	25.476	1.107	18.884	0.709
5	8.459	4.407		
6	34.902	1.114		
		NITRIC OXIDE		
2	-5.0071	-1.751		
3	38.003	1.273	296.878	0.604
5	6.821	2.582		
6	8.828	1.362		

Where:

1 Environmental Capacity
2 Traffic speed (km/hr)
3 Pollutant concentration predicted by time series based transfer function models(ppm)
4 Percentage composition of auto-rickshaws
5 Percentage composition of two-wheelers
6 Ambient Air Quality Standards (ppm)

Table 8.4 MODELS FOR PREDICTING ENVIRONMENTAL CAPACITY STANDARDS (MAVOOR ROAD)

List of variables	Beta Weights	t-test values	Intercept constant	Multiple R square value
		CARBON MONOXIDE		
2	-3.124	-0.742		
3	7.108	2.587		
4	-0.657	-1.071	483.837	0.701
5	-1.585	-0.448		
6	89.968	3.231		
		HYDRO CARBONS		
2	-7.340	-1.804		
3	62.792	3.315		
5	-0.596	-1.169	605.982	0.651
6	7.478	1.379		
		NITRIC OXIDE		
2	-3.124	-0.742		
3	71.083	2.587		
4	-0.657	-1.071	483.837	0.701
5	-1.585	-0.449		
6	89.968	3.231		

Where:

1 Environmental Capacity
2 Traffic speed (km/hr)
3 Pollutant concentration predicted by time series based transfer function models(ppm)
4 Percentage composition of auto-rickshaws
5 Percentage composition of two-wheelers
6 Ambient Air Quality Standards (ppm)

Table 8.5 ENVIRONMENTAL CAPACITY OF DIFFERENT ROADS

Road	Width (in m)	Maximum Flow Observed (veh/hr)	Capacity (veh/hr) VC	Environmental capacity (veh/hr) EC	EC/VC Ratio
MAVOOR	7.9	1432	1500	1054	0.703
WYNAD	6.9	1018	1250	635	0.508
KANNUR	7.6	1498	1700	1033	0.608
KALLAI	6.8	2232	2400	1815	0.756

rickshaws and the ambient air quality standards for each pollutant. Tables 8.1 to 8.4 give the models selected for the determination of environmental capacity for the four trunk roads based on t-test and R^2 value. The minimum service volume corresponding to National Ambient Air Quality Standards for different pollutants was selected as the environmental capacity. From the values, it was observed that the environmental capacity standards were below the capacity values for all the four major roads of the Calicut city. From the analysis of the selected values of the environmental capacities, it was found that, the environmental capacities for highways were in the range of 50-75 per cent of the highway capacity values.

It should be the endeavor of the Traffic Engineer to suggest effective Traffic Management Measures so as to limit the service volumes to the environmental capacities as worked out in this study, so that the resulting pollutant concentrations do not exceed the National Ambient Air Quality Standards. If that is found to be impossible in a city, elaborate network expansions may have to be taken up.

Table 8.5 gives the values of environmental capacity for different roads along with the maximum flow observed, the capacity, the road width and ratio of environmental capacity to traffic capacity of roads.

8.5 CONCLUSIONS

An extension of the use of integrated ambient air quality models towards the development of Environmental Capacity Standards has been discussed in this chapter. It is felt that the Traffic Engineer must plan the Traffic Management Measures in the city to limit the service volumes to the environmental capacities as developed in this study. If that is found to be not practicable, elaborate construction programme of new road facilities may become necessary. The summary, the conclusion, the limitation and the scope for further study are presented in Chapter 9.

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SUMMARY, CONCLUSIONS, LIMITATIONS AND SCOPE FOR FURTHER STUDY

Cini A. “Modelling and evaluation of ambient air quality levels due to mixed traffic on city roads” Thesis. Department of Civil Engineering ,Regional Engineering College, University of Calicut, 1999

CHAPTER 9

SUMMARY, CONCLUSIONS, LIMITATIONS AND SCOPE FOR FURTHER STUDY

9.1 SUMMARY

9.1.1 Traffic in general, has been identified as major source of air pollution in urban areas. From various studies it has been observed that about 60 percent of the air pollution in our cities is due to the automobile emissions.

9.1.2 Numerous investigations have reported the use of Guassian Dispersion theory for general pollutant concentration studies, but the use of this theory for the prediction of ambient air quality levels due to road traffic has been found to be riddled with many uncertainties because of the dynamic behavior of the moving vehicles.

9.1.3 Clean Air Act Amendments(1990) warrant a continuous and a coordinated effort for air quality monitoring adjacent to heavily used travel corridors. In order to facilitate air quality assessment, modelling of air pollutant concentrations, incorporating traffic parameters like the traffic volume, the speed and the composition, becomes necessary.

9.1.4 Calicut city was selected as the study area. The tremendous growth of vehicular traffic coupled with the lack of basic road infrastructure for transportation has contributed to the drastic deterioration of the environment of the city.

9.1.5 In order to get a general idea about the air quality levels near major trunk roads of Calicut city, a Pilot Survey was organised at different locations within the study area.

