Evaluation of Planning Options to Alleviate Traffic Congestion and Resulting Air Pollution in Dhaka City

by

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August, 2002

Khandker Mohammed Nurul Habib

DEDICATION

To My Parents

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LIST OF ABBREVIATIONS

BRTA	Bangladesh Road Transportation Authority
BRTC	Bangladesh Road Transportation Corporation
CO	Carbon Oxides
CBD	Central Business Density
CSI	Congestion Severity Index
DCC	Dhaka City Corporation
DITS	Dhaka Integrated Transport Study
DIT	Dhaka Improvement Trust
DoE	Department of Environment
DUTM	Dhaka Urban Transport Model
HCM	Highway Capacity Manual
IAP	Immediate Action Plan
MAD	Mean Assigned Deviation
NO_x	Nitrogen Oxides
NCHRP	National Cooperative Highway Research Program
RCI	Roadway Congestion Index
SO_x	Sulfur Oxides
SPZ	Specific Zone
TAZ	Transportation Analysis Zone
TRB	Transportation Research Board
TRI	Travel Rate Index
TTI	Texas Transportation Institute
TDM	Transportation Demand Management
TSM	Transportation System Management
UTMS	Urban Transportation Modeling System
UNDP	United Nation Development Program
VCI	Volume Capacity Index
WB	World Bank

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ABSTRACT

Traffic congestion has now become a very serious problem particularly in metropolitan Dhaka, the capital of Bangladesh. Because of the rapid socio-economic changes and increase in population, the city expanded dynamically without any planning and control. Such rapid and uncontrolled developments have created an unacceptable level of disparity in the transportation demand and supply scenario, which resulted in traffic congestion and environmental degradation through air pollution. To reach at an equilibrium level between the demand and the supply, it is required to implement traffic engineering and transport planning measures on the basis of scientific studies.

Considering the grievousness of the situation, concerned authorities like Bangladesh Road Transport Authority (BRTA), Dhaka Metropolitan Police (DMP), Dhaka Transport Coordination Board (DTCB) and Bangladesh Road Transport Corporation (BRTC) have taken several measures for its improvements. But these were implemented in ad-hoc and disintegrated way thereby failing to achieve the desired result. In fact to tackle the problems of increasing traffic congestion and resulting air pollution, quantitative analyses of the situations are deemed necessary and the plans should be designed on the basis of the results of analyses.

This study is devoted to analyze present and future traffic congestion and resulting air pollution in Dhaka city. In the study, a few immediately feasible alternative planning options are considered for evaluation which include elimination of rickshaw and auto-rickshaw, improvement of road network, improvement of bus transit and introduction of rail transit system in Dhaka city. In this regard a transportation model, named as 'Dhaka Urban Transportation Model' (DUTM) has been developed and calibrated for the study area. The area included in this study comprises 154 km^2 of central urban portion of Dhaka city, which is the area under jurisdiction of Dhaka City Corporation. This area includes 90 wards of Dhaka city Corporation with population of around six million and 350 kilometer roadway of the city. DUTM is used to simulate the peak period hourly traffic volume on roadway links within the study area. In this study, traffic congestion is evaluated by using four types of congestion indices and air pollution is evaluated by emission rates of SO_x, NO_x and CO in ton per hour. The congestion indices used in this study are Roadway Congestion Index (RCI), Volume Capacity Index (VCI), Travel Rate Index (TRI) and Congestion Severity Index (CSI).

For the present year of 2002, it is found that peak period total travel demand is 1.3 million vehicle-km and 59.5 thousand vehicle-hours. These demands increase exponentially with the increase in city population. At present 24% of total roadway length of the network carries peak period traffic with average speed less than 5 kilometer per hour, 62% of total roadway length carries peak period traffic with volume-capacity ratio greater than 1.25, the total travel demand exceed the total network capacity by 250 percent and 227 hours delay occurs per 1000 kilometer travel. The emissions of SO_x, NO_x and CO are 0.3 ton per hour, 0.8 ton per hour and 13.5 ton per hour respectively.

The analyses have been extended up to the planning period of 2020 for business as usual case, called the baseline analysis, as well as for the alternative options. In the baseline analysis, it is found that the percentage of roadway length with peak period traffic having average speed less than 5 kilometer per hour will increase to 42.5% in 2010 and to 58% in 2020. The total travel demand will exceed the total network capacity by 343 percent in 2010 and by 460 percent in 2020. The delay per 1000 kilometer travel will increase to 937 and 3575 hours in 2010 and 2020 respectively. The emission of SO_x , NO_x and CO will increase to 1.3, 4.1 and 62 ton per hour in 2020 respectively.

The evaluations of planning options imply that elimination of rickshaw reduces traffic congestion by more than 50 percent and reduces delay by more than 90 percent. It also reduces emission of SO_x , NO_x and CO by more than 50 percent in the long run. The effect of the elimination of auto-rickshaw on traffic congestion is not significant, but it reduces emission of SO_x and CO by more than 20 percent. Although the elimination of rickshaw and auto-rickshaw will result in considerable reduction in both traffic congestion and air pollution, in order to sustain the level of mobility, it is required to increase the number and quality of buses substantially. In connection with the improvement of the bus service, the study suggests that the improvement of the speed will be the most beneficial. In the study, it is observed that the significant increase in network traffic flow can be achieved through minor improvements at a few bottleneck points in the road network of the city. The feasibility of introducing rail transit using the existing surface rail lines of the Dhaka city is also examined in this study. The result implies that a system of rail network will be required in order to make it a feasible alternative. The results also suggest that the rail transit system will require suitable access modes to extract the optimum benefit.

Chapter 1

INTRODUCTION

1.1 General

Cities are the powerhouses of economic growth for any country. According to Bartone et. al. (1994), around eighty percent of GDP growth in developing countries is expected to come from cities. For the purpose of economic activities, it is imperative to facilitate movements. Transportation system provides the way for movements and medium for reaching destinations. Inadequate transportation system hampers economic activities and creates hindrances for development. In most of the developing countries, which are overburdened by huge population and extreme poverty, increasing economic activities and opportunities in the cities result in rapid increase in urban population and consequent need for transportation facilities. Authorities in these countries often fail to cope with the pressure of increasing population growth and economic activities in the cities, causing uncontrolled expansion of the cities, urban sprawl, traffic congestion and environmental degradation. The backbone of urban activities is the urban transportation network. The transportation network of an urban area is usually designed to accommodate the transportation activities of urban people. With growing population and diversified land-use activities, transportation system needs to be updated or readjusted. Any lag between growing transportation demand and network capacity results in traffic congestion, thereby economic loss and environmental degradation.

Major reasons of such urban dilapidation are the inability of understanding the factors causing problem and lack of proper planning to improve the situation. To cope with the situation, it is imperative to ensure proper use of available facilities and develop infrastructure through optimum utilization of resources. It is particularly true for developing countries like Bangladesh that because of scarcity of resources, planning provides scope for optimum utilization of available facilities and resources. For planning purpose, it is necessary to obtain quantitative visualization of the consequences of the planning and development policies for comparison among alternative options. Computer based models facilitate such visualization and evaluation of future consequences of planning options. Although such computer applications have some general structures, the models should be strategic and specifically developed for the area of interest. The planners of developing countries are severely constrained by unavailability of such planning tools.

The need for transportation model as a planning tool is particularly important due to the extent and characteristics of transportation systems. The demand for transportation is integrally related with economic activities, land-use, population and its distribution etc. Also transportation system development involves huge amount of money and substantial amount of time. Because of these reasons any decisions regarding transport sector needs adequate planning, which should be justified by analysis on the basis of transportation models.

For effectively dealing with traffic congestion and associated environmental problems, transportation planners need a tool to get a greater visibility of current and projected condition and comparative benefit of potential system improvement alternatives. In principle, strategic transportation planning models provide the best means of satisfying these requirements. With accurate database and careful specifications, such models are capable of affording planning insights that may not be obvious to the common sense. This study is devoted to develop an Urban Transportation Modeling System (UTMS) for Metropolitan Dhaka, then analyze baseline situation of traffic congestion and consequent environmental degradation, at last evaluation of some alternative planning options to improve the conditions.

1.2 Motivation of the Research

Dhaka, with a population of over 10 million, is among the top ten mega cities of Asia. With the prediction of a faster urbanization, the city will have to accommodate future influx of population. To what extent will Dhaka be able to meet the challenge of rapid urbanization and continue to offer a conducive environment for further economic development is a burning question for the planners, engineers and decision makers. Striving for an efficient transportation system is a crucial requirement of the urban development strategy for Dhaka city. Any constraints or bottleneck in this regard will seriously affect the economic potential of Dhaka, especially in the context of global market and world trade. Flaws in transportation system of Dhaka city are now pronounced as severe traffic congestion and resulting air pollution. This study is motivated by the traffic congestion and environmental condition prevailing in Dhaka city as the situation is deteriorating rapidly with increasing urban population and economic activities.

Such traffic congestion has become a ubiquitous incident in Metropolitan Dhaka. The enormity of the problem can be assessed from the fact that during peak hour it takes more than an hour to travel a distance of only five kilometer. The congested situation prevails almost whole day. A recent study reveals that the average speed of a major arterial road of Dhaka city, named "Mirpur road" is 15 to 17 kilometer per hour during peak period (Monayem, 2001). In addition to other losses (economic losses, discomfort etc.) traffic congestion worsens the environmental condition, which is already extremely poor in the urban areas of the Dhaka. Although the city wide average pollution level is still bellow the limit set by Department of Environment (DoE) and World Health Organization (WHO), the air pollution level in the central urban areas of the city exceeds the limit. A recent study reveals that the minimum emission rates of SO_x, NO_x and CO in major roadway intersections of Dhaka are 800, 500 and 33,200 $\mu gm/m^3$ respectively in comparison with corresponding Bangladesh standard of 100, 100 and 5000 $\mu gm/m^3$ respectively. The Air Quality Index (an aggregate measure of air pollution level) at many points of the city road network is found to be above 200, which is much higher than the acceptable limit of 50 for fairly clean air (Alam et al, 2000).

Several attempts have recently been made by agencies like Dhaka City Corporation (DCC), traffic police, BRTA, BRTC etc. to improve the situation. Most of these measures fall in the category of short-term traffic management, which have been implemented on adhoc basis and isolated ways, without adequate study. Also a lot of measures, which have been proved effective in other countries, have not been implemented yet. To keep the city mobile in the future, long-term policies need to be implemented. It should be remembered that successful measures of other countries might not be as fruitful due to indigenous characteristics. For example, decisions like promoting cars through reduced taxes may have an adverse effect on transportation system as well as national economy. Traffic composition and drivers' behavior in Metropolitan Dhaka is unique in the world.

Human pulled rickshaws is prevalent together with motorized vehicles. Also, while developing long run policies, one has to be very careful in selecting the future modes of transportation. Many developed countries, especially European countries, have been vigorously promoting non-motorized modes like walking and cycling. It is well recognized that public transportation has the potential to play an important role in improving traffic and environmental situation. But the demand is required to be assessed under different pricing and other level of service scenarios for public transportation system design and implementation.

For the purpose of developing a sustainable transportation system, long-term policies should be established. One of the major reasons of congestion is improper and imbalanced land-use. For congestion management, adequate considerations must be provided on this issue. The transportation system components, such as land-use, economic activity locations, selection of residential areas etc. are very much interrelated with one another. Any change in a single component of the system affects the other components as well. So to develop transportation policies and to reduce traffic congestion and environmental pollution, the alternative options are required to be analyzed by using transportation model. For Dhaka, although a model based study (DITS, 1993) had been performed, the practice of application of the model in decision making is yet to be established. Even a complete Urban Transportation Model System (UTMS) for Dhaka is not available to the urban planners. It is deemed necessary to develop an UTMS for urban areas of Dhaka and apply it for the evaluation of baseline situation and alternative planning options to alleviate traffic congestion and consequent air pollution.

1.3 Objectives of the Research

Development of an efficient transportation system requires rigorous planning, long before its utilization. Also, because of huge amount of resources involved the investment in transportation sector needs to be rigorously analyzed. Usually such analyses are performed through transportation models. The purpose of this research is to develop an Urban Transportation Modeling System (UTMS) for urban areas of Dhaka and apply it for evaluation of alternative planning options to alleviate traffic congestion and consequent environmental pollution.

The specific objectives of the study can be summarized as:

- Develop an Urban Transportation Model System (UTMS) for transportation planning of Dhaka, named 'Dhaka Urban Transportation Model' (DUTM).
- Assess the baseline situation of traffic congestion and environmental pollution caused by transportation in urban areas of Dhaka.
- Identify and analyze the deficiency of transportation system in urban areas of Dhaka.
- Evaluate selective alternative strategies for alleviation of traffic congestion and consequent air pollution in the city.

1.4 Scope of the Study

The study is designed to develop a UTMS for Dhaka city and then simulate peak period traffic volume on road network. In view of constraints, like computational facilities, time and information resources, the study is dedicated to the only central urban portion of Dhaka (Area under jurisdiction of Dhaka City Corporation) and evaluation of some selected alternative planning options, which include elimination of rickshaw, elimination of auto-rickshaw, improvement of road network, improvement of bus service, and incorporation of railway in urban transportation network. Again it is well recognized that changes in transportation system have always some long-term effects with corresponding land-use pattern changes. Such long term effects with changes in land-use pattern are also out of the scope of this study.

1.5 Organization of the Thesis

The thesis is composed of the seven chapters, references and appendix. Chapter 2 reviews the related literatures about transportation system of Dhaka City and similar transport studies in Bangladesh and other countries. It also includes summaries of the prior research on urban transportation planning particularly methodological and specification related aspects.

Chapter 3 describes the methodology of the study, which includes the overview of the strategic UTMS and the ways to quantify transportation system performance, particularly traffic congestion and consequent air pollution.

Chapter 4 describes the process of development and calibration of UTMS for Dhaka city. The individual components of the UTMS developed for urban areas of Dhaka are also described in this chapter.

Chapter 5 describes the baseline situation of traffic congestion and air pollution of urban areas of Dhaka in terms of various indices and measures for transportation system performance.

Chapter 6 describes the effectiveness of some alternative planning options to improve the situations of traffic congestion and air pollution of urban areas of Dhaka.

Chapter 7 gives the summary and conclusion of the study. It also makes some recommendations for future studies in this field.

The reference chapter provides the various references used within this thesis.

The appendix chapter provides map of road network of this study, basic employment data of the study area and a sample output file of DUTM.

The plan of the research work is presented schematically in Figure 1.1, which outlines the broad structure of the thesis.

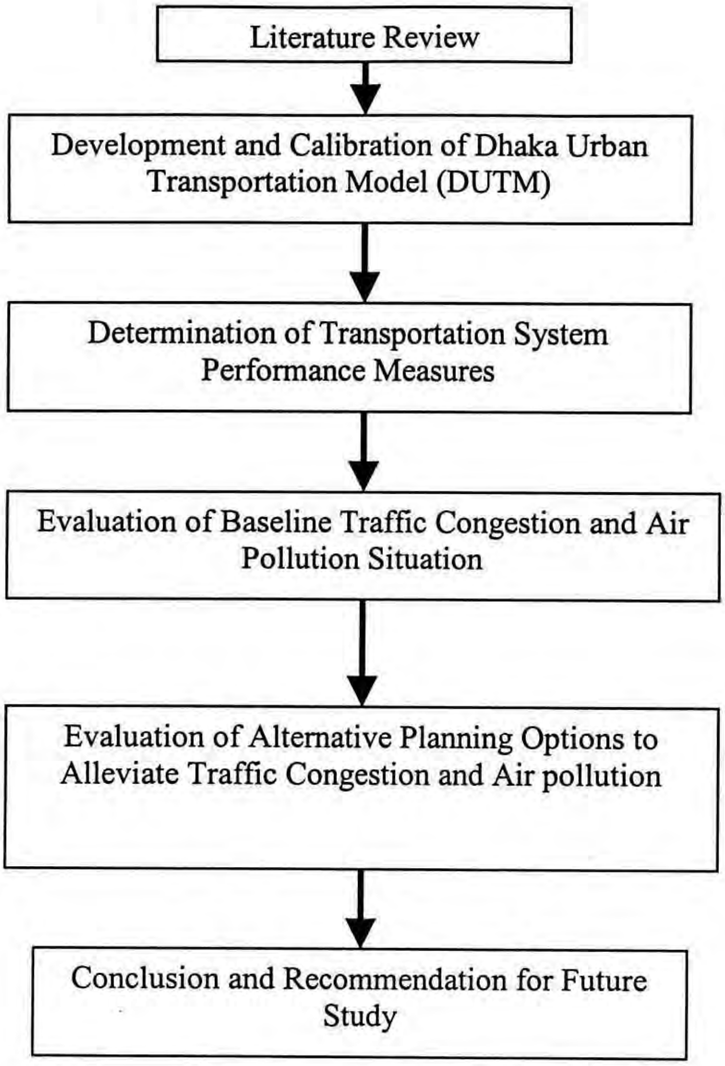


Figure 1. 1: Flow Chart Showing the Outline of the Thesis

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of literature on transportation system and the different transportation studies on Dhaka City with special emphasis on traffic congestion and consequent air pollution. An extensive literature survey of the documents on relevant researches and studies both in Bangladesh and oversees, has been performed and some of them are abstracted in this chapter. A review of literatures reveals that, only a limited number of studies have been accomplished on Dhaka City and no studies have so far been accomplished to quantify the traffic congestion in Dhaka City. Some ideas from this review have been incorporated in the current study.

2.2 Transport Studies in Bangladesh

Before starting the present study, it is desirable and informative to review the past studies in Bangladesh, especially those relating the Metropolitan Dhaka. This section summarizes those studies.

2.2.1 Planning and Policy Related Study

Though Dhaka is a very old city, detailed study and research based planning is relatively new. The first study on road network planning "Dhaka City Master Plan" was prepared in 1959 by then Dhaka Improvement Trust (DIT), covering roughly 830 square kilometer area with a population slightly exceeding 0.5 million. It provided a detailed plan for future construction of roads in the metropolis, (Khan, 2001). Another study was made on economy and engineering feasibility of the "Dhaka bypass" in 1968. In that study along with recommendations for design and construction of roads, some suggestions were made on traffic control and traffic management.

Baquee (1979) conducted a study regarding traffic problem in Old Dhaka. It was a comprehensive study on nature, cause and probable solution of traffic congestion in Old

Dhaka. In that study it was found that traffic congestion arouse partly because the city road network was not designed to cope with new forms of road transport and their increasing numbers. In that study traffic management had been neglected.

Baquee pointed out some ways of controlling the use of roads that could be a solution to the problem of traffic congestion. She recommended some traffic management techniques to solve the problem; such as time restriction for the related vehicles, parking provisions improvement, one-way system, banning of selected vehicles from selected roads etc. She also pointed out that changes in land-use pattern could improve the situation greatly.

Shankland Cox Partnership (1979) Study was a comprehensive study on transport development in metropolitan Dhaka, which emphasized on the construction and management of road network. It also described physical characteristics such as capital cost, life of vehicles and capacity of different modes in the study area. Furthermore, it suggested to include special design consideration for rickshaw in road construction. Shankland Cox Partnership (1979) also made a study on engineering infrastructure for flood protection in Metropolitan Dhaka. It suggested for surface railway on the proposed flood protection embankment.

Gupta (1980) conducted a study regarding rickshaw pullers, rickshaw owners and role of rickshaw in Metropolitan Dhaka. Gupta pointed out that if the growth of rickshaws was allowed to continue at prevailing rate without any restrictions, an increase in number would likely to exceed the limit. On the other hand, if rickshaws were eliminated from metropolis, the situation would create serious pressure on other modes of transportation, which were grossly inadequate at that time and would also have impact on general living conditions of the public, as the traveling cost in general would likely to elevate. The most serious impact, however, will be the employment situation, since a large number of people would be rendered jobless.

Kiwan (1988) conducted a study on pedestrianization in Dhaka city. He worked on pedestrian traffic safety, mobility, accessibility and environment. He mainly focused on pedestrian-vehicle conflicts and provided a package of recommended measures and guidelines termed as Environmental Traffic Safety Planning and Management.

Gallagher (1992) made a study on rickshaw of Bangladesh. He investigated the uses and characteristics of rickshaw, rickshaw pullers and growth trend of rickshaw. Gallagher found that 78 percent of rickshaws were carrying only passenger and 22 percent were carrying goods with passenger.

Alam (1992) performed a model based study on Dhaka city. He analyzed traffic optimization options by using traffic assignment model.

With new perspective, the Dhaka Metropolitan Development Plan (DMDP, 1995-2015) was prepared for sustainable growth of Dhaka. The plan comprised of three levels. The first level, "The Structural Plan" provided a long term strategy including transport network for the 20 years (1995-2015) for the Greater Dhaka with population target of 15 million. The second level, "The Urban Area Plan" provided an interim mid-term strategy for 10 years (1995-2005) and covered for the development of urban areas within Metropolitan Dhaka. The third level, "The Detailed Area Plan" provided detailed planning proposals and transport network for specific sub-areas of Dhaka, (Hafiz, 2001, Nagari, 2001)

The Greater Dhaka Metropolitan Area Integrated Transport Study (DITS) (1991-1993) was an initiative of the Government of Bangladesh with assistance from UNDP. The project was aimed at collection of information about the demand for transport services and the infrastructure to deliver those services to greater Dhaka, preparation of an immediate action plan for the effective management of existing traffic and transport system, preparation of a sound basis for the development of policies and the strategic planning of longer term transport infrastructure investments in the Greater Dhaka Metropolitan Area. DITS began in 1991 and ended in 1993. DITS produced numerous recommendations within its Immediate Action Plan (IAP). Those vary from schemes at a micro level (such as how to improve traffic flow at a particular intersection) to macro level reviews of institutional matters. Recommendations had embraced projects ranging from capital investments to strategic policy advice involving little or no expenditure.

Recognizing the need for a sustainable increase in investment in Dhaka's transport sector, Government of Bangladesh with the help of World Bank (WB) approved a project named Dhaka Urban Transport Project (DUTP). DUTP is a technical assistance project. It started in two phases. DUTP I ended in 1998 and DUTP II started in 1998 with reference to work of DUTP I. The main objective of this project was to provide detailed plan and scope for structural improvement of road transportation system of Dhaka city. DUTP-I resulted in the following main recommendations:

- Promotion of the operation of public busses.
- Provision for pedestrian only areas in old Dhaka.
- Provision of NMT (Non Motorized Transport) main route network.
- Improvement of function of the major intersections by constructing flyovers at three locations.
- Improvement of existing truck stands.
- Development of a comprehensive parking policy.
- Enhancement of management and enforcement capabilities of DCC, DMP and BRTA.
- Provision of adequate compensation and reinstatement elsewhere for families, commerce, and establishments affected by the projects (new construction).
- Addressing a broad context of environmental issues.

Jaigirdar (1998) conducted a study to asses the ambient air quality of Dhaka City. He investigated the impacts of improved bus service in reducing environmental pollution. He pointed out that improved bus service might be the best option for a mass transit system in Dhaka.

2.2.2 Traffic Management and Safety Study

Ahmed (1980), Ahmed and Hoque (1988) discussed different aspect of failure of traffic management and administration of Dhaka City. It was found that existing transport facilities were not adequate to meet travel demand and mixed mode situation, which resulted in traffic congestion and danger. Suggestions for modifications of traffic management and policies had been made.

Hoque (1981, 1986) mainly dealt with different aspects of road safety. He identified several types of road accidents in Metropolitan Dhaka. He also pointed out their causes and recommended some remedial actions.

Replogle (1992) made a comprehensive study on NMTs in different Asian cities. According to him, in Bangladesh, although rickshaw contributed majority of the road traffic, it accounted only 10 percent of traffic deaths. Major portion of rickshaw accidents were for the collision with buses and trucks.

2.2.3 Studies on Urban Travel Pattern of Dhaka

Ara (1983) investigated the factors that are responsible for the selection of particular transport mode. In particular, he analyzed the travel behavior of some particular localities in the Metropolitan Dhaka. It was found that total family income was the most important factor in determining its members' choice of appropriate transport mode for different trip purposes. Other factors that influenced selection of travel mode were age and sex, car ownership etc.