9.1.6 In the first stage of this study, the pollutant concentrations were predicted using Guassian Dispersion models with modifications suggested by TRRL (1982) and U.S.EPA (1980). (Matzoros, 1992)

9.1.7 For the purpose of this study, the area under investigation was divided into four bands in relation to their distances from the city center. Trichur, Kannur, Wynad and Mavoor roads are the trunk roads entering the city. The traffic stream variables and pollutant concentrations were collected at four locations on all these trunk roads.

9.1.8 Key coverage surveys were conducted for a period of 10 hours, one in each of the four bands of the study area, to collect comprehensive data on traffic stream variables and pollutant concentrations, so that the surveys conducted at different time points could be deduced to the required time frame.

9.1.9 The seed O-D matrices required for assignment models were generated by a computer package called NIPTAC-NODIAC by Nagaraj (1984). The travel time–flow relationship required for assignment model was established from the moving car observer studies.

9.2 CONCLUSIONS

9.2.1 Gussian Dispersion models and its variants that were tested have been found to have very high RMS percentage error. The high values of RMS percentage errors indicated that Guassian Dispersion Theory alone is not in a position to be used for the prediction of ambient air quality near highways due to a system of moving vehicles.

9.2.2 From the analysis of field data obtained from the Pilot survey, it has been observed that the meteorological parameters are less significant in explaining the variations in pollutant concentrations due to road traffic and the pollutant concentration levels exceed the permissible value.

9.2.3 It has been observed that concentration of both CO and HC concentrations are higher in the city center compared to sub-urban sections. On the other hand, the NO concentrations have been found to be low when the speeds are low and vice versa.

9.2.4 From the analysis of the field data it has been observed that there is a lagged relationship between pollutant concentration and traffic volume.

9.2.5 It has been established in this study, that the predicting ability of a simple regression type models for predicting pollutant concentrations near roads, using traffic stream variables could be very much improved by incorporating the pollution levels as predicted from time series based transfer function models. The other variables of influence that have been identified are the traffic volume, the average stream speed, the percentage composition of auto-rickshaws and the percentage composition of two-wheelers.

9.2.6 A composite model that has been developed in this study, combining the traffic assignment model SATASS of SATURN package and the pollution concentration model with time lagged response, has indicated that the city roads of Calicut are highly polluted. A comparison of the predicted pollution concentration with National Ambient Air Quality Standards has indicated that the Carbon monoxide, the Hydrocarbon and the Nitrogen oxide concentrations exceed those of permissible standards in the city of Calicut at present in 41, 61 and 24 locations, respectively.

9.2.7 In this study, four alternative routing patterns have been developed for the routing of buses using the combination model. Based on this evaluation, an alternative routing pattern for vehicles in Calicut city has been suggested, which has been observed to be better than the present arrangement not only from the point of view of traffic flow, but also from the point of view of limiting the ambient air quality within the acceptable limits.

9.2.8 The combination model developed in this study has then been used for the calculation of Environmental Capacity. It has been observed that the Environmental Capacity of Calicut city roads are in the range of 50-75 percent of the traffic capacity.

9.3 LIMITATIONS OF THE STUDY

Inspite of several advantages claimed by the combination modelling approach suggested in this study, there are many limitations, some of these and other limitations are listed below.

i) The pollutant concentrations predicted by the combination models have two components each: One of them coming from the causal factors responsible for the pollution concentration and the other resulting from the time lagged response which are predicted by the transfer function time series approach. In order to predict the latter, it is essential to have a continuous data base of both traffic influencing variables and pollution concentrations observed at each locations over several days and years. It is prohibitively costly to have such a data base established. What has been done in this study, is to gather the required data for a limited time period at each location, and to predict the expected levels of those influencing variables by 'ratio analysis', in relation to the observations at a few key counting stations. There are many ' if's and but's ' in that kind of indirect approach for compiling primary data.

ii) The speed-flow relationships for mixed traffic situation that have been established in this study are very rudimentary. Several researchers in India are actively engaged in the development of those relationships, using, several sophisticated approaches like Simulation, Neural Network and Fuzzy System approach, Simulated Annealing approach etc. Compared to that, the procedure used in this study for the calculation of traffic capacity of roads do lack sophistication in all fronts.

However, the development of traffic capacity standards in mixed mode environment, was not the real objective of this study. As and when accurate results are available, it can always be incorporated in the proposed combination model suggested.

iii) Several routing patterns of vehicles have been suggested in this study, on the assumption that the existing traffic volumes are capable of accommodating the resulting traffic volumes. In fact, some of the roads may not have the required capacities. However, if the accurate capacity values are available, then the routing patterns could be appropriately altered using the traffic assignment packages.

iv) Many of the developed relationships in this study appear to be based on insufficient data (Delay Vs traffic flow relationship, travel time Vs flow relationship using moving car observation, etc.). But limitations of budgetary constraints could permit only that amount of sophistication. As and when more data are available, all those relationships could be accurately modelled.

9.4 SCOPE FOR FURTHER WORK

There is a need for the development of an interactive package between the traffic assignment model and the pollution model suggested in this study, so that it is possible to develop Environmental Capacity Standards of the roads on the network. Such a package will ultimately suggest a routing pattern of vehicles in the city so that the environmental and the traffic capacity standards are not violated in the city. If that is impossible, then it will at least be able to workout a routing pattern which has minimum environmental violations. A generalised Least Square Econometric Model development may be the ultimate step in this direction.

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