2.2.4 Studies on Urban Public Transport

Firdous (1984) highlighted some of the problems in the bus operation in Metropolitan Dhaka. He pointed out the problems faced by the users. He argued that although there was an ever increasing demand for busses, the bus fleet did not increase keeping pace with the increase in population.

Ahsan (1990) investigated the status of public transport systems in Metropolitan Dhaka. Particular attention was given to the necessity of a functional and cost effective mass transit system. He pointed out that the existing mass transit system needed to be expanded in terms of both fleet size and route network. He also recommended to improve maintenance facilities, stop and terminal layouts, the quality of services and development of more advance forms of transit facility, such as rapid transit system.

2.2.5 An Overview

In Bangladesh only a few studies have been made in transport sector. Out of all, however, the urban transport sector was given more emphasis than rural transport sector also public transport sector was given more emphasis than private sector. But these studies are not adequate to provide a comprehensive picture of urban passenger transport situation. Studies, concerning, transport situation of Metropolitan Dhaka, were mostly related to transport inventory, traffic management, safety problems, and physical characteristics of different modes. None of them are especially related to traffic congestion and consequent air pollution of the Dhaka City.

2.3 Research on Traffic Planning and Management

Many studies relating to urban travel behavior and its relation to socio-economic variables of urban dwellers have been done in different countries. Some of them, which deal with traffic planning, management and related variables, are discussed below.

2.3.1 Urban Land Use Pattern

Owen (1966) pointed out that planners and engineers were designing large-scale urban development considering the salient features of transport problems. He mentioned two sides of the process. First, design process to achieve a good mix of work places and housing, served by conveniently located shopping, schools and other services in a pleasant environment. The second, semi-independent centers or clusters of activities to provide ready access to major highways or rail transits to ensure close links with the central city and abutting region. The transportation corridors help to bring about some degree of order in the movement of traffic among the multiple centers of the urban region and their points of access provide logical sites for concentrating commercial development. Japan planned its community development for a nationwide dispersal effort using the technique explained above. Both high speed rail and telecommunications are used to help spread the benefits of urbanization and reduce diseconomies of over concentration. Owen emphasized on the need for traffic simulation modeling for the design of large-scale urban development. He also suggested traffic optimization modeling as a tool for such process.

2.3.2 Choice of Travel Mode

.Burton (1974) showed that three main factors were responsible for the choice of mode for person trips. These are

1. Characteristics of Journey that includes: Journey time/length and Journey purpose.

2. Characteristics of travelers that includes income and car-ownership.

3. Characteristics of transport system that includes relative travel time, relative travel cost, relative level of service and accessibility indices.

For modeling of any transport or traffic system, these are the variables on which calculation for optimization can be based.

2.3.3 Transport Modes - Performance, Planning and Management

Extensive research has been done in USA, UK, Australia and Japan on different transport modes to optimize their performance. A considerable amount of literature is available on this topic.

Case and Latchford (1981) examined characteristics of different public transport modes, mainly from the user's point of view, on the basis of information gathered from eight cities in South-East Asia. Heraty (1980) investigated the organization and operation of conventional busses and minibuses in the city of Kingston, Jamaica. Maunder and Fouracre (1983) investigated the operational characteristics of specialized bus services in two Indian Cities, Hydarabad and Delhi and in Bangkok, Thailand. Victor (1979) described some recent developments in mass transit modes. Fielding and Anderson (1983) and Jadaan (1988) investigated the system characteristics, usage and operations of urban public transport system and derived a set of indicators to represent all desirable dimensions of transit performance. World Bank (1986) developed another method specifically to evaluate the performance of reasonably well managed bus companies in developing countries.

Greenstein et al (1988) investigated the transport situation in Quito, Ecuador and proposed a new planning of bus scheduling program for the city. Umigar et al (1988) examined the various management policy alternative within three broad ownership patterns - private, public-private mixed and public, in Indian bus transit system.

These studies provide idea about variables of traffic planning and management and parameter for evaluation of performance. They also give basic idea for analysis and optimization of mixed type of vehicles.

Young (1986) investigated computer-aided design in local street planning and management. The study described the relevance and application of procedures from the new information technology, especially computer aided design in planning and management of local street networks. It pointed out that those new techniques offered traffic planners new and perhaps more approximate means for using computers in their work.

Young et al (1988) extensively described the application of Micro Computer in traffic system design. In the study they examined different types of software packages available in traffic system design together with their advantages limitations and applicability.

Yi- Chin Hu and Schonfeld (1984) studied and developed a macroscopic model for Traffic Simulation and Optimization of regional highway networks. It was applied to the Maryland Eastern Shore network, where heavy recreational traffic created severe congestion and long queues. It was used to find out cost-effectiveness of route diversion as a substitute for new constructions on intercity networks - where high demand peaks were infrequent.

Intelligent Transportation System (ITS) involves the integrated application of a range of technologies – computer, sensor, electronics, communications – and management strategies to transportation problems in order to increase the safety and efficiency of the surface transportation system.

2.3.4 An Overview

Urban planners are taking traffic engineering variables more seriously than ever before and also their understanding of the same are much clear now. They are giving more emphasis on the coordinated development of both land use and transport planning aspects.

In all the countries, including developing country like Bangladesh, importance is given in the field of urban traffic planning and management. Methods for evaluating the performance of any transport system are becoming key interest to transport planners and a variety of methods are suggested by different researchers. Proper management techniques for improving the traffic flow situation were suggested by many people.

Another area of interest of the researchers is the assessment of requirement, - utility and performance of investment in road transport.

2.4 Traffic Modeling

2.4.1 Overview

All of the road users are aware that traffic conditions vary widely over the road system. The situations in most of the cases may be unsatisfactory. Though all are concerned about the situation, their recommendations for its improvement vary from person to person. Traffic modeling represents one method of resolving some of these conflicts. It is directed towards the gain of an understanding, how the traffic system operates. Models are, however, developed for many purposes such as traffic flow-volume relationship study, traffic management, traffic plans, road-use planning etc. Traffic system models also vary from the most detailed (micro-) level to the regional (macro-) level.

To prevent the use of inappropriate models, the creation of models should be embedded within the context of a hierarchy framework and a defined development process. The defined process, during development, includes setting of criteria, objective and problem definition, system analysis, parameter estimation, validation and data collection. The final step in model building is application.

One of the most difficult parts of model building is parameter identification. Morlok (1978) argued that the most popular approach was to use some form of deterministic 'fitting' process so that model parameters could be adjusted to provide best fit to the corresponding real world observations. A least square sense worked behind this argument.

There always exist some constraints on model application. The level of considerations for variables chosen is important. The higher level models are concerned with the problems of modes, destinations, general route choice and overall travel and congestion characteristics. The lower level models are concerned with number and types of lanes, traffic signaling, geometric design of road and fleet composition etc.

2.4.2 Comments on Transportation Modeling Systems

This is a relatively new field of study. Currently there are very few systems known to be commercially available or used in transportation engineering practice on commercial basis. Some of the systems, which are operational and others, which are under development are discussed below. All of them are remained to be tested extensively under user environment.

LOGOIL, a rule based expert system that provides advice on shipment plans for crude oil distribution. It is the result of doctoral research of Auselano Braun at Polytechnic University at New York (Ritche et al, 1987).

TRAIL is an expert system that provides assistance to traffic engineers in designing traffic signal settings. It was developed by Carlos Zozaya Gorostiza and Chris Hendrikson in the Department of Civil Engineering at Carnegie Mellon University (Ritche et al, 1987).

EXPERT-UFOS is an expert system for large scale transportation network design problems that are evaluated using multiple conflicting criteria. The system addresses the design of single mode, fixed demand, and discrete equilibrium transportation network. The system was a part of doctoral dissertation by Shein-I Tung in the Department of Civil Engineering at University of Washington (Ritche et al, 1987).

TRANSTEP is a transport demand model to predict traveler responses to transport policies and practices. It is a flexible microcomputer based demand model suitable for the analysis of a variety of urban land-use/transport planning issues at either the strategic or detailed planning level (Young et al, 1988).

SATURN is a tool for testing the impacts of one-way streets, traffic control measures and bus-only streets. SATURN is abbreviated form of 'Simulation and assignment of Traffic in Urban Networks'. The model was developed by Institute of Transport Studies at University of Leeds. It is useful for the analysis and evaluation of traffic management systems over relatively localized road networks (Young et al 1988).

MULATM is a traffic-planning model designed for studying local street networks. It can account for detailed street networks, including individual street and intersection characteristics, and can be used to study the effects of different control devises and measures such as street closers, roundabout, humps, 'slow points' etc. For an engineer or planner this model offers a systematic tool for the investigation of possible effects of alternate traffic management schemes, and the selection of appropriate plans to meet established goals and objectives (Young et al 1988).

NETSIM is one of the most generally used micro-simulation models of traffic movement on networks. It is a microscopic model developed by US Federal Highway Administration. It can be used to evaluate a wide mix of traffic control and management strategies (Young et al 1988).

TRAFFICQ is a developed by UK Department of Transport. This model intended for relatively small road networks, but which may contain complex traffic and pedestrian control techniques (Young et al 1988).

TRANPLAN is a set of integrated programs for the transportation planning process. It encompasses the four-step travel demand model of trip generation, trip distribution, mode choice and trip assignment for both highway and transit systems. The public transit software utilizes coding and analysis techniques similar to the U.S. Department of Transportation's Planning System (UTPS).

NIS (Network Information System) is a flexible iterative graphic editor for displaying and maintaining spatial data, including highway and transit network descriptions and area boundary data.

TPMENU is a menu shell, which flexibly combines TRANPLAN and NIS and provides integrated user interface.

MEPLAN and TRANUS are economically based integrated land use-transportation modeling systems, which can address freight movement as well as passenger travel. These models integrate economic theory with operational planning methods (Rosenbaum & Koenig, 1997). The basis of the framework is the interaction of two parallel markets; one for land, one for transportation. The land portion of the model predicts volumes and locations of activities and their economic linkages with a formulation that explicitly consider cost of land and development. The economic linkages include good, services and labor. These are then used to predict travel demand both passenger and freight, which are assigned to modes and routes on the basis of travel impedance measures. The travel impedance then influences the location of activities in future periods.

2.5 Transport System of Dhaka City

Transport system of Dhaka is mainly road based. Though there is a limited use of waterways, the rail and air transportation for movement within the metropolitan area is totally absent. The road network basically determines the accessibility to the different locations of the metropolitan area. For this reason the next of all descriptions about transportation system of Dhaka City will be that of road transport system only. This section provides the description of road transportation network, road transport modes, existing road transportation management system, road traffic characteristics, problems of road traffic congestion and consequent air pollution.

2.5.1 Road Transportation Network

Established on the bank of river Buriganga, Dhaka has been increasing in north-south direction. With the expansion of the city, the road network of the city has also been growing time to time. The major roads in the old part of Dhaka have been developed in the east-west direction and major roads in the new part have been developed in the north-south direction. The road network of the city had never been planned specifically in cognizance with the well-developed process of trip generation, trip distribution, modal split and route assignment. As a result, an irregular pattern of network, rather than a more efficient pattern such as gridiron or redial-circumferential pattern, has been developed. (Ahsan, 1990)

The road network of Dhaka city is composed of 199 kilometer of primary roads, 109 kilometer of secondary roads, 152 kilometer of collector roads, and about 2540 kilometer of access roads and others (Quium, 1995). Except for some primary roads, almost all other roads are single carriageway. With the exception of some well-planned residential areas, in most of the areas the road network is quite narrow and alignment is poor. Widths of streets, within the old part of Dhaka are narrower than other newly developed parts. All intersections are at grade intersections. Minor intersections are uncontrolled but major intersections are controlled manually. Traffic signals are just ornaments of few intersections without practical application. There are some rotary and roundabouts. Only few intersections have chanalization measures. There are only a few pedestrian overpass and underpass. At present one flyover at Mailbag intersection is under construction and some others are proposed for construction at Jatrabari intersection, airport road etc.

The existing road network in metropolitan Dhaka needs a planned restructuring to support an efficient transport system. This restructuring should be based on standard and functional road classification system, which provides a hierarchy of roads, viz: Local streets, Collectors, Arterials, Access Controlled Freeways etc. The scope of the present study is to evaluate and find out some planning and management related measures, which can improve overall road network performance of the city.

2.5.2 Road Transport Modes

Metropolitan Dhaka has traditionally been served by a wide variety of transport modes. These modes can be broadly classified into two groups, the Motorized transport (viz. bus, mini-bus, truck, car, auto-rickshaw, auto-tempo, motorcycle etc.) and Non-motorized transports (viz. rickshaw, rickshaw van, bicycle, push cart etc.)

***Motorized Transport*:** Estimation from the data provided by 'Statistical Year Book of Bangladesh' reveals that the motor vehicle fleet in Bangladesh is growing as an average rate of 7% per year. But DUTP-II (1998) claims that the vehicle population on road is growing as an average rate of 10% annually. The estimates of different type vehicle population are shown in Table 2.1, which are based on annual registration data from BRTA (Bangladesh Road transport Authority). However, the BRTA information does not include data of the number of vehicle that are retired from the fleet each year. The table indicates that Passenger car, bus and truck are the fastest growing vehicle categories.

Reliable statistics of the size of vehicle fleet in Dhaka are not available (DUTP-II, 1998). The vehicle registration authority (BRTA) has the record of the number of motor vehicle registered in Dhaka each year but no information of the number of vehicles retired each year is available. By applying a retirement profile (the proportion of vehicles that survive from one year to the next) for each vehicle type to the BRTA data on vehicle registrations, the estimates in Table 2.1 were derived as an indication of the fleet by the vehicle types. The figures in the table show quite clearly the indication of the rapid rate of motorization of Dhaka over a period of eight years from 1992 to 1999. Four categories;

motor car, truck, auto rickshaws and motor-cycle have higher growth rates. The comparisons between the estimated vehicle population of different types of Dhaka city and of whole country are shown in Table 2.2.

Table 2. 1: Changes in Number of Registered Vehicles in Bangladesh (1992-1999)

Item	Registered Vehicles			Estimated vehicles on Road		
	Year 1991	Year 1999	Annual Growth Rate	Year 1991	Year 1999	Annual Growth Rate
Car	71,373	1,18,033	6	33,397	56,377	7
Jeep	27,762	32,651	2	8,721	10,346	2
Bus/Minibus	26,449	33,180	3	20,973	26,707	3
Trucks	38,448	55,500	5	30,175	42,756	4
Auto-rickshaws	36,796	90,798	12	27,156	89,317	16
Motor-cycles	1,50,171	2,37,050	6	1,08,922	1,65,460	5
Total	**3,50,999**	**5,67,212**	**6**	**2,29,344**	**3,90,963**	**7**

Source: Bangladesh Bureau of Statistics (BBS).

Table 2. 2: Comparison between Estimated Number of Motor Vehicles in Whole Country and Greater Dhaka.

Vehicle Type	Year 1996			Year 1999	
		Dhaka			
	Whole Country	Number	% of Whole Country	Whole Country	Dhaka
Car	98,854	23,241	24	1,18,033	28,328
Jeep	30,597	12,705	42	32,651	13,713
Bus/Minibus	30,428	3,610	12	33,180	3,982
Trucks	48,734	3,858	8	55,500	4,440
3 Wheelers	79,293	27,443	35	90,798	31,779
2 Wheelers	1,96,012	40,127	20	2,37,050	47,410
Total	**4,83,918**	**1,10,984**	**23**	**5,67,212**	**1,29,652**

Source: Bangladesh Bureau of Statistics (BBS) and (DUTP-II, 1998)

Non-Motorized Transport: Reliable estimate of non-motorized vehicle fleet is more difficult to obtain. Dhaka City Corporation (DCC) limits the number of license issued to rickshaw owners to some 70,000. However, unofficial estimates claim that the number of rickshaws plying in Dhaka city is three times the DCC figure (DUTP-II, 1998).

2.5.3 Road Transport Management

Dhaka has a multi-modal transport infrasture, which caters to the needs of intra-city and inter-city passenger and freight traffic. Most of this traffic (95 percent) is handled by road based transport system. Rail, water, and air transport system primarily cater to the inter-city travel segment and hardly play any role in city transport. Many agencies are involved in providing, operating and maintaining the infrastructure and services within each mode of transport.

Evidently, government agencies have the main provider and operator of transport infrasture and services. Two major factors have contributed to such a situation. The relatively high investment required and high risk involved in the provision and management of infrasture had hitherto discouraged the private sector from entering into this area. But this has changed dramatically in the past two decades. In the case of services, governments have felt that by controlling entry, product characteristics, price levels, profit rates etc. through regulatory mechanisms or direct control, the public would be protected from being exploited by the private operators. Experience in many countries with de-regulated markets has demonstrated that such government interventions were not as efficient as was thought to be.

Table 2. 3: Agencies Responsible for Urban Transport Infrastructure in Dhaka.

Sub-Sector of Transport	**Agencies Responsible for**			
	Infrastructure (Fixed Assets)	**Infrastructure (Movable Assets)**	**Operation and Maintenance of Assets**	**Regulation and Enforcement**
Road	RHD, RAJUK, DCC, LGED, BRTC	BRTC, Private operators	RHD, DCC, BRTC, Private operators	BRTA, Dhaka Metropolitan Police

Source: (Herur, 2001),

The changing focus in transport policy implies a substantial change in the role of government. It should get away from being a supplier, operator, and service provider. Instead it should concentrate on being an effective regulator, a facilitator for private sector participation, custodian of environmental and social interests. This means that the government needs to create the proper institutional framework for competition, set economically efficient user charges for the use of publicly provided infrastructure, allocate the scarce public resources carefully and increase involve the community in the decision making process. These will ensure better transport facility for the city dwellers.

2.5.4 Travel Characteristics of People of Dhaka City

Household Income and Transport Usage: According to DITS (1993), on an average transport expenditure of people of Dhaka is around 12% of total household monthly income. Those people with income less than Taka 1500 per month spend relatively more; and around 16% of household monthly income. This is due to the necessity of people in this income group needing to spend more to gain access to work. The low level of expenditure as 8.4% of household income for households with monthly incomes of Taka 30,000 or greater can be explained by car owners not including capital and other costs associated with owing a car in the reported daily expenditure. These costs are about 40% of the total costs running a car, which would bring the expenditure on transport to 14% of household monthly income for those households earning Taka 30,000 or more. Expenditure on transport services in Greater Dhaka, based on Household Interview survey (DITS, 1993) is about 1,100 crore (US$ 280 million) annually.

The DITS household survey data shows that the main users of transport in Dhaka are higher income households. It is seen that higher income groups are main users of most of the modes. The car is mostly used by the wealthiest segments of the society but also rickshaw use increases with income. The relatively even distribution across income classes of bus passengers emphasizes its importance in improving transport access of all income groups. Improved bus service will be particularly important to the lower and middle-income groups.

Mode Choice and Travel Pattern: A wide variety of transport modes are available to meet the travel needs of the people of Metropolitan Dhaka. The surveys by DITS (1993), DUTP-II (1998) revealed the fact that people are highly dependent on public transport, non-motorized modes and walking. The situation is likely to remain unchanged for years unless there is an increase in disposal income, which may shift people to private modes. The Table 5 is a summary of transport task in Dhaka by modes of travel. According to DUTP-II (1998), as shown in Table 2.5, on the basis of number of trips; walking mode (60%) dominates, followed by rickshaw (19%). However, in terms of passenger-kilometer travel, bus travel dominates (46%), followed by rickshaw (16%), walk trips (12%), and private car (8%); the role of auto-rickshaw and tempo is relatively minor (about 4% each). (Monayem, 2001). If only central metropolitan area of Dhaka is considered, the Table 2.6 shows that car share 10.5%, bus 27%, auto-rickshaw 15.2%, rickshaw and others 47.3% of total person-trip. DUTP-II (1998) suggested that there was a strong case for implementing measures to assist the operation of bus service while also providing for the safe operation of non-motorized transport at least for the foreseeable future. Table 2.5 shows that for all modes of travel the average trip time was ranged between 15 minutes for walk trips to 45 minutes for bus trips.

From another point of view, passenger-kilometer per day for different modes in the metropolitan area reflects the travel pattern of its inhabitants. It is calculated from average passenger boarding, average trip length, and average number of trips per day for each vehicle. According to DITS (1993), among the motorized transport in Greater Dhaka, busses run the highest passenger-miles per day (9520 passenger-miles) while motorcycle runs the lowest passenger miles (passenger-35 miles). On the other hand among non-motorized transports, rickshaws contribute the highest average passenger miles per vehicle per day (72 miles) and bicycle runs the lowest average passenger miles (10 miles). So when the passenger miles per day is considered, rickshaw runs 10,800,000 miles, which is around 36 percent of the total passenger miles per day by all the modes in metropolitan Dhaka.

Again if only mechanized transports and central metropolitan area of Dhaka are considered, then busses run the highest passenger-km per day (39.8% of total passenger-km) while car runs the lowest passenger-km (11.9% of total passenger-km), (Hoque and Alam, 2002). On the other hand, in terms of passenger trip, rickshaw is the highest and car is the lowest. Customarily the modal share of any urban area is expressed in terms of passenger trips (Hoque and Alam, 2002). So, if only four major types of modes and only the inter-zonal trips are considered, then Rickshaw shares 40% to 45% of total person-trips, Auto Rickshaw Shares 13% to 16% of total person-trips, Bus shares 25% to 35% of person-trips and car shares 10% to 12% of person-trips.

Table 2. 4: Trip Task by Mode in Greater Dhaka.

Mode	Daily Trips	% by Mode	Average Trip Time (Minute)
Auto Rickshaw	1,21,542	1.42	45
Bicycle	76,737	0.90	22
Bus	7,87,028	9.19	54
Car	2,66,243	3.11	25
Motorcycle	1,29,761	1.51	22
Rickshaw	16,46,064	19.21	26
Tempo	93,582	1.01	51
Train	2,752	0.03	118
Walk	51,59,007	60.22	15
Water	2,74,634	3.32	50
Total	85,67,350	100.00	----

Source: (DUTP-II, 1998)

Table 2. 5: Metro-Dhaka: Person Trip by Modes.

Mode	No. of Person Trips		Avg. Trip Length per Day (km)	Passenger – km	
	'000 / day	%		'000 / day	%
Car	576	4.0 **(10.5)**	10.4	5,990	11.9
Bus	1,482	10.2 **(27.0)**	13.5	20,007	39.8
Auto Rickshaw	845	5.8 **(15.2)**	12.8	10,816	21.6
Rickshaw	1,927	13.3 **(35.0)**	4.3	8,286	16.5
Others	675	4.7 **(12.3)**	7.5	5,066	10.1
Subtotal	5,505	38.0 **(100)**	9.1	50,165	100.0
Walk	9,000	62.0	1.0	9,000	(15)
Total	14,505	100	4.1	59,165	(100)

Source: (Hoque and Alam, 2002)

Base upon the statistics provided by DUTP (1998), Hoque and Alam (2002) and DITS (1993) the modal share of central urban portion of Dhaka is estimated as rickshaw (40%-45%), Auto-rickshaw (13%-16%), Bus (25%-35%) and Car (10%-12%). The estimated modal share is shown in Figure 2.1.

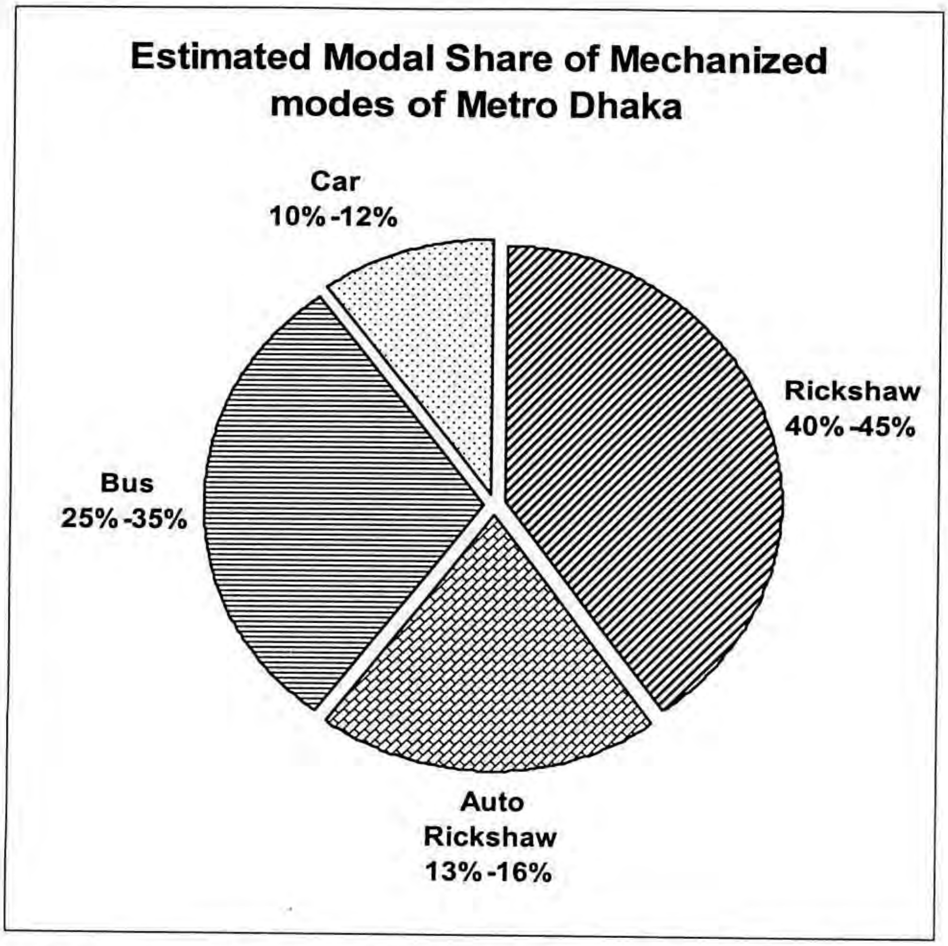


Figure 2. 1: Estimated Modal Share of Urban Area of Dhaka in Person-Trips

2.5.5 Road Traffic Congestion in Dhaka City

The common terms that can be used to describe the present condition of Dhaka City are: congestion, delays, pollution, etc. These are the symptoms of transportation system deficiencies of Dhaka. The population of Dhaka has grown in 50 years from less than a million to over ten million. Now the population is expanding at an average rate of 4.5% (DCC, 2001) annually. Motor vehicle ownership faces a growth rate of average 10% annually (Monayem, 2001). According to DITS (1993), although compared to other large cities of the world, Dhaka has a very low level of motorization (about 60% of trips are made on foot, while almost half of the remaining trips are on human pulled vehicles), intermingle of motorized and non-motorized modes results in a very low speed travel in its streets. With increasing rate of motorization, together with heterogeneous mix of traffic, the road traffic situation of Dhaka is degrading day by day. This picture becomes clear during the morning and evening peak hours, when long queue of vehicles remain stagnant for long time on roads. It might sound inane that we are in a hurry, because we are actually late. If the society reacts very slowly, if at all, the result will be like in Mexico city, where twenty percent of workers spend more than 3 hours traveling to and from work place everyday, and 10% people has that over 5 hours (DSM, 2001). The causes of traffic congestion in Dhaka city can be divided into three broad categories. These are site-specific causes, transportation system capacity related causes and planning or policy related causes.

The site-specific causes are mainly traffic management related problems. The important maneuverings like left turning, through movement along the intersections etc. are often seriously obstructed for the poor quality and in maximum cases absence of traffic management system, uncontrolled parking of both motorized and non-motorized vehicles etc. In many locations of the road network, the effective roadway spaces are reduced by roadside activities, presence of dustbins, hawkers etc. Such reduction in effective roadway spaces in links and intersections creates bottlenecks to traffic flow and causes congestion.

The transportation system of Dhaka city is mainly road based. The population of the city is increasing day by day but the capacity of the road network is not increasing at the same pace. The lag between increasing travel demand and system capacity is resulting traffic congestion. Another important factor is the uncontrolled increase in rickshaw traffic. As there is no segregation of motorized and non-motorized traffic in the network, the increasing rickshaws are occupying the maximum roadway space and compelling the other modes to move slowly and creating congestion.

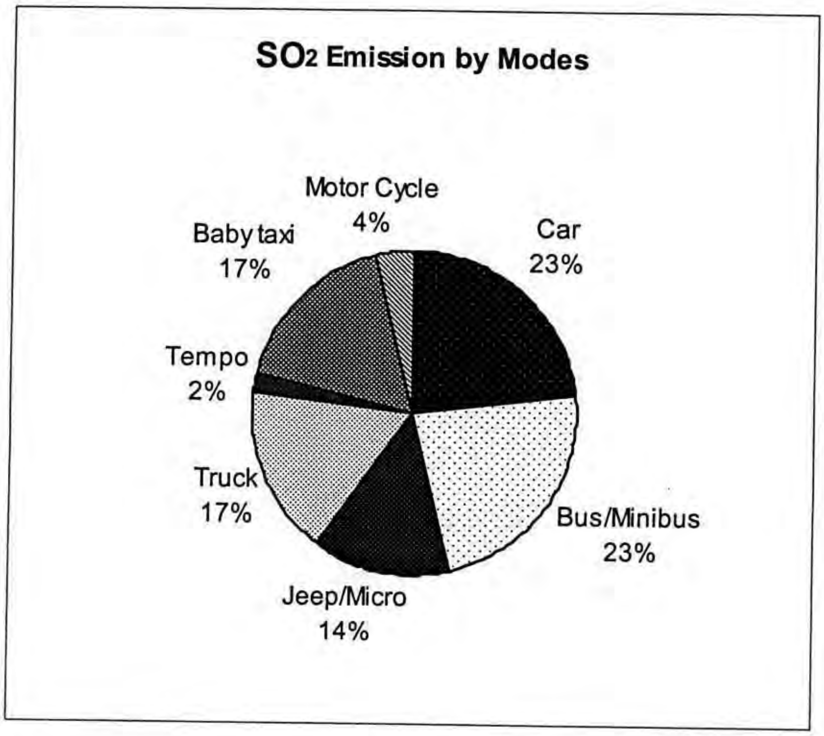
The overall transportation system of Dhaka city has not been developed in a planned way rather it has been developed in dynamic response to increasing travel demand. Even there is no definite policy to a sustainable transportation system. Uncontrolled land-use together with increasing migration of rural people towards Dhaka is increasing pressure on transportation system and creating traffic congestion and other related problems.

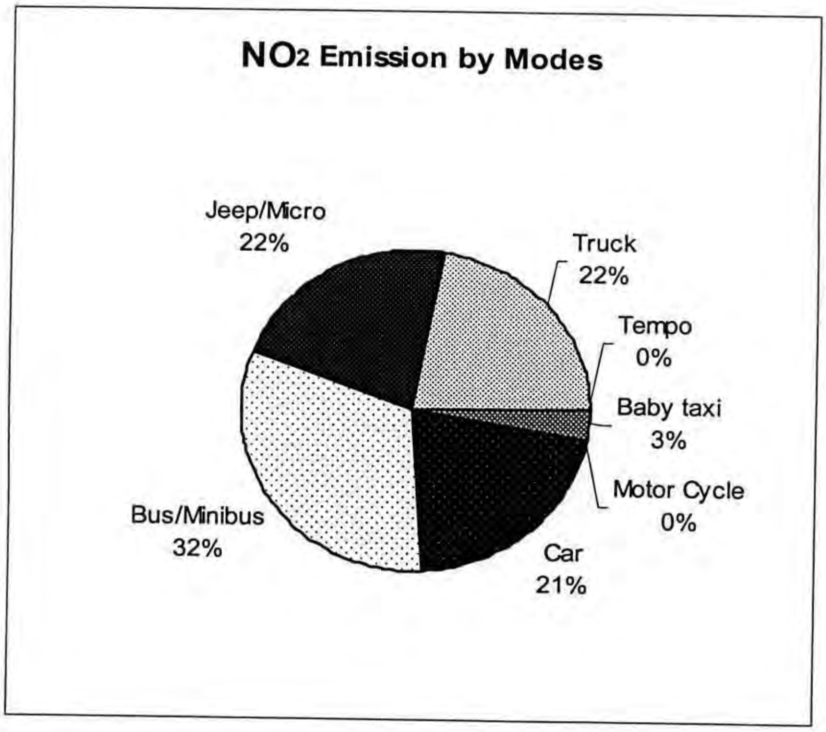
2.5.6 Traffic Induced Air Pollution in Dhaka City

Air pollution is recognized as a major health hazard. Vehicle emissions are increasingly being recognized as the dominant cause of air pollution and health problems in Dhaka city (Bhuiyan, 2001). The pressing demands for motorized form of personal mobility are generating pressures on road network and resulting in congestion, which threatens the sustainability of the socio-economic progress. Our country generally has been much slower than other industrialized countries in recognizing these risks and taking technical steps to reduce air pollution from automobiles. A few meaningful research works have been done in Bangladesh in this regard. Most recently a detail study was carried out by Jaigirdar (1998) to identify the motor vehicle induced pollution in Dhaka City.

According to Jaigirdar (1998), the maximum instantaneous concentrations of SO_2, NO_2 and CO are 0.7 ppm, 0.3 ppm, and 93 ppm respectively. Instantaneous concentration of SO_2 and NO_2 are high at two intersections named Gulistan and Mohakhali where diesel fuelled vehicles like busses, trucks operation are high. The concentration of CO is high where car, microbus, two stroke vehicles like baby taxi and tempo movements are high. Most of the road intersections are highly polluted by SO_2 and NO_2. Although the concentration of CO is seemed to be moderate as compared with SO_2 and NO_2, the concentration of CO in most of the intersections is harmful for heart patients (Stewart, 1975). Large number of rickshaws and other vehicles in the city streets frequently cause severe traffic jam, which consequently cause the city dwellers to be exposed to highly polluted air for a long period and immediate surrounding of vehicle emission. This causes serious damage to public health. SO_2 emission of truck is highest 5.98 gm / l of fuel consumption, followed by tempo 4.78 gm / l and double decker bus 4.25 gm /l of fuel consumption. SO_2 emission for premium bus is 2.69 gm /l of fuel consumption, whereas from car and baby taxi is 2.85 gm / l and 3.6 gm / l of fuel consumption respectively. Diesel fuelled vehicles like truck, bus etc produce high rate of SO_2. NO_2 emission of truck is the highest, which is 31.65 gm / l of fuel consumption. For premium bus, car, tempo and baby taxi, the SO_2 emissions are 18.87 gm / l, 10.39 gm / l, 1.99 gm / l and 2.39 gm / l of fuel consumption respectively. CO emission of microbus is the highest, which is 276.2 gm / l of fuel consumption, followed by tempo and baby taxi that are 268.3 gm / l and 226.5 gm / l respectively.

Estimated total emissions of SO_2, NO_2 and CO in Dhaka city are 5.43 ton / day, 21.57 ton /day and 215.34 ton / day respectively. Bus/minibus emits the highest amount of SO_2 (23% of daily emission) and NO_2 (32% of daily emission). In case of CO emission car takes the lead and emits 40% of total daily emission. Baby taxi also emits a significant amount, which is 26% of total daily CO emission. Total daily emission of SO_2, NO_2 and CO indicates that emission from Dhaka's vehicles is higher than the Bombay city with respect to number of vehicles (Jaigirdar, 1998). The relative contribution of Different modes in air pollution can be easily understood by the following pie charts.





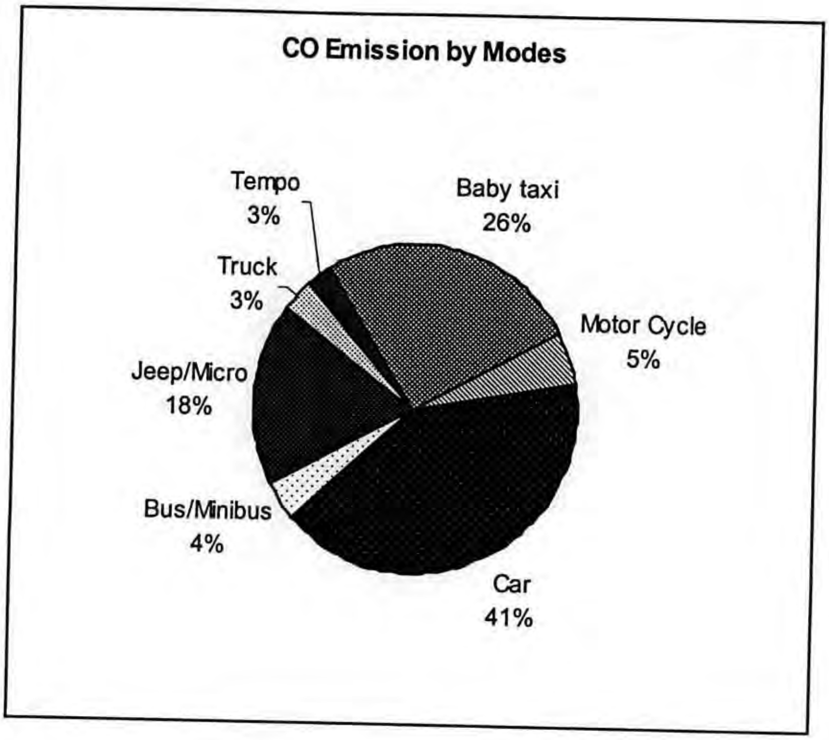


Figure 2. 2: Relative Pollution by Different Motorized Modes of Travel
Source: (Jaigirdar, 1998)

2.6 Summary

From the above review, it appeared that most of the transport studies in metropolitan Dhaka were related to the transport inventory and traffic management. Some of them dealt with mass transit system in the metropolitan area. There had been no study dedicated to traffic congestion, consequent air pollution and their evaluation techniques. Information on parameters relating to the system development and performance evaluation techniques of the existing road network was not available in these literatures. Tools and methods for assessing the performance of a road network are the first requirement of transport planners. Standard procedures to procure information about the impact of changes in road network is deemed important in providing guidelines for future policies investments and improvements in the existing road network. Although DITS and DUTP dealt a little about the transportation system performance, they concentrated on Greater Dhaka. Traffic congestion and consequent air pollution is more serious in the central urban portion of Dhaka than its periphery. So if the Greater Dhaka is taken as study area, the central's problems may be under estimated. That is why, a study on traffic congestion and consequent air pollution, especially on the central urban portion of Dhaka is felt necessary. The following chapters describe the approaches for the development of a transportation model for Dhaka city and its application for evaluation for some planning options to alleviate traffic congestion and air pollution problems of Dhaka city.

Chapter 3

STUDY DESIGN AND METHODOLOGY

3.1 Introduction

Traffic congestion is a consequence of disparity between transportation demand and supply. Demand for transportation in urban areas is an increasing phenomenon for the continuous increase in urban population and economic activities lagging behind the transportation supply. As a result, traffic congestion has already become a part of urban transportation system. Such traffic congestion not only causes problems to urban transportation activities but also causes degradation to natural environment by increasing the magnitude and intensity of air pollution. Efforts to eliminate traffic congestion completely from the transportation network may be unrealistic; rather the way to minimize traffic congestion and consequent air pollution is a challenge for transportation engineers and urban planners.

The methodology used for evaluation of different planning options as well as baseline situation is described in the following sections. The evaluation is based on two parameters: traffic congestion and air pollution. The parameters are estimated for both baseline situation and different alternative planning options using the output form a UTMS developed in this study. The model is named Dhaka Urban Transport Model (DUTM). The steps involved in the evaluation process are shown in Figure 3.1.

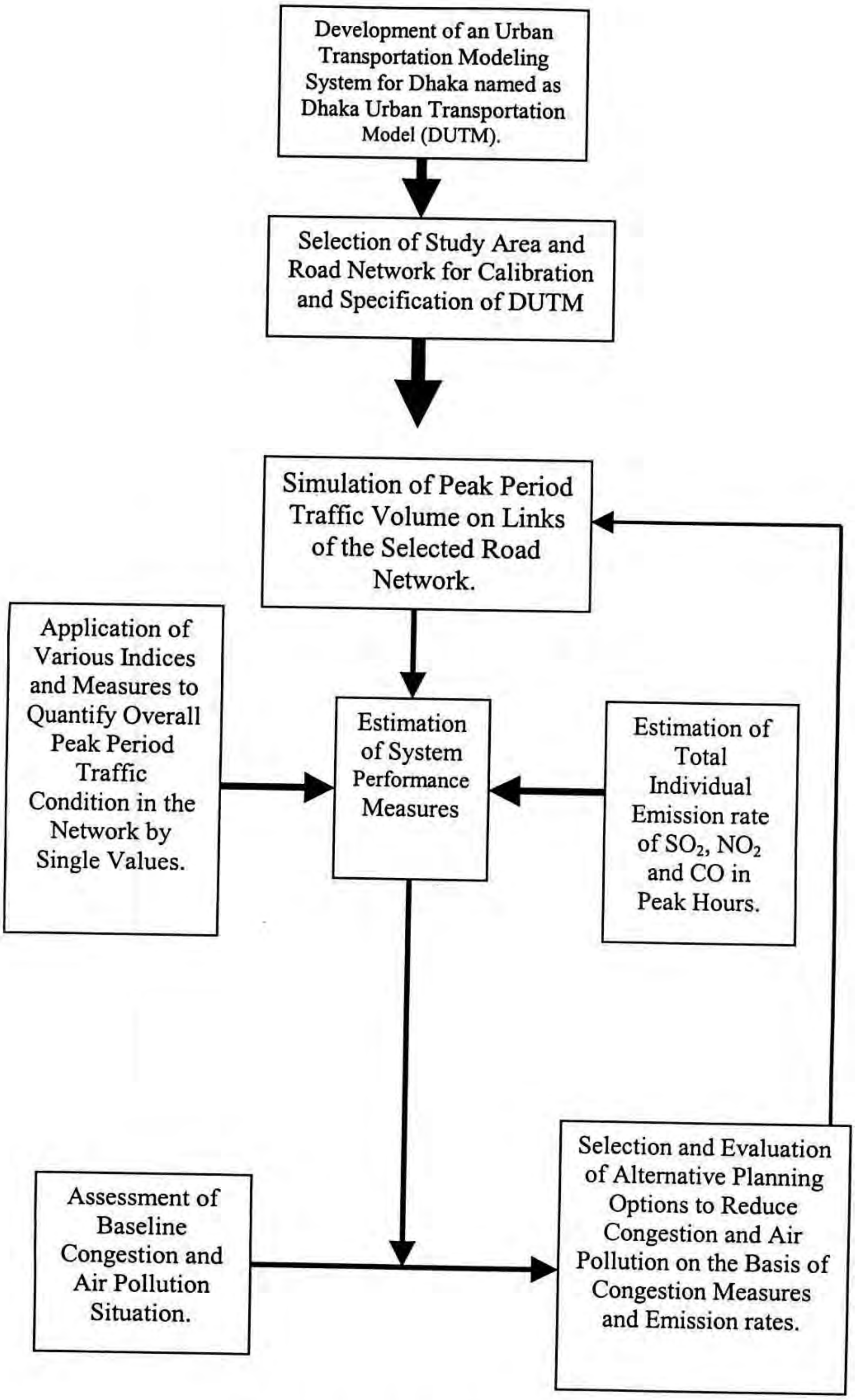


Figure 3. 1 The Evaluation Process

3.2 Development of a Strategic Urban Transportation Model for Dhaka

3.2.1Outline of the Model Structure

The overall structure of the DUTM is traditional in terms of the sequence of the structural form i.e. Trip Generation and Attraction, Trip Distribution, Modal Split and then Trip Assignment stages. The general approach follows the line taken by different studies for development of urban transportation model and it has been possible to develop a free-standing model of considerable complexity for Dhaka city. Because of the inclusion of capacity effects, the model is designed to iterate to convergence. Again because of time and need to run the model many times, it was essential to keep the modeling at the 'strategic' level and to aim for fast turnaround. Most of the components of the model are conventional, in transportation modeling terms. What are perhaps less conventional are the features, which justify the term 'strategic' that are:

- A restriction in the number of analysis zones and road network.
- The emphasis given to 'supply-side constraints' and iterative structure, which achieves equilibrium between supply and demand.

The general structure of the strategic model is shown in the Figure 4.1 and it can be seen that it has two independent parts:

- Pure changes in demand brought about by external changes (e.g. effects due to population, employment, land-use etc.)
- Changes brought about by the transport system, including the result of supply-side constraints (in terms of travel time, cost, and comfort).

The basic demand for travel varies by person-type in term of his job, and changes in the distribution of such person-types and job opportunities will have repercussions on total demand. There is therefore a need for an interface between the 'trip generation' stage and 'planning' data assumptions. Given a basic forecast, the function of transport model is to predict the result of a transport strategy – that is, a combination of different transport components. This model is postulated on the basis that any changes in the transportation system can be represented by the changes in the components of the generalized cost (journey time, cost, comfort etc). Where the changes relate to capacity (number of lanes, new links, new modes etc.) there is the option as to whether the forecast of changes in travel time etc. should be directly input, or deduced in the model via an appropriate modification of the supply-side relationship. For this reason the strategies to be tested may impact either directly on generalized cost, or on the way in which the supply effects modify the generalized cost.

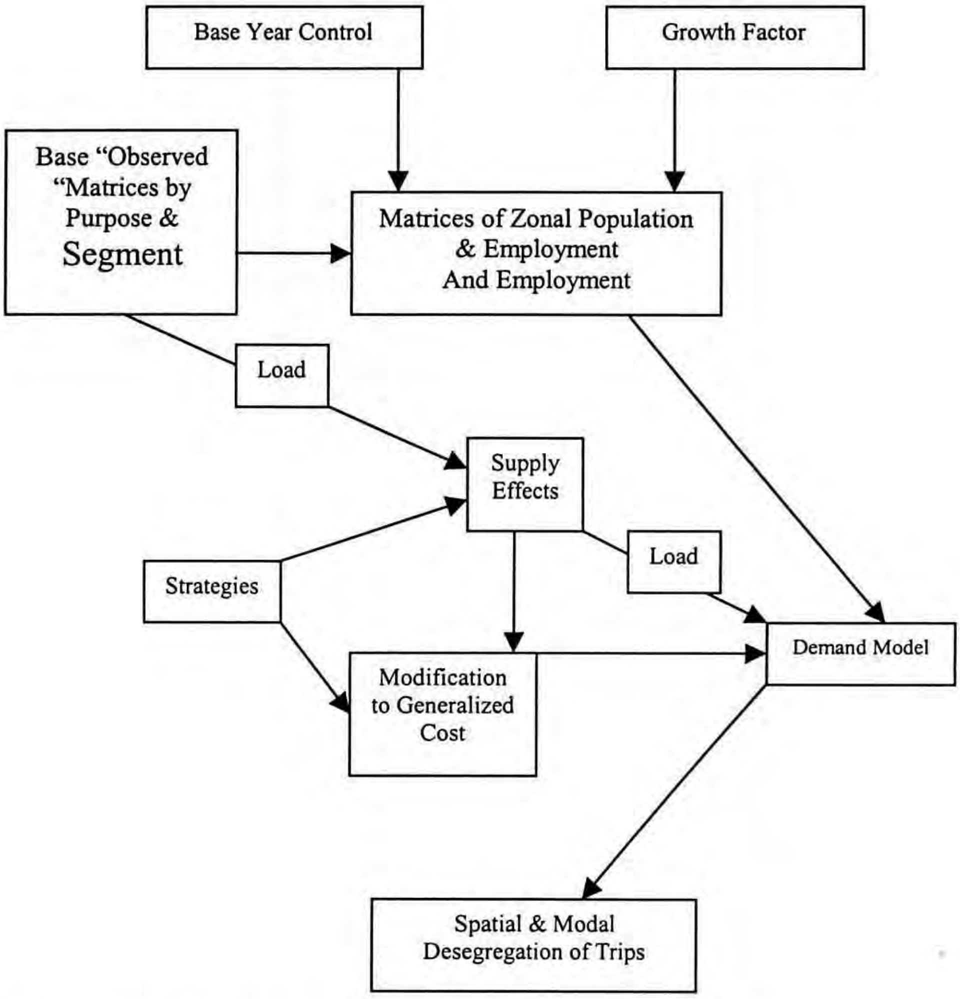


Figure 3. 2: Overall Structure of Strategic Model

Due to lack of sufficient data, the model has not been calibrated for the whole study area (rather calibrated for small parts of the whole study area) at the preliminary building stages. Instead, matrices have been built to reflect the current travel pattern and modal share. As far as mode is concerned, the original intention was to include car trips, bus and other para transit trips, baby taxi or scooter trips, rickshaw trips and walk and cycle trips. However, unable to assemble anything resembling a reliable matrix of walk and cycle movement, these two modes therefore had to be dropped and only inter-zonal trips are considered. So the model will deal only with trips by mechanized modes. It has the provision to add any new modes in the system, provided appropriate attribute data will have to be supplied. The individual components of DUTM are

1. Trip generation.
2. Trip distribution.
3. Modal split.
4. Trip assignment.

Having presented a broad outline of the model structure, the next sections indicate the individual components of DUTM.

3.2.2 Trip Generation and Attraction

Trip generation is the prediction of number of trips produced by and attracted to each zone, that is, the number of trip ends "generated" within the urban area. Trip generation models are basically of two types. One is 'multiple linear regression analysis' the other is 'category analysis', (Meyer and Miller, 1984).

Multiple linear regression analysis: The 'multiple linear regression analysis' method establishes a mathematical relationship between the number of trip ends and different socio-economic variables. It is again divided into two types, such as 'aggregate analyses and 'disaggregate analyses'. In 'aggregate analyses' each Transportation Analysis Zone (TAZ) is treated as one observation, where as 'disaggregate' analyses treat individual household or person as an observation. Disaggregate analyses provides more accurate result than aggregate analyses.

Category analysis or Cross-classification technique: It determines the number of trip ends individually from certain defined category of household or people. The whole concept of household trip making is simplified in this technique by categorizing the households according to certain socio-economic characteristics. Unlike regression analysis technique, no mathematical relationship is derived between trip making and household characteristics and thus takes away many statistical drawbacks of regression analysis. But the problem is that this type needs accurate census data of the analysis zones.

Due to the lack of availability of proper census data of the study area, 'disaggregate multiple linear regressions' type model is taken as the trip generation part of DUTM.

3.2.3 Trip Distribution

Trip distribution is the prediction of origin-destination flows that is linking of trip ends predicted by the trip generation models together to form trip interchanges or flows. Trip distribution models are basically two types. Theses are 'Growth factor methods' and 'Synthetic methods', (Meyer and Miller, 1984).

Growth factor methods: The growth factor methods are again of four types. These are (1) Uniform factor method, (2) Average factor method, (3) Fratar method, (4) Furness method. The basic theory of these four types is that the design year number of trips from one zone to another is the multiplication of base year trips and a growth factor. The application of 'growth factor' is different for different types of growth factor methods but the problem is that, for each type, the present trip distribution matrix has to be obtained first, for which a large scale O-D studies and high sampling sizes are needed. Again these methods do not provide a measure of resistance to travel and imply that the resistance to travel will remain constant. This methods neglect the effect of changes in travel pattern by the construction of new facilities.

Synthetic methods: In synthetic models of trip distribution, an attempt is made to discern the underlying causes of movement between places, and relationships are developed between trips and measures of attraction, generation and travel resistance. Synthetic models have an important advantage that they can be used not only to predict future trip distributions but also to synthesize the base year flows. The necessity of having survey of every individual cell in the trip matrix is thus obviated and cost of data collection is reduced. Such synthetic models are mainly of two types. These are: (1) Gravity model, (2) opportunity model.

The Gravity model uses deterministic approach to trip distribution, where it is assumed that according to Newton's concept of gravity, the interchanges of trips between zones of the area is depended upon the relative attraction between zones and spatial separation between them as measured by an appropriate function of distance. These functions of spatial separation adjust the relative attraction of each zone for the ability, desire or necessity of the trip maker to overcome the spatial separation.

Opportunity models, such as 'Intervening opportunities model' and 'Competing Opportunity model' use statistical theory of probability as the theoretical foundation. In such types of model, it is assumed that the trip interchange between an origin and destination zone is equal to the total trips emanating from the origin zone multiplied by the probability that each trip will find an acceptable terminal at the destination. It is further assumed that the probability that a destination will be acceptable is determined by two zonal characteristics: the size of the destination and the order in which it is encountered as trips proceed from the origins.

The opportunity models are suitable for developed countries, where the urban people with abundant employment opportunities can decide their residence and work place considering the available transportation facilities. In case of cities of developing countries, where due to lack of enough employment opportunities the urban people get little scope to change work places to avoid transportation difficulties, the deterministic approach is more realistic. For this reason, the trip distribution model of the DUTM is selected as a gravity type model.

3.2.4 Modal Split

Modal split models predict the percentages of flow, which will use each of the modes that are available for travel between each origin-destination pair. When modal split occurs after trip distribution then the model is known as a 'trip-interchange model'. If modal split is performed prior to distribution, the model is known as 'trip-end model'. Since trip-end model splits trip ends, rather than flows, the characteristics of transportation system are fed on an average area wide basis. Trip-end model is insensitive to future developments in inter-zonal travel and does not consider the trip generation characteristics. Trip-end model is also insensitive to transportation policy change like improvement of public transportation systems where significantly different levels of service are contemplated. On the other hand, although the trip-interchange model is more complex, it is free from above mentioned problems of trip-end model, (Meyer and Miller, 1984).

The modal split analyses are basically of two types. These are: (1) Probit analysis and (2) Logit analysis, (BenAkiva and Lerman, 1985).

Probit analysis: In this analysis the stimulus is assumed to be made up of relative disutility of travel of two modes and of users' characteristics. The probit equation can be written as

$$Y = a_0 + a_1x_1 + a_2x_2 + \cdots\cdots\cdots + a_nx_n \qquad (3.1)$$

The determination of coefficients of disutility is often very lengthy and time consuming. But the logit analysis is simpler than probit analysis for use and interpretation.

Logit analysis: The logit analysis assumes that probability of occurrence an event varies like a function of sigmoid curve called the logistic curve. The logit choice model is of two types, Binary Logit model and Multinomial Logit model.

In random utility Logit models, the probability of any alternative i being selected by person n from choice set C_n is given by the following:

$$P(i/C_n) = \Pr(U_{in} \geq U_{jn}, \forall j \in C_n) \qquad (3.2)$$

Where the probability that $U_{in} = U_{jn}$ for any i and j in the choice set is normally ignored. Formally, the distribution of U_{in} and U_{jn} can be characterized by a probability density function,

$\Pr(U_{in}=U_{jn}) = 0$, Denoting the choice set C_n as $\{i, j\}$, where, for example, alternative *i* might be the option of driving to work and alternative *j* would be using transit. The probability of person n choosing *i* is

$P_n(i) = \Pr(U_{in} \geq U_{jn})$ and probability of choosing j is $P_n(j) = 1 - P_n(i)$

Now each of the utility U_{in} and U_{jn} can be divided into two additive parts as follows:

$U_{in} = V_{in} + \xi_{in}$

$U_{jn} = V_{jn} + \xi_{jn}$

V_{in} and V_{jn} are called systemic component of utility of *i* and *j*; ξ_{in} and ξ_{jn} are called the random components. Rewriting the probability that *n* chooses alternative *i* as

$$P_n(i) = \Pr(U_{in} \geq U_{jn}) = \Pr(V_{in} + \xi_{in} \geq V_{jn} + \xi_{jn}$$

or

$$p_n(i) = (\xi_{jn} - \xi_{in} \leq V_{in} - V_{jn})$$

It can be seen that for binary choice situation, the absolute levels of V and ξ do not matter; all that matters is whether the difference in V's is less than that of ξ's

The first issue in specifying V_{in} and V_{jn} is to ask what type of variable can enter this function? For any individual n, any alternative i can be characterized by a vector of attributes Z_{in}. It is also useful to characterize the decision maker n by another vector of attribute, S_n. The function V_{in} and V_{jn} consist of Z_{in}, Z_{jn} and S_n, which reflect reasonable hypothesis about the effects of such variables. It will generally be convenient to define a new vector of attribute X, which includes both Z_{jn} and S_n. That means $X_{in}=h(Z_{in}, S_n)$ and $X_{jn}=h(Z_{jn}, S_n)$, where h is a vector-valued function. Now it can be written that the synthetic component of the utilities of i and j as

$V_{in} = V(X_{in})$ and $V_{jn} = V(X_{jn})$

If it is taken that, $\beta = \{\beta_1, \beta_2, \ldots\ldots\ldots \beta_k\}$ as the vector of K unknown parameters,

$$V_{in} = \beta_1 X_{in1} + \beta_2 X_{in2} + \beta_3 X_{in3} + \cdots\cdots + \beta_k X_{ink} \quad (3.3)$$

$$V_{jn} = \beta_1 X_{jn1} + \beta_2 X_{jn2} + \beta_3 X_{jn3} + \cdots\cdots + \beta_k X_{jnk} \quad (3.4)$$

Both utilities have the same vector parameters. It is important to stress that this is only a notational convention because, by appropriately defining the various parameter X, each systematic utility function can be given different coefficients effectively.

The binary logit model arises from the assumption that $\xi_n = \xi_{jn} - \xi_{in}$ is logistically distributed, namely

$F(\xi_n) = 1 / (1+e^{-\mu\xi_n})$, $\mu>0, -\alpha< \varepsilon_n < \alpha$

$F(\xi_n) = \mu\, e^{-\mu\,\xi_n} / (1 + e^{-\mu\,\xi_n})^2$

Where μ is a positive scale parameter. Besides approximating the normal distribution quite well, the logistic distribution is analytically convenient. To provide continuity with the development of multimodal choice models, the assumption that ξ_n is logistically distributed is equivalent to assuming that ξ_{in} and ξ_{jn} are independent and identically Gumbel distributed.

Under the assumption that ξ_n is logistically distributed, the probability for alternative i is given by

$$P_n(i) = \Pr(U_{in} \geq U_{jn}) = \frac{1}{1+e^{-\mu(V_{in}-V_{jn})}} = \frac{e^{\mu V_{in}}}{e^{\mu V_{in}} - e^{\mu V_{jn}}}$$

This is binary logit model. If V_{in} and V_{jn} are linear in their parameters, then

$$P_n(i) = \frac{e^{\mu\beta x_{in}}}{e^{\mu\beta x_{in}} + e^{\mu\beta x_{jn}}} = \frac{1}{1+e^{-\mu\beta(x_{in}-x_{jn})}}$$

In the case of linear-in-parameter utilities the parameter μ cannot be distinguished from the overall scale of β's. For convenience it is generally made an arbitrary assumption that $\mu = 1$. This correspond to assuming the variances of ξ_{in} and ξ_{jn} are both $\pi^2/6$, implying the $var(\xi_{in} - \xi_{jn}) = 1$, and it implies that the scaled probit coefficients are $\pi / \sqrt{3}$ times larger than the scaled logit coefficients.

The above mentioned methods are only for two types of modes. In the present study total number of modes is greater than 2, so the modal choice equation used in this study is a multinomial logit model. Here the choice phenomenon is called multinomial choice rather than binary choice. The analysis of multinomial choice is based on 'Gumbel Distribution'. The choice probability in this case is give by

$$\Pr(in) = \frac{e^{\mu V_{in}}}{(e^{\mu V_{1n}} + e^{\mu V_{2n}} + e^{\mu V_{3n}} + \dots\dots\dots + e^{\mu V_{mn}})} = \frac{e^{\mu V_{in}}}{\sum_{i=1}^{m} e^{\mu V_{in}}} \qquad (3.5)$$

As described earlier, the scale parameter 'μ' is not identifiable and it can arbitrarily be set to 1.0 without influencing the relative importance of parameters of indirect utility function.

The parameters of multinomial logit model are estimated using 'Maximum likelihood method. In this approach, the parameters are estimated through optimizing the likelihood (or log-likelihood) function. If N denotes the sample size and the choice variable is defined as follows,

$y = \begin{cases} 1 \\ 0 \end{cases}$, where 1 is for observation n chose alternative I and o is for otherwise.

Then, the likelihood function is defined as,

$$L^{*} = \prod_{n=1}^{N} \prod_{i \in C_n} P_n(i)^{y_{in}} \tag{3.6}$$

Here $P_n(i)$ is defined in Equation 3.5

Putting the value of $P_n(i)$ in Equation 3.2 and taking logarithm, the following log-likelihood function can be obtained.

$$L = \sum_{n=1}^{N} \sum_{i \in C_n} y_n \left[\beta' x_{in} - \ln \sum_{j \in C_n} e\beta' x_{in} \right] \tag{3.7}$$

The parameters (β) are estimated at the maximum value of log-likelihood function. By setting the first derivatives of the function with respect to the parameters equal to zero, the necessary first order conditions can be obtained.

$$\frac{\partial L}{\partial \beta_k} = \sum_{n=1}^{N} \sum_{i \in C_n} y_n \left[x_{ink} - \frac{\sum_{j \in C_n} x_{ink} e^{\beta' x_{ink}}}{\sum_{j \in C_n} e^{\beta' x_{ink}}} \right] = 0 \tag{3.8}$$

$$or, \sum_{n=1}^{N} \sum_{i \in C_n} \left[y_{in} - P_n(i) \right] x_{ink} = 0, \forall k \tag{3.9}$$

By solving these equation using Newton-Rapson Method, the parameter (β) can be estimated. To satisfy second order condition, the Hessian matrix (second derivatives) must be examined. The component of the matrix is given by

$$\frac{\partial^2 L}{\partial \beta_k \partial \beta_1} = -\sum_{n=1}^{N} \sum_{i \in C_n} P_n(i) \left[x_{ink} - \sum_{j \in C_n} x_{ink} P_n(j) \right] \left[x_{ink} - \sum_{j \in C_n} x_{inl} P_n(j) \right] \tag{3.10}$$

3.2.5 Trip Assignment

Traffic assignment is last the part of the process of estimating traffic volume on urban transportation network. It deals with the steps, which follow the trip distribution and modal split of traffic. Thus the origin to destination trip table for trips via a particular mode in question is known in this stage. There are various approaches to traffic assignment. Three widely used methods are 'All-or-nothing assignment', 'Capacity restraint assignment' and 'Stochastic assignment', (Meyer and Miller, 1984).

All-or-nothing Assignment: It is called all or nothing because every path from an origin to a destination has either all the traffic or none of them. Here it is assumed that all travelers will use the minimum path. Once all of the minimum paths have been determined, the flow between each origin destination pair is associated with that path. The total flow is the sum of all flows on each of the links of network. The principal shortcoming of this method is that it completely ignores the effect of volume of traffic on a link on user's cost, time and level of service.

Capacity Restraint method: It overcomes the problems of all-or-nothing assignment method by assigning fraction of total flow incrementally, considering the changes in travel time after each cycle of assignment. The adjusted link speed or its associated travel impedance (time) is computed by using the following capacity restraint functions:

$$T_1 = T_0 [1 + 0.15 (V/C)^{0.15}] \quad (3.11)$$

Stochastic Assignment: This type of assignment recognizes that several routes between an origin and destination might be perceived to have equal travel time or otherwise be equally attractive to a traveler and, as a result, might be equally likely to be used by that traveler. Or in other words it treats link costs as random variables that can vary among individuals (given their individual preferences, experiences and perceptions) rather than deterministically (as is done by other assignment techniques discussed above).

Stochastic types of assignments are suitable where city people have a lot of choice about their jobs. But in developing cities, like Dhaka, due to limited job scopes the origin-destination of maximum people is more or less fixed. For such condition capacity restraint type assignment gives more accurate result. So in DUTM capacity restraint type assignment is used.

3.3 Selection of Study Area

3.3.1 Overview of the Study Area

The study area selected for this study comprises 154 km^2 area of central urban portion of Dhaka Metropolitan City. The administrative authority of this portion is Dhaka City

Corporation (DCC). This portion is the core of Greater Dhaka and contains all major government and private commercial activities. Due to lack of proper planning and control over land use activities, people from all over the country rush to this portion and made it a horde of residential, commercial and business centers. According to Bureau of Statistics (BBS, 1991) and DCC, the total population of this area was 3.5 million in 1991. DCC estimates that this portion has the average growth rate of 4.5 percent annually (2 percent national growth rate plus 2.5 percent migration). So this portion has the population of over six million at present and by 2020 it will be over nine million. Considering the whole area of Greater Dhaka, although it is told that Dhaka is a mega city (population greater than 10 million), by 2020 the core of the city itself will be have around 10 million people. Traffic congestion and resulting air pollution problems are concentrated here and are much greater than other peripheral portions of Greater Dhaka.

3.3.2 Zoning of the Study Area for Analysis

For the analysis of regional transportation activities, the study area, which is under the authorization of Dhaka City Corporation (DCC), is divided into eight broad sub-regions or Specific Zones (SPZ). These are:

1. Sub-Region A: Central metropolitan of CBD (Central Business District).
2. Sub-Region B: Old Dhaka.
3. Sub-Region C: North-West Dhaka.
4. Sub-Region D: Greater Mirpur.
5. Sub-Region E: Greater Gulshan.
6. Sub-Region F: Uttara.
7. Sub-Region G: Eastern Metropolitan.
8. Sub-Region H: Dhanmondi & Farmgate Area.

Sub-Region A covers 11 DCC wards; Sub-Region B covers 27 DCC wards; Sub-Region C covers 15 DCC wards; Sub-Region D cover 7 DCC wards; Sub-Region E covers 5 DCC wards; Sub-Region F Covers 1 DCC ward, Sub-Region G covers 15 DCC wards, Sub-Region H covers 9 DCC wards. In accordance with DCC wards, all SPZs are again divided into a number of Transportation Analysis Zones (TAZ). The identification numbers of TAZs are kept same as their DCC ward number. The total number of TAZs is equal to the total number of DCC wards. The map of study area is shown in Figure 3.3. In the figure the ward numbers are actually the TAZ numbers.

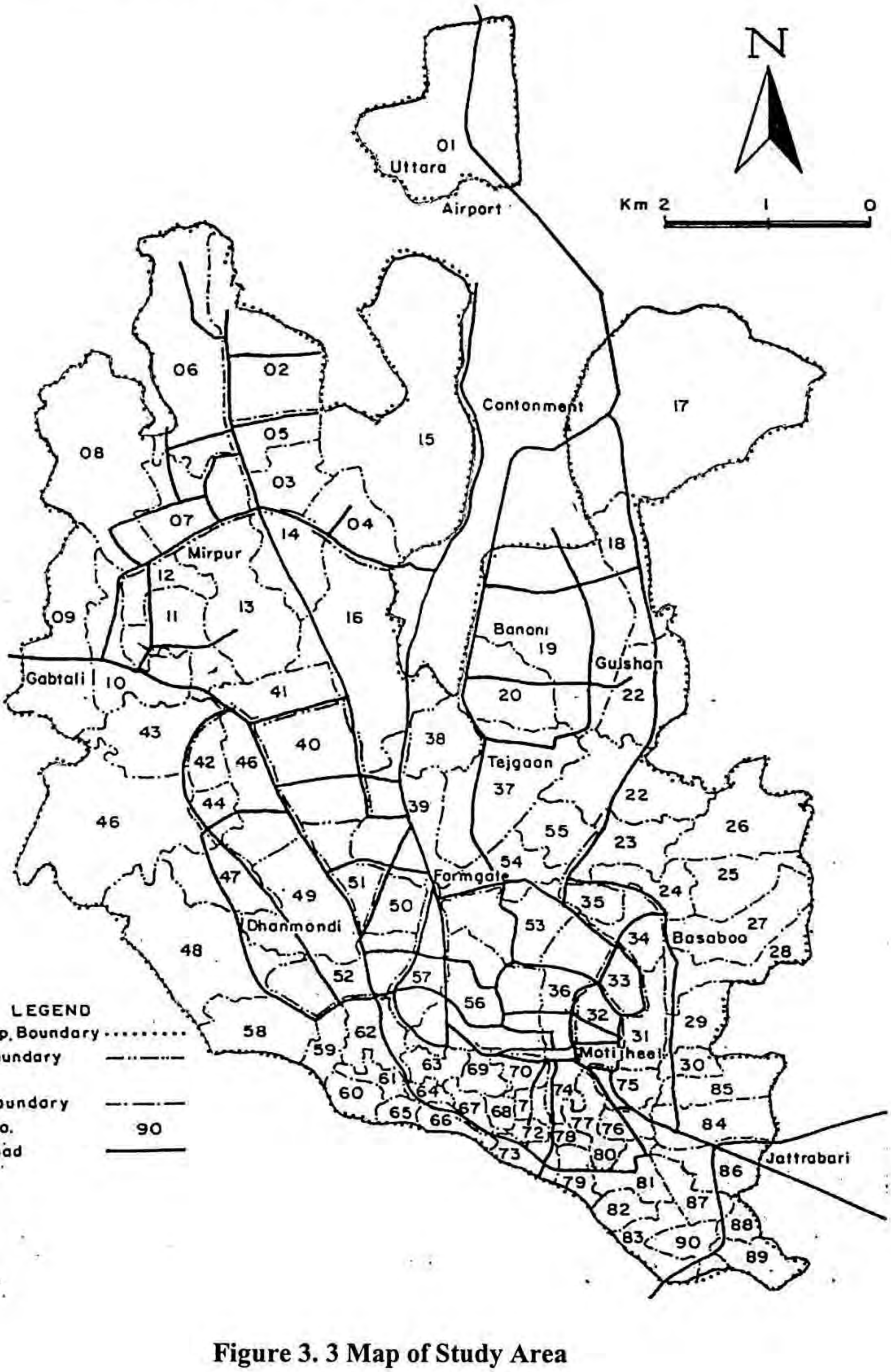


Figure 3. 3 Map of Study Area

3.3.3 Employment and Demographic Characteristics of Study Area

The objective of sub-regional division of the study area is to use employment data from suitable secondary sources and the selection of TAZ number same as that of ward number is to get population data from census report. DITS (1993) performed a rigorous employment survey in Greater Dhaka. The present study area was also a part of DITS. By analyzing the gross data of Household Interview Survey of DITS, the percentage of total employments provided by each Sub-Region is determined and shown in the Table 3.1. The employment attraction variation within the Sub-Region is also calculated. At last employment attraction by each individual TAZ is determined as a percentage of total employment opportunity present in the whole study area (90 TAZs).

Table 3. 1: Employment opportunity in Sub-Regions of Study Area

Sub-Region	No. of DCC Wards	Name of the Sub-region	% of Total Employment Opportunity of the Urban Dhaka
A	11	Central Metropolitan Area	25
B	27	Old Dhaka Area	25
C	15	North-West Dhaka.	12
D	7	Greater Mirpur	4
E	5	Greater Gulshan	4
F	1	Uttara.	4
G	15	Eastern Metropolitan	13
H	9	Dhanmondi & Farmgate Area	13

Source: (DITS, 1993)

The total employment of the study area is expressed as a percentage to total population. According to DITS, 40 percent of total population of the Urban Dhaka is employed in such types of employments that require the use of transportation facilities of the city. The employment attractions to different types of employment of each individual TAZ are also estimated according to the percentage of its share to total employment opportunity of the whole study area. The employment shares of individual TAZs within the sub-region are shown in Appendix-B (TABLE-I, II and III).

It is estimated that on an average 0.6 percent of city people are employed in Primary types, 8.6 percent are in Secondary type and 30.8 percent are in Tertiary types of employment (DITS, 1993). Where Primary types are Agricultural works, Secondary types are Manufacturing, Food, Textile, Heavy Engineering, and Laboring types of works and

Tertiary types are Professional, Administration, Transport, Sales and Services types of works.

The population data of TAZs are estimated on the basis of census, 1991 and considering the constant growth rate of 4.5 percent annually. The estimated population of 90 TAZs in 2002 is 61,38,526. Among 90 TAZs, the largest one is TAZ no. 82 having the estimated population of 3,55,644 and the smallest one is TAZ no. 64 having the estimated population of 29,311 in the year of 2002. The population concentration is the highest in Sub-region B (Old Dhaka) and the lowest in Sub-region F (Uttara).

3.3.4 Transportation Network of Study Area

The DUTM is designed to produce output of hourly traffic volume on the links of the road network. The model takes the geometric inventory of the road network as the number of road-way intersections or nodes, number of road links to be analyzed, connectivity of the nodes to form road links including length of each link in kilometer. For each individual link the number of lanes available in one direction, number of ways, average speed of all types of vehicles in the link, average speed of each individual type of vehicle in the link etc. are to input.

The information about the road network is collected from city guide map. A total of 350 km of road is selected for present study. Only the main roadway links, which are normally used for inter zonal movements are taken into consideration in this study. The network considered in this study consists of 242 nodes and 355 links with total length 350 kilometer. Each TAZ is assigned to a single node (zone centroid). Although the length of roadway links are collected from guide maps, more than 30 link lengths are compared with observed length got from field odometer survey. It is seen that the link lengths measured from guide map give more than 90 percent fit with the field measurement. The map of road network used in this study is shown in Appendix-A in four divided portions (FIGURE-I, FIGURE-II, FIGURE-III, FIGURE-IV and FIGURE V).

3.4 Evaluation of Transportation System Performance

The basic terms, normally used to indicate the transportation system performance are Mobility, Accessibility, Traffic Congestion and resulting Environmental Pollution. According to the NCHRP report 398, the definitions of these terms are as follows:
Mobility is the ability of people and goods to move quickly, easily and cheaply to where they are destined at a speed that represents free flow and comparably high-quality conditions.

Accessibility is the achievement of travel objectives within time limits regarded as acceptable.

Congestion is the roadway traffic condition, which occurs in a particular section of road, in an intersection or within a network when the capacity of that particular area to accommodate traffic can not cope with the demand of that time. It may occur either recurrently or incidentally. It costs extra travel time, fuel cost and discomfort to the road users. Congestion is often considered as a situation reciprocal of mobility and accessibility. Hence the magnitude of congestion during urban peak hours indirectly indicates the level of mobility and accessibility of that situation. In this study, therefore recurrent traffic congestion is taken as a major transportation system performance indicator.

Environmental pollution means creating imbalance in natural environment. Modern motorized transportation system is fully dependent on fossil fuel. The use of fossil fuel has some serious effects on natural environment. The effects are both direct and indirect and result from the production, use, servicing, and disposal of motor vehicles. Environmental effects include air and water pollution, ozone depletion, effects on climate, hazardous and solid waste production, noise pollution, loss of habitat, species and biodiversity, and reduced visibility (ICF, 1997). Out of all, the air pollution is most direct impact of transportation activities on environment (Bhuiyan, 2001). For this reason, air pollution is taken as indicator of environmental pollution.

3.4.1 Way to Quantify Congestion

According to the review of various literatures and reports, the traffic congestion measures can be broadly categorized into six categories (NCHRP, 1997). These are as follows:

1. Early empirical concepts;
2. Highway Capacity Manual (HCM) related concept;
3. Lane occupancy rate and queues;
4. Travel time measures;
5. Miscellaneous measures (e.g. headway distribution);
6. Traffic flow per effective lane measures and congestion indices.
7. Measure of mobility level by peak hour volume-capacity ratio or peak hour average link speed.

Empirical measures (such as Green Shield's quality of transmission index) are difficult to visualize and comprehend, require extensive data collection and complicate any statistical analyses, relate specifically automobile and truck and thus lack applicability to several other modes of travel, (NCHRP, 1997).

HCM related measures are primarily based upon Level of Service determination. Such measures are easy to understand but require detail site and location specific input data and in some instances, the application of complex models. These measures are well suited to analyze intersections or short roadway section problems but not well suited for policy or large scale planning analyses (NCHRP, 1997).

Lane occupancy rates, travel time, headway distribution etc. are direct measures and need real-time traffic information. The primary problems with these direct measures are that, they are difficult to use in predicting future congestion levels. Again it is difficult to address non-technical audiences without meaningful summary of congestion statistics. These difficulties have led many to suggest the need for a Surrogate measures called congestion indices (NCHRP, 1997).

A number of studies have been carried out by a number of researchers and professional organization to develop Congestion Indices. Pioneers of such studies are National Cooperative Highway Research Program (USA); Texas Transportation Institute (TTI), and Federal Highway Administration etc. A number of indices have also been proposed but they are mainly for freeways, corridor analysis or arterial roads etc. For regional or area wide analysis such type of indices can not be used directly but the theme can be translated from a particular scope to a broader perspective. The congestion indices selected for this study are described as follows:

Roadway Congestion Index (RCI): The overall regional Volume/Capacity ratio is a useful indicator of regional congestion (Shrank and Lomax, 1998). Shrank and Lomax define their "Roadway Congestion Index", RCI, as a weighted average Volume/Capacity ratio comprising Freeway and Principle Arterial components. The equation is:

$$RCI = [Fv^2 / FLM + AV^2 / ALM] / [13000 * FV + 5000 * AV] \quad (3.1)$$

Where,

FV = Regional Freeway Volume, Vehicle-miles / day

AV = Regional Arterial Volume, Vehicle-miles / day

FLM = Regional freeway Lane-miles

ALM = Regional Arterial Lane-miles

To further illustrate the significance of RCI, it is useful to define,

FC = Freeway Nominal Capacity = 13000 * FLM veh-mile/day

AC =Arterial nominal Capacity = 5000 * ALM veh-mile/day.

Here 13000 and 5000 are freeway and arterial capacity per lane per day respectively. It should be understood that nominal capacity is not the maximum capacity rather it is a capacity close to the threshold of significant congestion. Further it must be emphasized that FC and AC thus defined are not the capacity defined by ITE or TRB, which refer to a point or screen line along a roadway rather than a region as a whole (Mallinckrodt, 2001). Using definition of nominal capacity, the RCI, equation (1) can be written as

$$RCI = [(FV/FC)*FW + (AV/AC)*AW] / [FW + AW] \quad (3.2)$$

Where,

FW = 13000 * FV

AW = 5000*AV

Expression in this form may be recognized as the weighting coefficients in a weighted average of freeway and arterial volume to capacity ratios. The ratios for these particular coefficients are not clear. Nevertheless the resulting RCI has a close relationship to congestion and perhaps it was on the basis, the weighting was chosen.

For the present study on Dhaka, the road network is not well classified. Again this study is being carried out for a four-hour peak period rather than whole day. So according to the suggestion of TTI, if the equation (3.2) for RCI is modified for the present study it stands as

$$RCI = \sum [(LV/LC)*LW] / \sum LW \qquad (3.3)$$

Where,

LV = Link volume in Vehicle-km in peak hour = Vehicle per peak hour * Link Length.

LC = Link nominal capacity = Total capacity in vehicle per peak hour.

LW = (Capacity per Lane per Peak hour)*LV

If, for the whole network, capacity per lane per peak hour is taken as 650 (as per HCM, 1994), then after generalization it stands as;

$$\begin{aligned} \text{RCI} &= \sum [(\text{LV/LC})*(650)*\text{LV}] / \sum 650*\text{LV} \\ &= \sum [(\text{LV/LC})*\text{LV}] / \sum \text{LV} \\ &= \sum (\text{LV}^2/\text{LC}) / \sum \text{LV} \end{aligned}$$

$$RCI = \frac{\sum \frac{(\text{Vehicle per Peak Hour} * \text{Link Length})^2}{(\textit{Link}\ \text{Capacity} * \text{Link Length})}}{\sum (\text{Vehicle per Peak Hour} * \text{Link Length})}$$

$$RCI = \frac{\sum \frac{(\text{Vehicle per Peak Hour})}{(\textit{Link}\ \text{Capacity})} * (\text{Vehicle per Peak Hour} * \text{Link Length})}{\sum (\text{Vehicle per Peak Hour} * \text{Link Length})}$$

Here the RCI stands as the network weighted average volume capacity ratio, which indicates the index value of extra vehicle kilometer travel needed due to congestion in peak hours.

Travel Rate Index (TRI): The Travel Rate Index is a way of looking travel condition in peak period (Schrank and Lomax, 1999). It focuses on travel time rather than more traditional measure-speed. The TRI indicates how much longer it takes to make a trip than would be the case if trip occurred in free-flow conditions. For example, a TRI value of 1.3 indicates that it takes 30 percent longer time to make a trip than it would take if travel occurred at free-flow speed. In general TRI equation stands as a weighted average of peak period travel on freeway and arterial streets.

$$TRI = \left(\frac{\frac{\text{Freeway Peak Period Travel Rate}}{\text{Freeway Free Flow Travel Rate}} * \text{Freeway Peak VMT} + \frac{\text{Freeway Peak Period Travel Rate}}{\text{Freeway Free Flow Travel Rate}} * \text{FreewayPeakVMT}}{\text{Freeway Peak VMT} + \text{Arterial Peak VMT}} \right)$$

This equation can be modified for the present study to determine TRI of the network as follows:

$$\left(TRI = \frac{\sum \frac{\text{Peak Period Travel Rate}}{\text{Free Flow Travel Rate}} * \text{Peak Period Vehicle Kilometer Travel}}{\sum \text{Peak Period Vehicle Kilometer Travel}} \right) \quad (3.13)$$

Here individual link vehicle-kilometer travel is increased by a factor equal to the ratio of congested and free flow travel time. Actually it gives the value of network weighted average congested to free flow travel time ratio.

Multimodal Congestion Index (MCI) or Volume-Capacity Index (VCI): According to Mallinckrodt (2001), adhering as closely as possible to the TRB Highway Capacity Manual, the definition of '*effective regional capacity or RC*', herein for the purpose of congestion mitigation, can be stated as follows:

For congesting subsystems:

RC = the maximum volume of traffic, persons or vehicle kilometer per peak hour, which under the prevailing conditions, can reasonably expected to be supported by the subsystem at an acceptable or better level of congestion. Operating conditions specifically include public acceptance as well as managerial controls.

For non-congesting sub-systems:

RC = the maximum volume of traffic, persons or vehicle kilometer per peak hour, which under the prevailing operating conditions, can reasonably expected to be diverted from congesting sub-systems. Operating conditions specifically include public acceptance as well as managerial controls.

VCI Defined: These definitions lead to define the Multimodal "Volume / Capacity Index" (VCI) as follows:

$$VCI = \frac{RVs - RVnc}{RCc} \tag{3.14}$$

Where:

RVs = Total (all Modes) System Demand Volume, Vehicle-kilometer per peak hour.

RVnc = Summed effective volume (Vehicle-kilometer per peak hour) of non-congesting elements or links.

R'Cc = Summed Effective capacity (Vehicle-kilometer per peak hour) of all congesting sub-systems.

Here the definition (Mallinckrodt, 2001) is changed from persons to vehicle to simplify the calculation according to the objective of present study.

Congestion Severity Index (CSI): It is used by Federal highway Administration Authority (FHA, USA) in reporting the results of system analyses using 'Highway Performance Monitoring System' data. The CSI has units of roadway delay per million vehicle kilometer of travel. For present study, if only peak period is considered rather than daily basis and the index is determined for thousand vehicle-kilometer travel, then the equation of CSI is stands as follows:

$$CSI = \left(\frac{Total\ Delay(Vehicle - hours) \text{ per Peak Hour}}{Total\ Vehicle - Kilometer\ Travel\ in\ Thousand \text{ per Peak Hour}} \right) \tag{3.15}$$

It indicates the loss of Vehicle-hour per Thousand Vehicle-Kilometer travel in Peak Hour. It can easily be converted to delay per vehicle-km travel.

3.4.2 Mobility Level

Sometimes the mobility level of an individual link is measured by volume-capacity ratio. Such type of measure is proposed by Houston-Galveston Council of Traffic Modeling (HGAC,1998), which is shown in Table 3.2.

Table 3. 2: Scale of Different Mobility Levels

Level of Mobility	Volume / Capacity
Tolerable	< 0.85
Moderate	>= 0.85 < 1.00
Serious	>= 1.00 < 1.25
Severe	>= 1.25

This type of measure divides the roadway lengths of the network into a number of classes, expressed as percentage of total lengths according to mobility levels.

3.4.3 Measurement of Air Pollution

Air pollution by vehicular activity is quantified by using emission factor. The emission factor is defined as the estimated average emission rate of a given pollutant for a given class of vehicle. It is estimated by emission produced by kilometer traveled or hour traveled by the vehicle. Estimates of vehicle emissions are obtained by multiplying an estimate of distance traveled or time of running by a given class of vehicle with an appropriate emission factor (Alam et al, 2000). A comprehensive study was carried out by Jaigirdar (1998) to determine the average emission factors of SO_x, NO_x and CO for typical vehicular modes present in Dhaka city. The average emission rates of of SO_x, NO_x and CO for common types of vehicles of Dhaka city are shown in Table 3.3

Table 3. 3: Emissions by Different Types of Vehicles

Vehicle Mode	SO_2		NO_2		CO	
	gm/pass-km	Gm/minute	gm/pass-km	gm/minute	gm/pass-km	gm/minute
Rickshaw	0	0	0	0	0	0
Baby Taxi and Scooter	0.0909	0.21	0.0606	0.1399	5.7218	13.2174
Bus and Mini Bus	0.0528	1.7470	0.2720	8.9963	0.3504	11.5919
Car	0.1852	0.4532	0.6749	1.6515	12.8848	31.5276

Reference: (Jaigirdar, 1998)

3.3 Summary

This chapter described the overall methodology of the development of a transportation model and its application for Dhaka city through the sections of transportation model review, selection of study area and selection of transportation system performance. In model review sections, the underlying concepts and principal components of transportation models were described. The details of the study area together with method of zoning and selection of road network were described. In transportation system performance sections, the concepts and definitions of various system performance parameters were illustrated. Based on the concepts and methods described in this chapter, an urban transportation model for Dhaka city is developed, calibrated and applied to analyze planning options. The next chapter describes the details of the transportation model developed for Dhaka (DUTM).

Chapter 4

MODEL DEVELOPMENT AND CALIBRATION

4.1 Introduction

The standard approach to urban transport demand modeling, commonly employed to transportation planning professionals, is embodied in a system of models generally known as urban transportation modeling system (UTMS), (Meyer and Miller, 1984). Model is used to predict the number of trips made within an urban area, time of day (peak-period, daily) and zonal origin-destination (O-D) pair. Models also determine the mode of travel used to make these trips and the routes taken through the transportation network by these trips. The final product of UTMS is a predicted set of modal flows on links in a network. As such it represents an "equilibrium" procedure, in which the demand for transportation (representing by zonal O-D flows by modes) is assigned to modal networks that constitute the transportation system as a function of their performance (supply) characteristics. The major inputs to UTMS are a specification of the activity system generating these flows and characteristics of transport system, which is to serve these flows. This chapter describes the components of the model developed for Dhaka, named as DUTM and the ways to adjust its parameters. The individual modules of the DUTM are developed by using limited surveys at different parts of the study area and taking basic ideas and patterns followed in similar type of study by DITS (1993). So the performance of the model should be carefully verified to represent the actual situation of the area of concern. Keeping this fact in mind, DUTM is formulated in such a way that the basic model parameters (impedance factors, ratio of inter-zonal to total trip ratio or trip generation factor, coefficients of 'generalized cost' components etc) can be determined indirectly, that means by comparing the model prediction with the observed data. The objectives of such indirect method of fixing the model parameters are to use the secondary data available and to make the DUTM suitable for adjustments in changing situation.

4.2 Components of DUTM

The DUTM is developed for urban areas of Dhaka and is based on conventional transportation planning models concept. There are four distinct components of DUTM, which are Trip Generation, Trip Distribution, Modal Split and Trip Assignment. The schematic diagram of DUTM is shown in Figure 4.1:

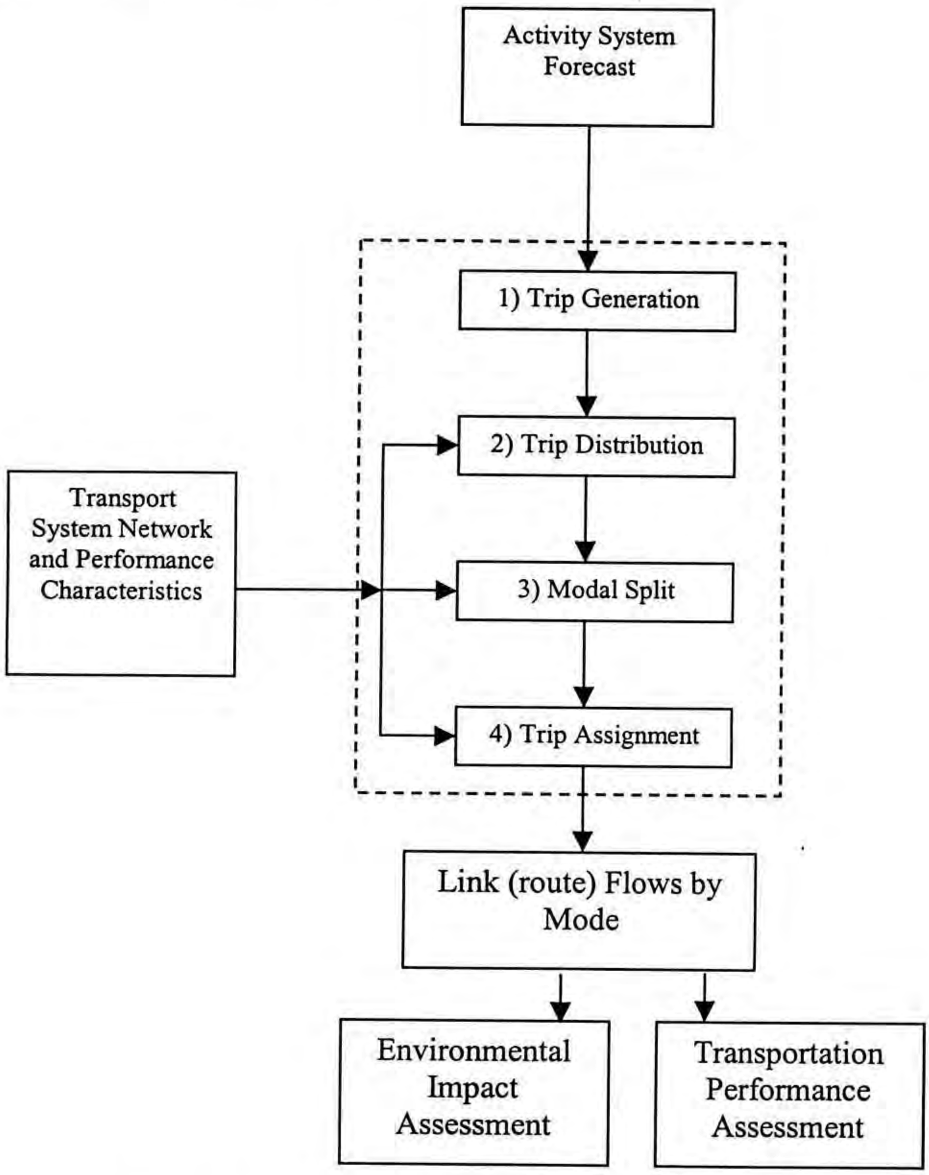


Figure 4. 1: The Urban Transportation Modeling System for Dhaka City

Traditionally such type of UTMS is referred as four-stage model. The details of individual components of the DUTM are described in the following sections.

4.2.1 Trip Generation Model

The trip generation component of DUTM is a 'disaggregate multiple linear regressions' type model. The general structures of the model are:

$$\text{Generated Trips} = \text{Trip Generation Factor} * \{a + \sum_x (b_x * p_x) + (c_x * e_x)\} \quad (4.1)$$

$$\text{Attracted Trips} = \text{Trip Generation Factor} * \{a + \sum_x (b_x * p_x) + (c_x * e_x)\} \quad (4.2)$$

Where 'a' is a constant, 'p' is the population of a particular type; 'e' is the employment of particular type; 'b' and 'c' are corresponding regression coefficients. Population and employments are categorized into three groups namely primary, secondary and tertiary, which are described bellow:

- Primary types: Agricultural Works.
- Secondary types: Manufacturing, Food, Textile, Heavy Engineering, Laboring.
- Tertiary types: Professional, Administration, Transport, Sales, Services, Building.

The regression coefficients are taken from a study undertaken on urban areas of Dhaka (Jaigirdar, 1998) and shown in Table 4.1. But the value of Trip Generation Factor is fixed through an iterative calibration process, which is described later.

Table 4. 1: Coefficients of Regression Equation for Trip Generation and Attraction

	Purpose of Trips	a	b_0	B_1	b_2	b_3	c_0	c_1	c_2	c_3
Generation	HW	1283	-	-	0.31	0.5	-	-	-	-
	HS	79.5	0.12	-	-	-	-	-	-	-
	WW	-1562.5	-	-	-	-	-	-	0.295	0.5
	HB	-777.5	0	0.195	0.11	0.5	-	-	0.095	0.5
	MIS	-2570.5	0.525	-	-	-	0.73	-	-	-
Attraction	HW	-803	-	-	-	-	-	-	0.39	0.5
	HS	326	0.115	-	-	-	-	-	-	-
	WW	-1517.5	-	-	-	-	-	-	0.29	0.5
	HB	-717	-	-	0.13	0.5	-	1.185	0.07	0.5
	MIS	-2576	0.765	-	-	-	-	-	0.29	0.5

Source: (Jaigirdar, 1998)

Where HW is "Home to Work"; HS is "Home to School"; WW is "Work to work"; HB is "Home based Business"; MIS is "Provision for commercial and through traffic"

4.2.2 Trip Distribution

The trip distribution component of the DUTM is a gravity type model. The model structure is as follows:

$$t_{ij} = A_i O_i B_j D_j * exp(-\beta * C_{ij}) \qquad (4.3)$$

Where 't_{ij}' is the number of trips from origin 'i' to destination 'j'; A and B are corresponding zonal attributes; β is the impedance factor; C_{ij} is the generalized cost of i-j pair, which represents a function of spatial separation of zones in terms of time, cost and comfort, O_i is total trips generated from zone 'i' and D_j is the total trips attracted to zone 'j'. Here O_i and D_j are output of 'Trip Generation model'. A_i and B_j are zonal balancing factors, which produce a balanced O-D matrix satisfying both trip generation and attraction constraints. These coefficients are endogenously determined as follows:

$Ai = \frac{1}{\sum_j B_j * \exp(-\beta * C_{ij})}$ and $Bj = \frac{1}{\sum_j A_i * \exp(-\beta * C_{ij})}$, where β is manually determined from trip length distribution characteristics and depends on unit as well as specification of generalized cost function.

The equation of generalized cost C_{ij} is:

$$C_{ij} = (a_c * Cost) + (a_t * Time) + (a_{comf} * Comfort) \qquad (4.4)$$

a_c, a_t and a_{comf} are coefficients of time, cost and comfort of O-D pair.

4.2.3 Modal Split

The modal split component of the DUTM is a multinomial trip interchange logit model. The choice probability in this case is give by

$$Pr(n) = \frac{e^{V_n}}{(e^{V_1} + e^{V_2} + e^{V_3} + \dots\dots\dots + e^{V_m})} = \frac{e^{V_n}}{\sum_{n=1}^{m} e^{V_n}} \qquad (4.5)$$

Where Pr(n) is the probability of choosing a mode 'n' for traveling between particular O-D pairs and V is the utility function of individual modes. The equation of utility function is:

$$V = (a_c * Cost^x + a_t * Time^y + a_{comf} * Comfort^z) \quad (4.6)$$

a_c, a_t, a_{comf} are the coefficient of cost, time and comfort of particular mode respectively. x, y and z are the corresponding power of cost, time and comfort respectively. Based on above mentioned probability function, the distributed traffic volumes of O-D pairs are assigned to different types of modes under consideration.

4.2.4 Traffic Assignment

The trip assignment component of DUTM uses the equilibrium capacity restraint type assignment in which traffic flow is incrementally loaded on network, allowing congestion to gradually "build up" and travel time estimates to adjust in response to this. The adjusted link speed or its associated travel impedance (time) is computed by using the following capacity restraint functions:

$$T_l = T_0 [1 + 0.15 (V/C)^{0.15}] \quad (4.7)$$

The assignment procedure used in this study can be summarized as follows:

1. Using free flow travel speed minimum path tree is calculated.
2. Some percentage (Q%) of traffic is assigned to the minimum path. The lower the percentage, the higher the accuracy. The best procedure is to assign one vehicle each time. But the time required for this process will be very high. For the analysis of this study the percentage selected is 25%.
3. After each cycle of assignment, new travel time tree is estimated for links of the network by using capacity restraint function, as shown in equation (4.15).
4. Step 2 and step 3 are repeated for required number of times to assign all the traffic.

   Number of repetition, N = 100 / Q

   For present study N = 4, so the number of repetition is 4.

4.3 Model Calibration

4.3.1 Calibration Process

The basic parameters of the UTMS to be fixed are:

- Value of travel time.
- Impedance factors of trip distribution and modal split.
- Fraction of total trips assigned to inter-zonal movement or Trip generation factor and duration of peak period.
- Coefficients of cost, speed and comfort for determination of generalized cost and power of elements of utility function.

The average value of travel time is fixed as 0.3 taka per minute (Alam et al, 1999). Average comfort unit, average occupancy, average PCE, average speed, average operating cost per kilometer for each individual mode are selected from a survey conducted on the urban areas of Dhaka (Jaigirdar, 1998).

Power of elements of utility function and impedance factor for trip distribution and modal split are first selected getting ideas from similar type of research study conducted on Dhaka (DITS, 1993; Jaigirdar, 1998; Khan, 2000; Monayem, 2001). These all are also adjusted time to time with adjustments of other parameters to obtain the required total modal share of the urban area and link volume of a number of links, whose observed volume (year 2001) are known.

The model parameters are determined by an iterative process. The parameters are more or less related to one another and thereby changes of any parameter have effects on the performance of others. First, the coefficients of generalized cost are estimated to get the modal share similar to the observed values. Then the trip generation factor is adjusted by comparing assigned volume of a number of links with corresponding observed volumes of the year of 2001. After a number of iterations the values of all coefficients and parameters are reached to a stable equilibrium state. The finally adjusted parameters and coefficients for the calibration base year of 2001 are shown in Table 4.2.

Table 4. 2: Values of Calibrated Parameters

Parameters	Values
x, y, z; the power of time, cost and comfort of utility function	1.25; 0.75; 1.25
Coefficient of Time, a_t	0.06
Coefficient of Cost, a_c	0.15
Coefficient of Comfort, a_{comf}	0.21
Impedance Factor for Assignment	0.005
Impedance Factor for Mode Choice	0.01
Trip Generation Factor	0.32

4.3.2 Calibration of Modal Split

Using the above mentioned calibrated parameters; the modal shares in terms of person-trip are got as shown in Figure 4.2. Here the modal share of rickshaw, auto-rickshaw, bus and car are got as 41%, 14%, 34% and 11% respectively for the year of 2001. These values of modal shares are within the range of estimated modal shares for urban Dhaka, as described in Chapter 2 (rickshaw 40% ~ 45%, auto-rickshaw 13% ~ 16%, bus 25% ~ 35% and car 10% ~ 12%)).

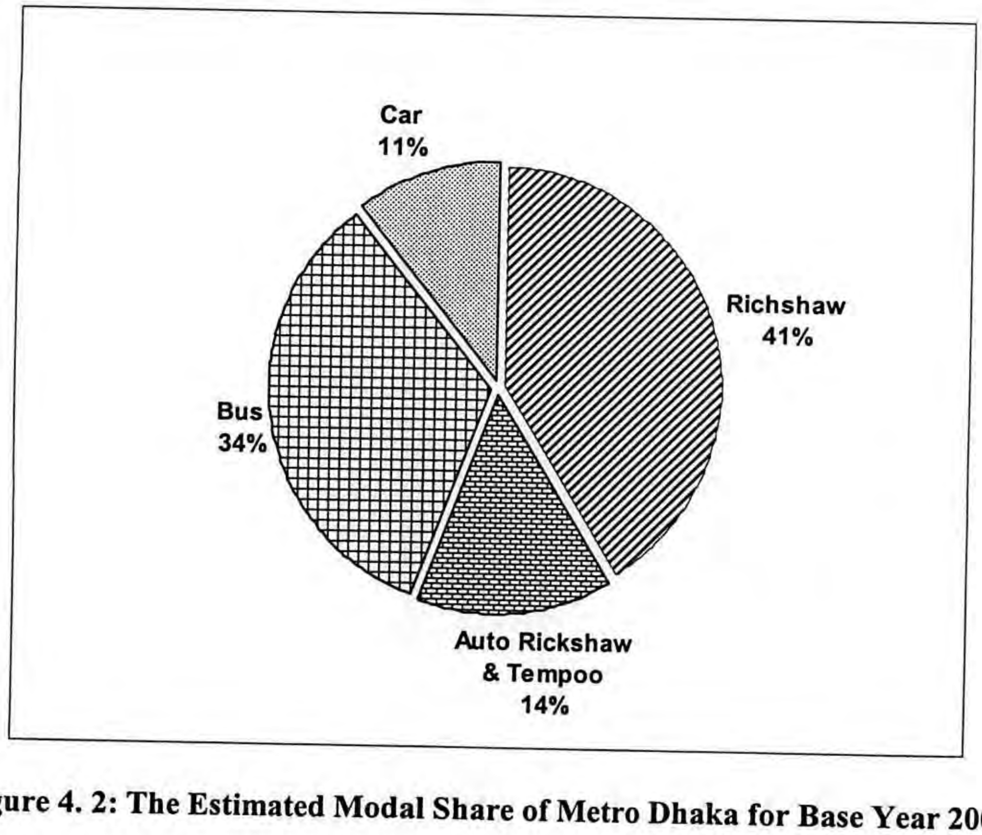


Figure 4. 2: The Estimated Modal Share of Metro Dhaka for Base Year 2001

4.3.3 Calibration of Link Volume

A measure often used to determine the degree of fit between observed traffic and predicted traffic is MAD (Mean Assigned Deviation) ratio. The MAD ratio is defined as:

$$MAD\ ratio = \{\sum_{j} Absolute(Estj - Countj) / Countj\} / n \qquad (4.8)$$

Where, Esti = Estimated Traffic Assignment at location j

Countj = Estimated Traffic Count at location j

n = Number of locations of traffic counts.

A very good fit would give a value of 0.35, which means that on average the difference between traffic assignment and observed count is 35% (DITS, 1993). But this type of measure is always biased to one side only. So it is better to use average of *Estj & Countj* in denominator of the MAD equation:

$$MAD\ ratio = \{\sum_{j} Absolute(Estj - Countj) / (Average\_of\_Countj\ \&\ Estj\} / n \qquad (4.9)$$

Actual hourly volume of traffic in peak period had been collected at 20 links of designated road network (Monayem, 2001). The prediction of the model for the same time and locations are checked against observed data. The MAD ratio for these 20 links is found as 0.30. This value of MAD ratio means that the model predictions fit with the real data by 70%, which implies an acceptable goodness of the fit statistically. The comparisons between observed and predicted values are shown in Table 4.3. Although the number of compared links is only 20, these 20 links are not parts of a single route, rather 1st to 12th number of observations are of a major arterial road named "Mirpur Road" and 13th to 20th number of observations are of another major arterial road named "Kazi Nazrul Islam Avenue". These two arterial roads are at the two opposite sides of the network; with one has restriction on a special type of vehicle (Rickshaw in Kazi Nazrul Islam Avenue). It is seen in that although the predicted values are almost similar to the observed values for Kazi Nazrul Islam Avenue, in case of Mirpur Road the model, to some extend, over estimates. This is due to the trip generation error. The trip generation part of DUTM is calibrated by a small-scale survey on some parts of the study area and it is considered that trip generation rate is same for all TAZs. Actually trip generation rate varies with socio-economic conditions of individual zones. Such as trip generation rate of

Gulshan area will be different from that of Mirpur area. To overcome this problem, comprehensive survey should be conducted for each TAZ, which is very expensive and time consuming.

For the minimum MAD ratio of 0.3, the trip generation factor is found as 0.32. Trip generation factor 0.32 means 32 percent of total generated trips are involved in inter-zonal movements. According to Hoque and Alam, (2002); in Dhaka 62 percent of total trips are walking trips, which are mainly intra-zonal trips; 13.3 percent of total trips are rickshaw trips, around fifty percent (6 percent) of which are intra-zonal trips. The remaining (100-62-6 = 32) 32 percent of total generated trips are inter-zonal trips, which are the main consideration of this study. So the trip generation factor of 0.32 is thus justified. The changing pattern of MAD ratio with changes of trip generation factor is shown in Figure 4.3.

Table 4. 3: Comparison of Model Assignments with Observed data of Base year 2001

From Node	To Node	No. of Observation	Model Assignment, PCU/Hr A	Actual Volume PCU/Hr B	Assigned Deviation From Mean of A & B	Mean assigned Deviation, MAD
61	144	1	4216	2546	0.491	0.30
144	61	2	2947	2725	0.078	
144	143	3	2935	3094	0.053	
143	144	4	2215	3032	0.311	
143	34	5	3420	3456	0.010	
34	143	6	2657	2775	0.043	
35	190	7	3976	4985	0.225	
190	35	8	3603	4246	0.164	
190	191	9	3925	5286	0.296	
191	190	10	3935	4298	0.088	
193	194	11	3709	5854	0.449	
194	193	12	4472	5707	0.243	
16	15	13	4305	2452	0.548	
15	16	14	4381	2682	0.481	
15	214	15	4296	2344	0.588	
214	15	16	4398	2691	0.482	
214	14	17	4638	4682	0.009	
14	214	18	5514	3081	0.566	
14	13	19	5123	3126	0.484	
13	14	20	5149	3280	0.443	

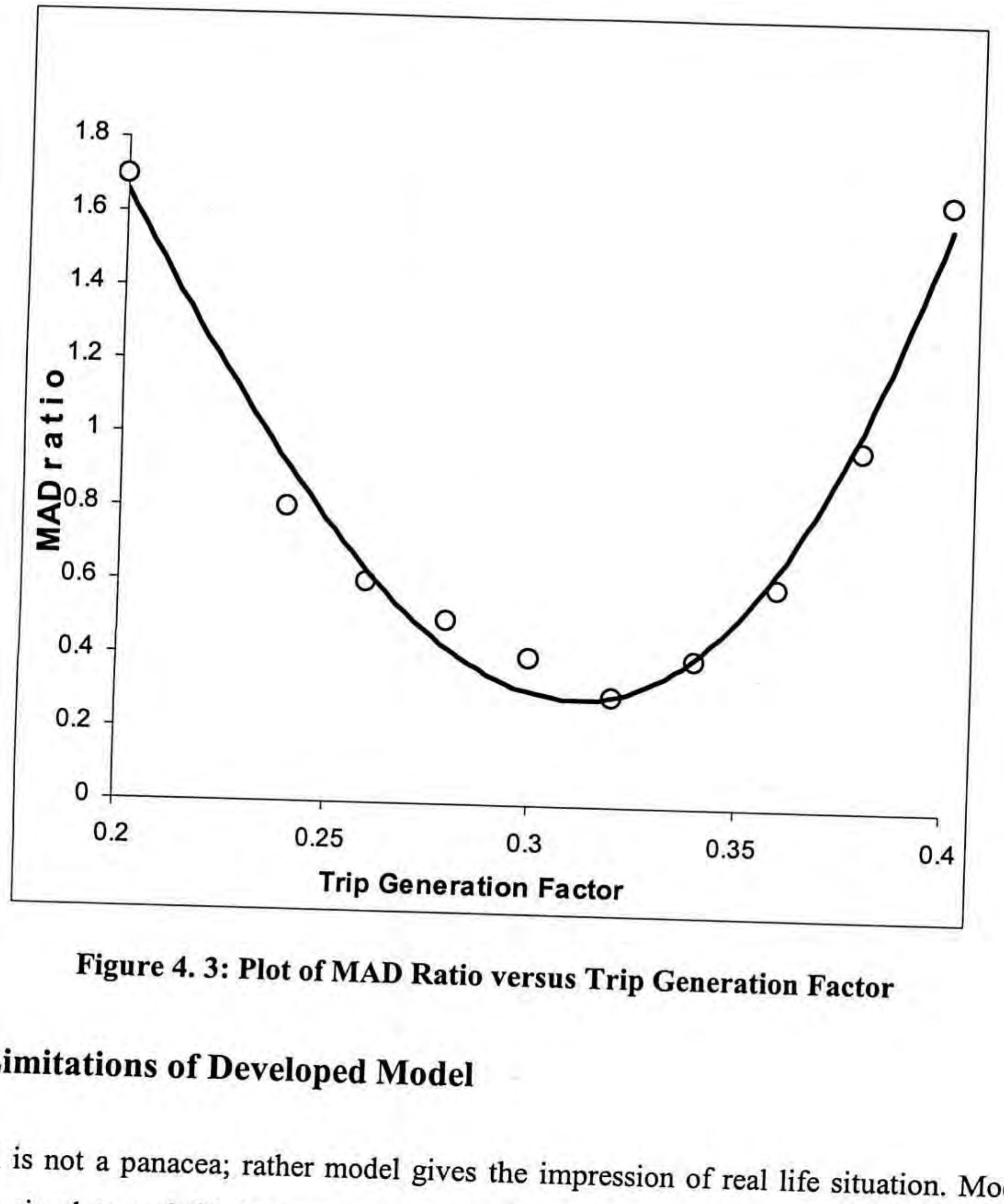


Figure 4. 3: Plot of MAD Ratio versus Trip Generation Factor

4.5 Limitations of Developed Model

Model is not a panacea; rather model gives the impression of real life situation. Model cannot simulate real life by cent percent. Again in transportation activity, where human behavior is involved in various decision-makings or choices, the uncertainty is obvious. In such uncertain situation, any type of model must have some limitations. For this reason, it is called that transport model is acceptable, if it can give 65% accurate result or maximum of 35% error (DITS, 1993). Although the DUTM, described above, gives 70% accurate (MAD ratio of 0.30) result, it have some limitations. The limitations can be summarized as follows:

- In trip generation analysis, multiple regression equation is used, where only trips are classified according to purpose and people are classified according to employment. It would give better result if cross-classification or category analysis was used. Due to lack of sufficient data it was not possible.

- The employment fraction sharing by each TAZ is got from DITS household interview survey (1991-1993) and considered constant over the years. It would be better, if a comprehensive household interview survey could be carried out and results were compared with those of DITS survey to get the changing trends of such ratios. But such type of household interview survey requires huge money and time.
- Walking, which provides 62% of total person-trips in Dhaka, is ignored in DUTM. Although almost 99% of walking is intra-zonal movement, which is avoided in this study on the ground of not using arterials and main links; it (pedestrian crossing) creates hindrances to traffic flow in arterials and main links during peak period and thereby contributes to roadway congestion. But due to lack of proper theoretical basis it could not be included.
- For calibration, out of 355 links, only 20 links were considered. The calibration would be more precise if number of link would be more. Again time and cost were the main obstacles in that purpose.
- DUTM can predict only peak period recurrent congestion. But non-recurrent traffic congestion is also very important. So further study is necessary to incorporate non-recurrent traffic congestion in DUTM.

4.6 Summary

This chapter described the details of individual components and calibration process of DUTM. It also described the scope of application and limitations of DUTM. It was seen that although there were some limitations, the developed DUTM could predict the peak-hour traffic conditions of the selected road network with high level of accuracy. The DUTM described in this chapter is designed in such a way that it is also capable of predicting the impact of changes in transportation system such as removal or addition of new modes, opening of missing links, improvement of modal characteristics etc. The next chapter describes the application of the model to analyze the present and future situation in do-nothing-case, termed as baseline situation.

Chapter 5

BASELINE ANALYSIS AND PLANNING NEED ASSESSMENT USING DUTM

5.1 Introduction

The situation of traffic congestion and consequent air pollution of Dhaka city is extremely poor, which is well recognized by the inhabitants of the city. Such recognition is qualitative and subjective in nature. For the purpose of planning and design of measures in order to improve the situation, it is required to obtain quantitative or objective evaluation regarding the situation. Particularly in the case of transportation system, it is required to visualize future situations on quantitative basis and design improvement measures satisfying a set of goals. Quantitative measurements of present and future situations may be obtained either from trend analysis using time series data or from model based analysis. In the absence of time series data, which is the case of Dhaka city, models become only tool for such analysis. Even where time series data are available, models are widely used to analyze alternative scenarios. This chapter presents the quantification of traffic congestion and air pollution of the whole road network of Dhaka in an aggregate way by using DUTM. Attempts have been made to estimate traffic congestion and consequent air pollution for the base year of DUTM (2001) and then extend the estimation for future and the past. Since analyses described in this chapter are for the past, existing and future situation without alteration of transportation system components (except for socio-economic variables change with time), these are termed as baseline analyses.

DUTM estimates peak hour traffic volume on the roadway links of the network for different socio-economic and operating conditions (a sample output of DUTM is shown in Appendix C). For baseline analysis, peak hour traffic data of different years are used to estimate current and projected regional traffic congestion and consequent air pollution of the study area. The results of baseline analyses are described in the following sections.

5.2 Impact Analysis

At present Metro Dhaka hosts for a population size of over six million. In addition to national growth rate (yearly around 2%), rapid urbanization attracts people to migrate (yearly around 2.5%) from rural areas (DCC, 2001). Population of Metro Dhaka is increasing irrespective of the necessary improvements of the urban facilities, especially in transport sectors. The impacts of population and employment changes are described bellow.

5.2.1 Impact on Peak Period Transportation Demands

With increasing population, demand for travel also increases. The travel demand is normally expressed in two terms. These are total Vehicle-Kilometer (Veh-km) travel and total Vehicle-Hour (veh-hr) travel. Total veh-km travel indicates the basic travel demand but total veh-hr travel includes transportation system deficiencies with the basic travel demand. The changes of population and travel demand in peak period with time are shown in Table 5.1. It is seen that total peak period vehicle-km demand of the year 2002 (13,45,260 veh-km) will be 1.76 times in the year 2020 (23,70,220 veh-km) and the total peak period vehicle-hour demand of the year 2002 (59,500 veh-hr) will be the 4.24 times in the year 2020 (252,550 veh-hr). When these data are plotted, as shown in Figure 5.1, it clarifies that population of Dhaka increases linearly but the travel demands increase exponentially. The rates of change in total veh-km travel and total veh-hr travel demands become clear from Figure 5.2. In Figure 5.2, it is seen that total vehicle-hour travel demand increases exponentially but with higher order than that of total vehicle-km travel demand. Actually such trend indicates transportation system deficiency. With increasing demand, the traffic volume in different road links approaches to the capacity and consequently congestion incurs. Traffic congestion consumes extra time. The cause of higher order increasing rate of total vehicle-hour demand than that of total vehicle-km demand is to satisfy the travel need at the same time compensate for the traffic congestion.

5.2.2 Impact on Peak Period Volume-Capacity Ratio and Average Speed

The transportation network performs by reduced average speed and increasing volume-capacity ratio with increasing travel demands. As shown in Table 5.1, in the present year of 2002, 62 percent of total road lengths of the network are to carry traffic flow with volume-capacity ratio greater than 1.25 in peak period and 47 percent of total road length of the network are to carry traffic flow with average speed bellow 15 kilometer per hour in peak period. Although in 2002, 47 percent of total length carries peak period traffic with average speed less than 15 kilometer per hour, 51 percent of them (24 percent of total) carry peak period traffic with average speed less than 5 kilometer per hour. With increasing travel demand the transportation network goes for saturation. The term saturation implies that the roadway links are approached to their capacity at the same time the average speed falls. The Figure 5.3 and Figure 5.4 show that with increasing demand, the transportation network of Dhaka goes for saturation in terms of increasing peak period volume-capacity ratio and becomes gridlocked with successively higher percentage of link lengths with peak period average speed less than 15 kilometer per hour in peak period.

Table 5. 1: Effects of Population Change on Peak Period Travel Demand and Mobility

Year	Popul-ation ('000)	Travel Demand		Percentage of Total Road Length with V/C > 1.25 (%)	Percentage of Total Road Length with Speed Less than 15 kilometer per hour (%)	Percentage of Total Road Length with Speed Less than 5 kilometer per hour (%)
		'000 Veh-hr	'000 Veh-km			
1997	4642	32.67	905.56	37	23	8.5
1998	4879	35.41	966.11	42	26	9.5
1999	5099	38.38	1026.60	45	31	11.5
2000	5328	41.65	1091.11	50	34	12
2001	5568	45.54	1161.67	52	37	15
2002	6139	59.50	1345.26	62	47	24
2003	6415	67.23	1430.10	65	48	28.5
2004	6704	76.17	1515.07	67	53	32.5
2005	7005	89.94	1614.39	73	56	35
2008	7320	102.92	1741.66	74	58	39
2010	7650	119.96	1865.24	79	57	42.5
2012	7994	142.32	1981.07	81	58	46.7
2014	8354	170.38	2126.08	82	61	51
2018	8730	210.82	2243.95	85	64	54.7
2020	9123	252.55	2370.22	85	68	58

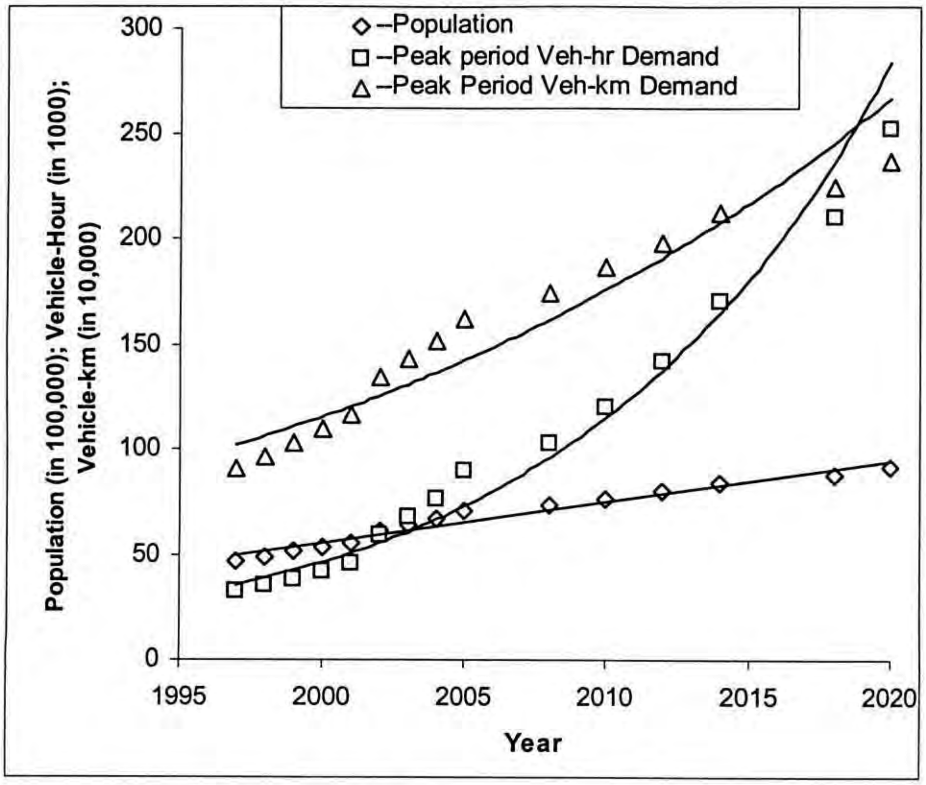


Figure 5. 1: Changes in Peak Period Travel Demand and Population with Time.

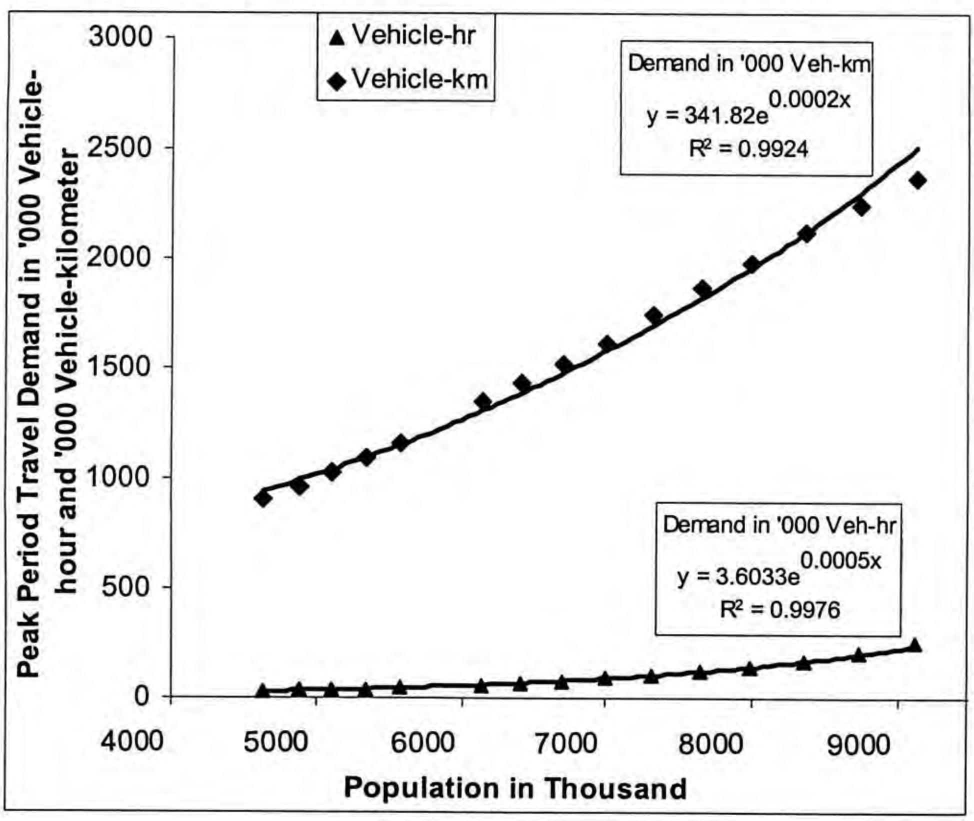


Figure 5. 2: Changes in Peak Period Travel Demand with Population Change.

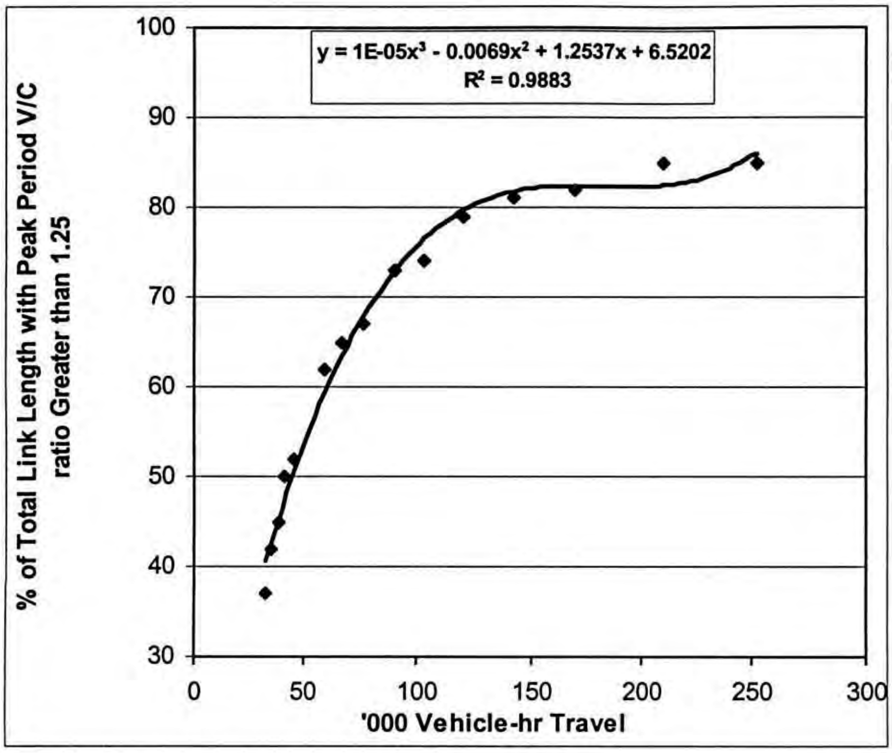


Figure 5. 3: Increase in Volume-Capacity ratios of Links with Increasing Demand.

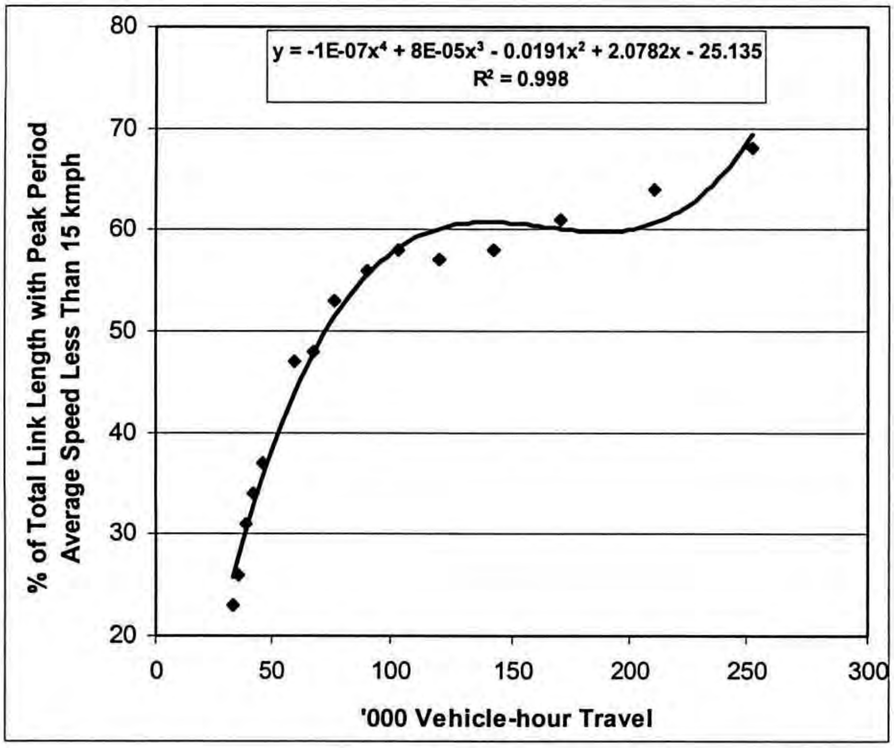


Figure 5. 4: Decrease in Peak Period Average Speeds of Links with Increasing Demand.

5.2.3 Impacts on Peak Period Mobility or Traffic congestion

Four types of indices have been described in Chapter 3 for measurement of traffic congestion or mobility. These are Roadway Congestion Index (RCI), Travel Rate Index (TRI), Volume-Capacity Index (VCI), and Congestion Severity Index (CSI). Details of each index have been discussed in Chapter 3. From those discussions, it is clear that RCI is a measure of mobility as well as congestion, which indicates the extra amount of veh-km travel need for increasing congestion or decreasing mobility. RCI takes the multiplying factor from peak period link Volume-Capacity ratio and estimates the overall network average of volume-capacity ratio. The higher value of RCI than 1 indicates lower mobility and higher congestion. Value of RCI less than or equal to 1 indicates non-congested situation. TRI is similar to RCI but TRI takes the multiplying factor from the ratio of peak-period and free flow travel time. TRI signifies the travel time rather than Volume-Capacity ratio and indicates the average fraction of extra time required in peak period overall for the network. It estimates the network average of peak period to free flow travel time ratio. VCI is somewhat different from RCI and TRI. VCI is actually the overall ratio of peak hour vehicle-km demand and peak hour vehicle-km capacity, excluding the non-congesting links. For this study, links with Volume-Capacity ratio less than 0.85 is considered as non-congesting links. Value of VCI indicates increasing demand as well as saturation of regional network. CSI measures the overall network average delay per thousand kilometer travel during peak hour. The values of RCI, TRI, VCI and CSI with increasing demand are shown in Table 5.2. The plots of the values of each four indices in different years are shown in Figure 5.5, 5.6, 5.7 and 5.8. These figures show the trend of traffic congestion in Dhaka.

From Table 5.2 it is seen than at present (2002) the value of RCI is 2.53. It means that the road network of study area carries peak period vehicle-kilometer demand, which is 2.5 times more than its capacity. If the present condition persists without any improvement of network capacity then Figure 5.5 shows that RCI value will increase linearly with time.

In case of TRI, for present year of 2002 the value is 5.67. This indicates that during peak hour the road network of the study area requires on an average 4.67 times more travel time than free flow travel time. TRI value gives the network average, as congestion may not be uniform throughout the whole network, this situation may not be realized by an individual traveling in a particular link of the network. This means that some parts of the network experience delays many times more than TRI value. The Figure 5.6 indicates that if no measures are taken to improve the network capacity, the TRI value increases exponentially with increasing population. The rate of change of TRI value remains slower unto when the whole network becomes congested, and then it increases abruptly.

In case of VCI, for the present year of 2002, the value of VCI is 2.26. It indicates that at present, the congested portions (Volume-Capacity >0.85) of road network are to carry traffic 2.26 times more than their capacity during peak hour. Figure 5.7 shows that VCI value increases almost linearly with time. This means if no improvement of network capacity is made, the whole network will be saturated gradually.

In case of CSI, for the present year of 2002, the value is 226.51. This means at present, during peak period, on an average the delay is 226.51 hours per 1000 kilometer travel. In simple words, on average 13.60 minute delay per kilometer travel occurs during peak hour in the road network of study area. Figure 5.8 shows the variation of CSI with time. It is clear that CSI value increases exponentially with increasing population. It means that the increase rate of CSI remain slower up to the time required to fully saturate the network, then it increase abruptly.

Table 5. 2: Changes of Peak Period Congestion Indices with Time

Year	Pop^n in '000	Peak Period Congestion Indices				Peak Period Travel Demand	
		RCI	TRI	VCI	CSI	Veh-hr '000	Veh-km '000
1997	4642	1.73	2.88	1.72	86.72	32.67	905.56
1998	4879	1.83	3.22	1.81	102.54	35.41	966.11
1999	5099	1.93	3.64	1.88	122.16	38.38	1026.60
2000	5328	2.03	4.01	1.93	139.73	41.65	1091.11
2001	5568	2.13	4.43	1.10	160.69	45.54	1161.67
2002	6139	2.53	5.67	2.26	226.51	59.50	1345.26
2003	6415	2.64	6.61	2.39	273.19	67.23	1430.10
2004	6704	2.82	7.87	2.50	340.32	76.17	1515.07
2005	7005	2.95	9.37	2.62	410.22	89.94	1614.39
2008	7320	3.17	13.30	2.72	608.22	102.92	1741.66
2010	7650	3.43	19.48	2.93	937.27	119.96	1865.23
2012	7994	3.70	32.25	3.09	1632.09	142.32	1981.07
2014	8354	4.10	47.54	3.34	2460.94	170.38	2126.08
2018	8730	4.33	51.26	3.55	2617.53	210.82	2243.95
2020	9123	4.60	68.53	3.75	3574.54	252.55	2370.22

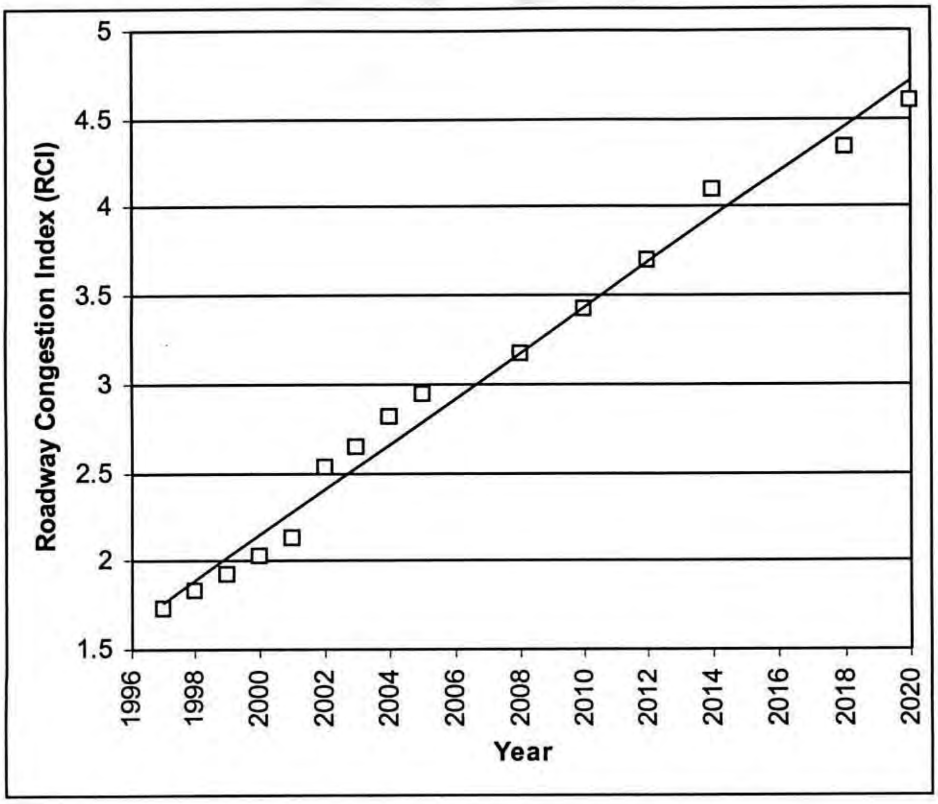


Figure 5. 5: Change of Peak Period RCI Value with Time

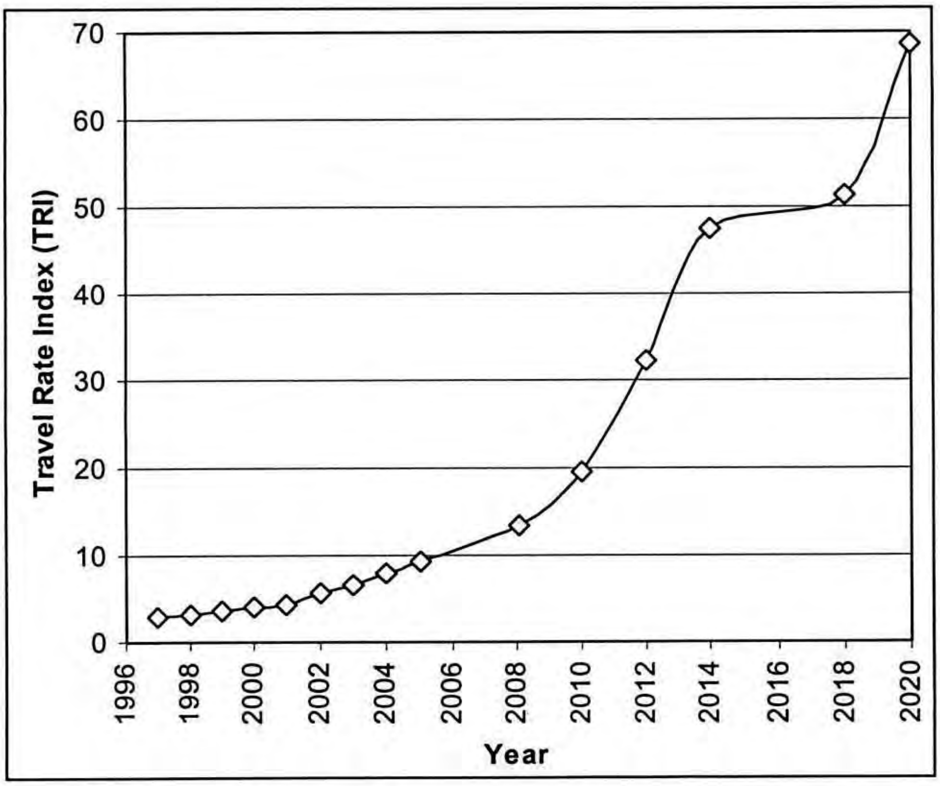


Figure 5. 6: Change of Peak Period TRI Value with Time

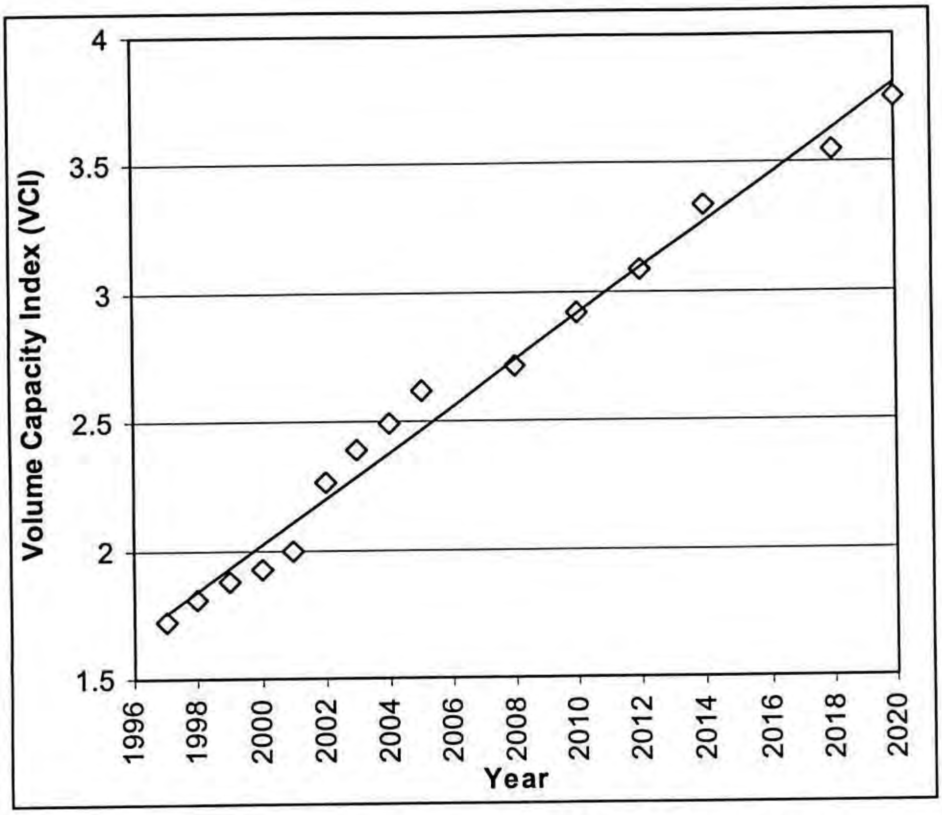


Figure 5. 7: Change of Peak Period VCI Value with Time

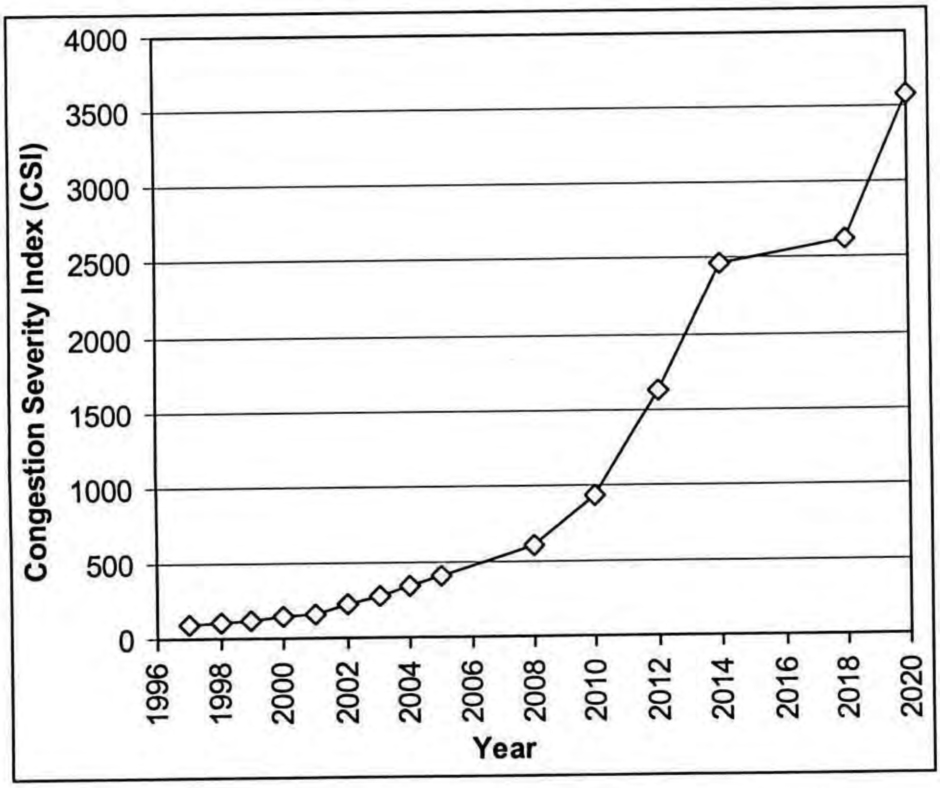


Figure 5. 8: Change of Peak Period CSI Value with Time

5.2.4 Impact of Air Pollution

The overall effect of transportation activity on natural environment has been described in Chapter 3. The urban transportation activities affect the environment mainly in term of air pollution. In this study the motor vehicle emissions, mainly SO_x, NO_x and CO emissions during peak hour have been estimated. The emissions in peak hour of different years are shown in Table 5.3. It is seen that at present (Year 2002) the average peak period emission rates of SO_2, NO_2 and CO are 0.26, 0.79 and 13.44 ton per hour. If no measures are taken to improve the situation by the year 2020 the emission rates of SO_2, NO_2 and CO will be 1.25, 4.11 and 61.68 ton per peak hour. The changing pattern of peak period emission rates with time are shown in Figure 5.9, 5.10, 5.11.

It is obvious that with increasing population, both peak period travel-length and peak period travel-time increases. The air polluting emissions from different vehicles are normally expressed as functions of total vehicle-kilometer travel or total vehicle-hour travel by different motorized vehicles. The emissions from total veh-km travel and total veh-hr travel are calculated individually and the higher one is taken as the actual emission rate. In this study it is revealed that emission rate as per total vehicle-hour travel governs over the emission rate as per total vehicle-km travel. It is the result of congestion. Due to traffic congestion, vehicles are to remain more times on road in peak period than off-peak hours to cross the same distance. If no traffic congestion exists that means if all vehicles can move in free flow speed then the emission rate from total veh-km travel and emission rate from total veh-hr travel will be the same.

As emissions of a particular pollutant are not same for all types of motorized vehicles, the changing patterns of emissions of SO_x, NO_x and CO are obviously functions of vehicle composition. The described table and figures of this chapter are for the present traffic composition of motorized traffic in Metropolitan Dhaka. (41% rickshaw, 14% auto-rickshaw & tempo, 34% bus and 11% car; in terms of person-trip). So the analysis of emission rates will evaluate different planning options both in terms of changes in travel demand as well as vehicle composition. For the present vehicle composition the relationship between peak period emission rate and peak period total travel demand (in veh-hr) are deduced and shown in Figure 5.12. 5.13 and 5.14. The relation ships are:

Peak period SO_2 emission in ton/hr = 0.0053·(Peak period Total Veh-hr Demand) - 0.0714

Peak period NO_2 emission in ton/hr = 0.0174·(Peak period Total Veh-hr Demand) - 0.2906

Peak period CO emission in ton/hr = 0.2574·(Peak period Total Veh-hr Demand) – 2.8931

It is seen that the emission rates are linearly related with total peak period travel demand in terms of vehicle-hour.

Table 5. 3: Changes of Emissions per Peak Hour with Population Change in Time

Year	Pollution (Emission per Peak Hour)			Peak Period Travel Demand	
	SO_2 in ton per Peak Hour	NO_2 in ton per Peak Hour	CO in ton per Peak Hour	'000 veh-hr	'000 veh-km
1997	0.08	0.22	4.08	32.67	905.56
1998	0.08	0.25	4.41	35.41	966.11
1999	0.09	0.28	4.77	38.38	1026.60
2000	0.17	0.5	9.1	41.65	1091.11
2001	0.19	0.56	9.96	45.54	1161.67
2002	0.26	0.79	13.44	59.50	1345.26
2003	0.3	0.92	15.29	67.23	1430.10
2004	0.34	1.07	17.45	76.17	1515.07
2005	0.41	1.3	20.92	89.94	1614.39
2008	0.48	1.52	24.1	102.92	1741.66
2010	0.56	1.8	28.18	119.96	1865.23
2012	0.67	2.18	33.83	142.32	1981.07
2014	0.82	2.66	40.82	170.38	2126.08
2018	1.03	3.36	50.87	210.82	2243.95
2020	1.25	4.11	61.68	252.55	2370.22

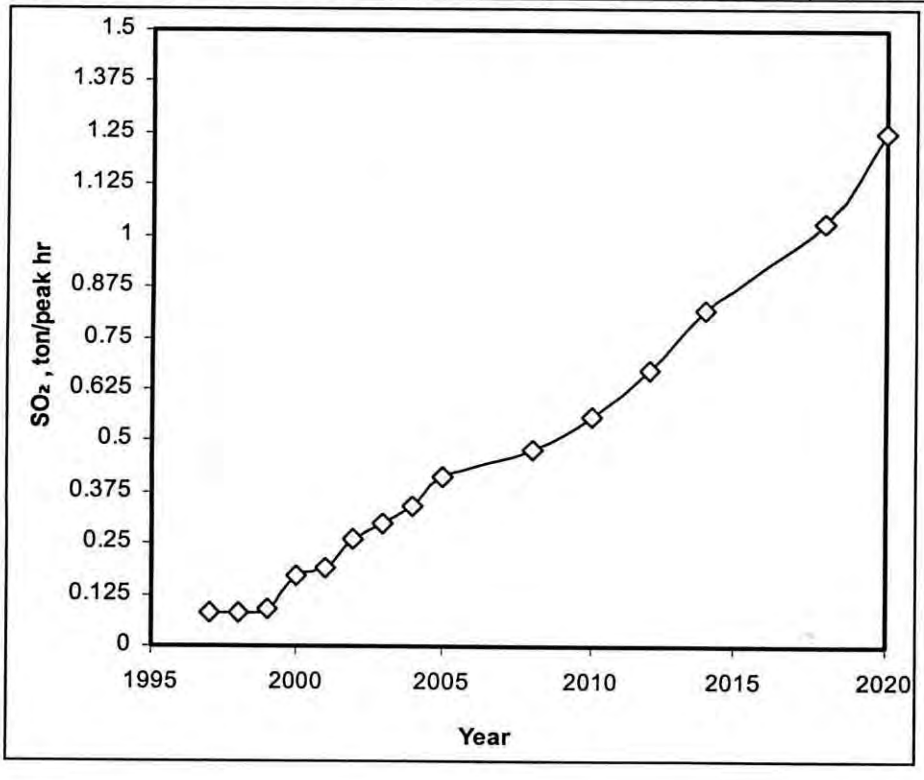


Figure 5. 9: Changes in Peak Period SO_2 Emission Rate with increasing population

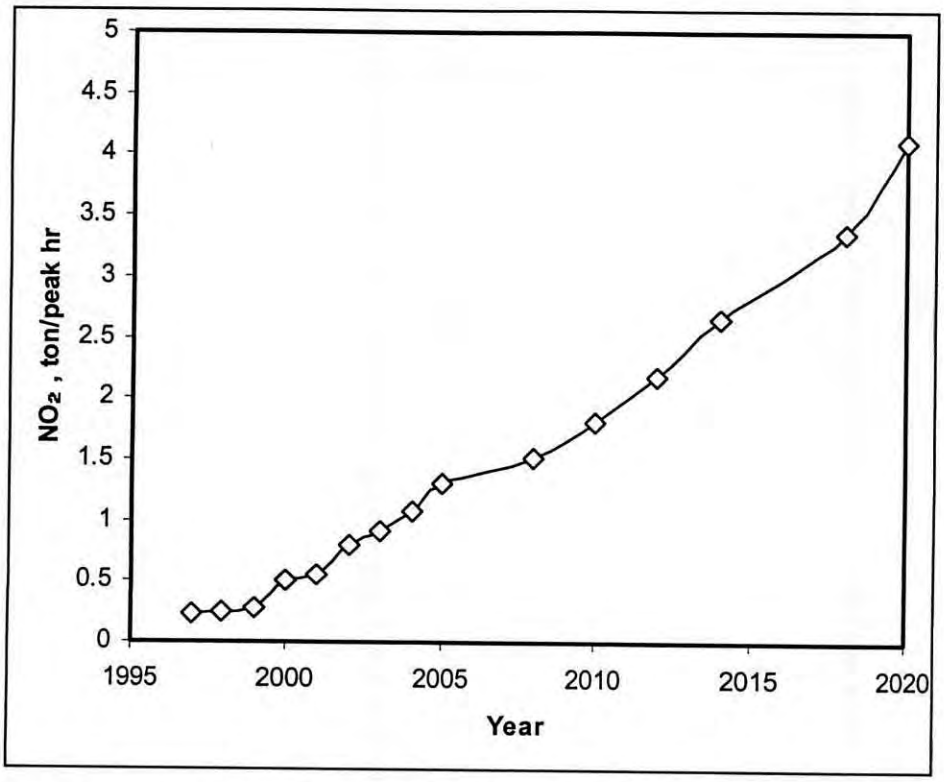


Figure 5. 10: Changes in Peak Period NO_2 Emission Rate with increasing population

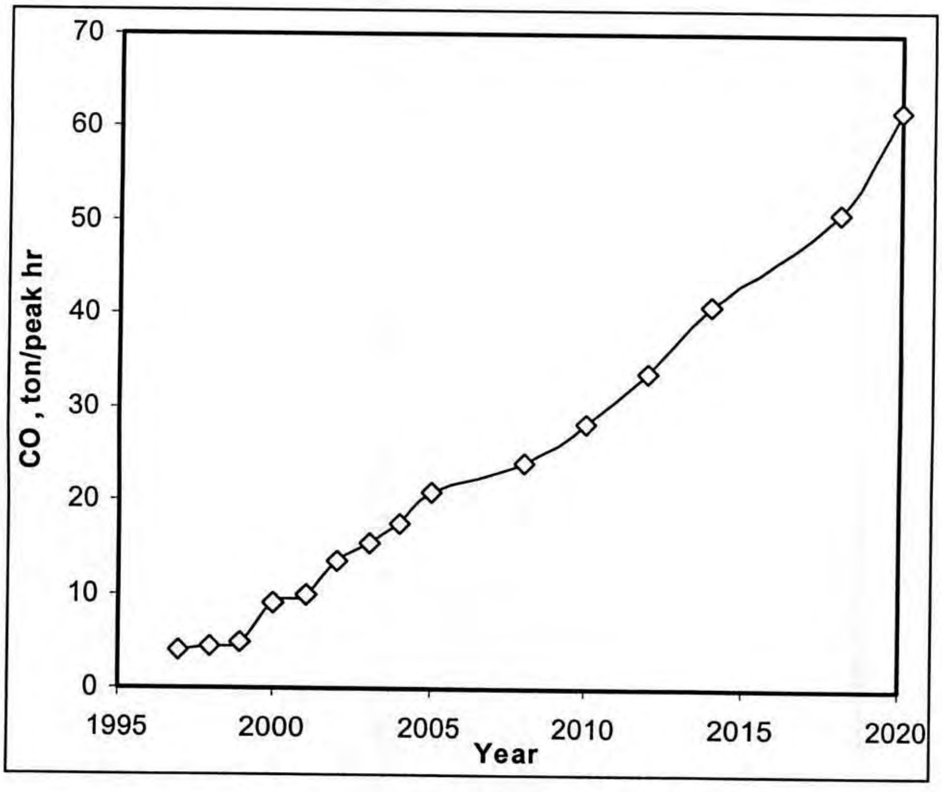


Figure 5. 11: Changes in CO Emission Rate with Time

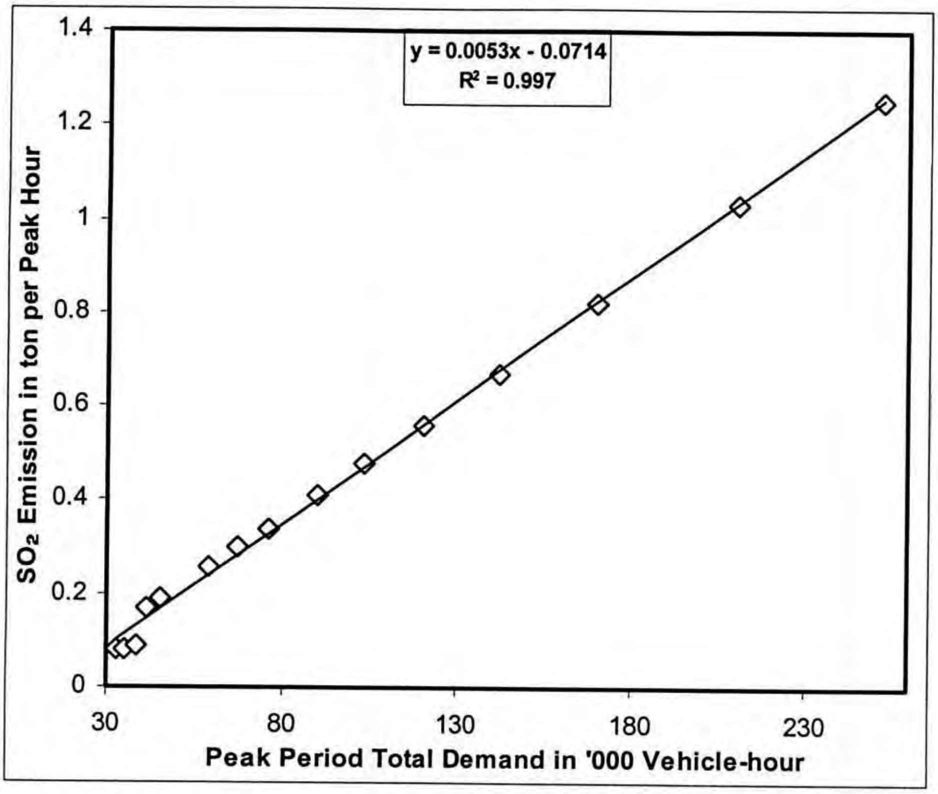


Figure 5. 12: Relationship between Peak Period SO_2 Emission Rate and Peak Period Total Travel Demand in Vehicle-hours

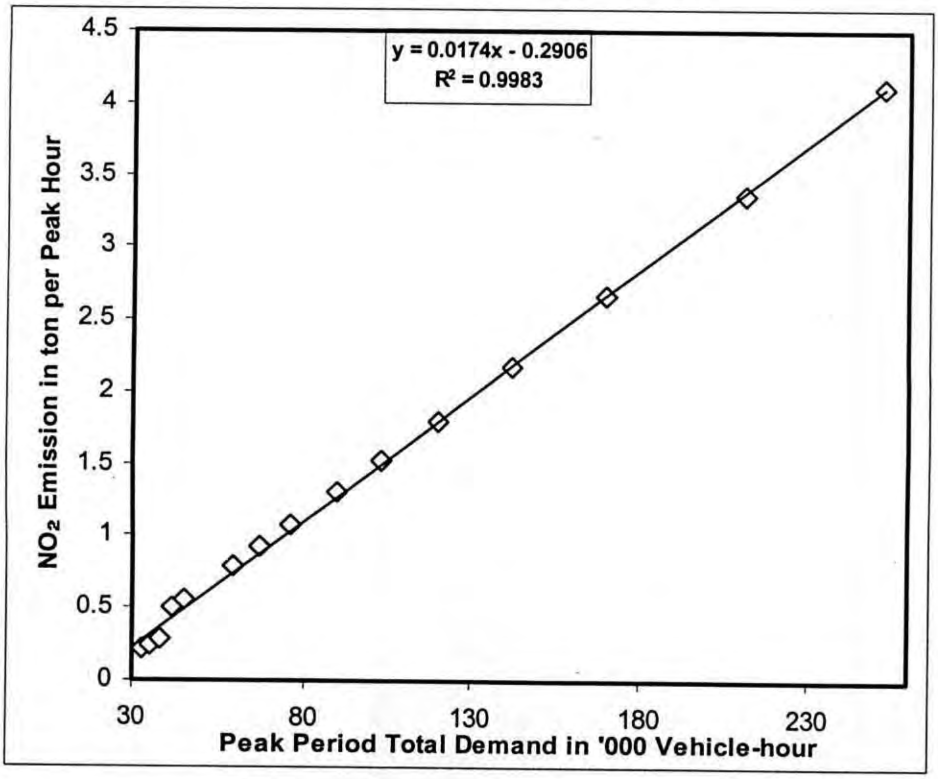


Figure 5. 13: Relationship between Peak Period NO_2 Emission Rate and Peak Period Total Travel Demand in Vehicle-hours

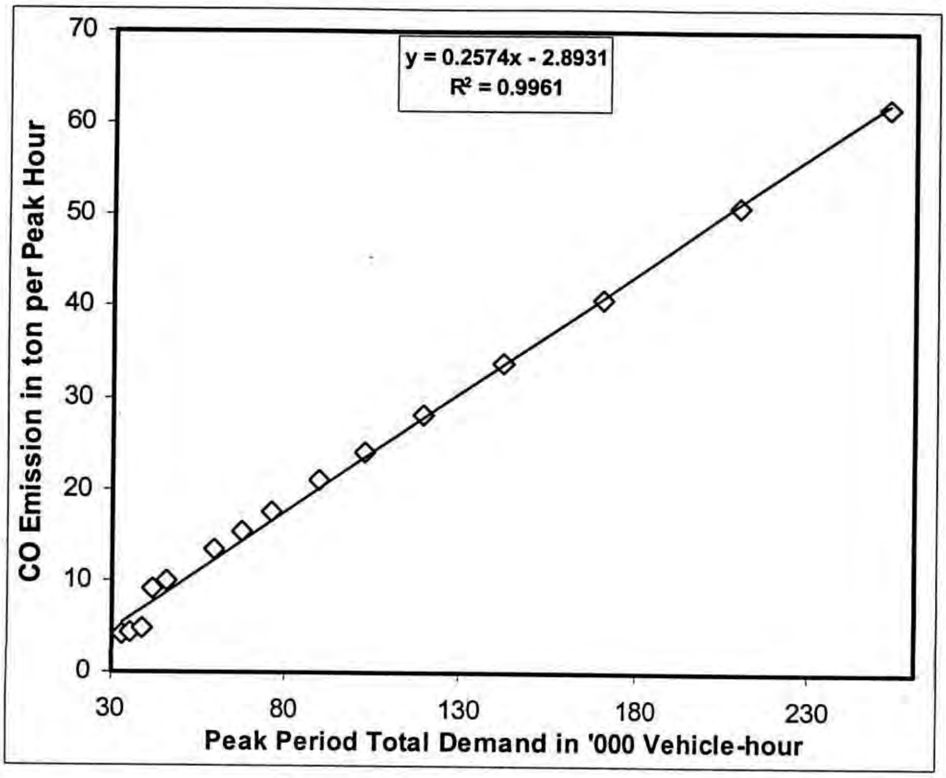


Figure 5. 14: Relationship between Peak Period NO_2 Emission Rate and Peak Period Total Travel Demand in Vehicle-hours

5.3 Summary

The aim of the analyses described in this chapter was to estimate the existing situation and changing patterns of traffic congestion and consequent air pollution in the central urban portion of Dhaka, which were termed as baseline analyses. The attempts had been made to quantify congestion and air pollution, and then the relationships of such congestion and air pollution with changing travel demand resulting from population increase over the years were deduced. From the analyses it was observed that the road traffic congestion and resulting air pollution in Dhaka would be unacceptably poor in base year of analyses and degrading in alarming rates with increasing population. Unfortunately, the elimination of such traffic congestion and resulting air pollution may not be a realistic goal. Some level of rush hour is likely to remain as a part of life in Metropolitan Dhaka. It should be tried to make the transportation investment decisions that maintain a level of mobility ensuring a functional urban transportation system. While free flowing urban traffic at all hours of the day may not be practical, the road network should not be allowed to become totally grid locked. Rather, the efficiency of the transportation system should be improved. The next chapter presents some alternative planning options and evaluates the impact of these measures on traffic congestion and air pollution.

Chapter 6

EVALUATION OF ALTERNATIVE PLANNING OPTIONS

6.1 Introduction

Chapter 5 described past, present and future conditions of road traffic and resulting air pollution situations for business as usual case of Dhaka city during peak period. Such analyses provided base-line situation of traffic congestion and consequent air pollution of Dhaka. Engineering and planning measures are usually taken to improve such situations. There exist numerous engineering measures from which the optimum solution should be selected through planning process. This chapter describes effectiveness of some alternative planning options to alleviate traffic congestion and to improve air pollution situation in comparison to baseline situations.

6.2 Alternative Planning Options

6.2.1 Planning Options Overview

One of the solutions to the problems of present traffic congestion and consequent air pollution of Dhaka is the construction of new roads and widening of existing roads. Such type of measure is called 'Structural Improvement' of network. This type of measure may resolve the problems for some period of time but the situations will again become as bad as before due to suppressed demands and increase in population. The best solutions are those, which require fewer amounts of money, easy to implement and effective for longer period of time. 'Transportation system management' (TSM) and 'Transportation demand management' (TDM) measures fulfill these purposes, (TDM Encyclopedia, 2000).

TSM is a process of optimizing an existing transportation system. These strategies consists of lower cost actions that increase the capacity of existing facilities in terms of their capacity to carry more persons by eliminating lower occupancy vehicles, slower vehicles etc. TDM describes a wide range of actions to increase the efficiency of network. Quite simply TDM programs are designed to maximize the people moving capability of the transportation system by increasing the number of persons in a vehicle, or by influencing the time of or need to travel. TDM programs must rely on incentives or disincentives to make these shifts in behavior attractive.

6.2.2 Planning Options for Immediate Implementation

Considering the feasibility, resource requirements and time frame regarding immediate implementation, the following measures are selected in this study as alternative options. The options analyzed in this study are:

1. Eliminating Rickshaws from main urban roadway links of Dhaka.
2. Eliminating Auto-Rickshaws from Dhaka.
3. Opening of some closed links and widening of some links creating bottlenecks to traffic movements.
4. Improvement of bus service in urban areas of Dhaka.
5. Incorporation of intra-city rail service.

Here option 1, 2, 4 and 5 are TSM and TDM types of measure and the option 3 is a 'structural improvement' type of measure. The impacts of above mentioned options on traffic congestion and resulting air pollution of Dhaka are described in the following sections.

6.3 Elimination of Rickshaws from Main Road links of urban Dhaka

Rickshaw is the non-motorized part of road traffic of Dhaka city. It is blamed for creating traffic congestion in the city, especially for its low operating speed and low occupancy level. Authorities often contemplate to alleviate traffic congestion by banning rickshaw in some links and making separate lanes for it. But the quantitative benefit of removal of rickshaw is yet to be estimated. This section describes the results of elimination of rickshaw from the road network of Dhaka in quantitative form.

6.3.1 Impact on Traffic Congestion

Table 6.1 shows that peak period total vehicle-km and vehicle-hour demand reduce for the removal of rickshaw. Figure 6.1 shows the comparative graphical presentations of the situations. For present year of 2002 the total peak period vehicular travel demands in network are 1345,260 vehicle-km and 59,500 vehicle-hours. If rickshaws are removed from the network, total vehicle-km demand reduces by 48.52% (692,550 veh-km) and total vehicle-hours demand reduces by 24.28% (45,049 vehicle-hours) and it also reduces the future increase rate of travel demand.

The cause of reduction of total vehicle-km travel demand is the shifting of rickshaw users to other modes having higher occupancy level than rickshaw. Such as occupancy level of bus, car and auto-rickshaw are 66 times, 1.6 times and 2 of times that of rickshaw respectively. Figure 6.1 shows that the total vehicle-km demand curve of with-rickshaw composition is steeper than that of without-rickshaw composition. The total demand in person-trip increases with the increase in population and due to the lower occupancy level (0.6, which is less than 1) of rickshaw, total peak period vehicle-km travel demand increases with higher degree than the increase rate of person-trip. Elimination of rickshaw from network reduces this increase rate of peak period total vehicle-kilometer travel demand.

The cause of reduction of total peak period vehicle-hour travel demand is the increase in average speed of traffic flow for rickshaw removal. The peak period total vehicle-hour travel demand is more reflective to traffic congestion than peak period total vehicle-km travel demand. With increasing traffic congestion, the average speed of traffic flow reduces and total vehicle-hour travel demand increases. For the year of 2002, removal of rickshaw reduces total vehicle-hour demand by 24.28% but for the year of 2020 it will be 62%. This is the indication of rickshaw's major contribution to city traffic congestion. The total peak period vehicle-hour demand increases exponentially if rickshaw presents but removal of rickshaw makes the increase rate from exponential to linear type. These are the sign of rickshaw's contribution to traffic congestion. The picture will be clear after comparing the congestion indices.

Table 6.2 shows that the values of indices fall drastically due to removal of rickshaw. For the year of 2002, if RCI and VCI are considered; where both are volume-capacity related measures; both of them reduces to almost half of their present value (RCI; 2.53 to 1.25 and VCI; 2.26 to 1.43) due to removal of rickshaw. That means without rickshaw, the links of urban road network will have to carry almost half of the peak period traffic volume than former condition. If TRI and CSI are considered; where both of them are travel time related measures; they reduce to almost one fourth (TRI; 5.67 to 1.51) to one tenth (CSI; 226.51 to 23.17) of their present value due to removal of rickshaw. The reduction of TRI value to around one fourth of original value means extra travel time required for congestion in peak hour, reduces to one fourth value if rickshaws are removed. On the other hand reduction of CSI value to one tenth of original value means, due to removal of rickshaw the delay per kilometer travel reduces to one tenth of original value. The changes of indices with time for with rickshaw and without rickshaw combination are shown in Figure 6.2. From the figure, it is clear that slopes of the curves of indices fall drastically and exponential type changing patterns become linear type due to removal of rickshaws. This means rickshaw removal not only reduces congestion for present time but also dampens the intensity of increase in congestion with time.

The situation after removal of rickshaw can be better perceived from the figures of Table 6.3 and Figure 6.3. Due to removal of rickshaw, the overall network will enjoy the significant reduction of peak hour volume and significant increase of peak hour average travel speed. For the present year of 2002, total 47% of urban roadway length has to carry peak period traffic with average speed of 15 kilometer per hour and for the year of 2020 it will be 68%, where as if rickshaws are removed, this percentage becomes 14% for the year of 2002 and 46% for the year of 2020. Again for the present year of 2002, total 62% of urban roadway length has to carry peak period traffic with volume-capacity ratio greater than 1.25 and this will be 85% for the year 2020, whereas if rickshaws are removed then this percentage becomes 21% for the year of 2002 and 61% for the year of 2020. So it is seen that the removal of rickshaw shifts the situations of the year 2002 to the year of 2020.

6.3.2 Impact on Air Pollution

One of the main logics in favor of rickshaw is that it is a pollution free mode. Rickshaw produces no direct air pollution, but the problem is that it intensifies traffic congestion and let the other motorized modes to remain more times on the road and thereby increases air pollution. The peak period emissions of SO_x, NO_x and CO in terms of ton/hr are shown in table 6.4. The graphical presentations of changes of emission rates over the years are shown in Figure 6.4. Although removal of rickshaws increases the emission rates of SO_x and NO_x in the present year of 2002, the Figure 6.4 shows that the rate of increase of emission rates of SO_x and NO_x fall if rickshaws are removed from the network and in future the rates will be much lower. In case of CO emission, it is seen that emission rate of CO reduces from the present year of 2002 due to removal of rickshaws. This is because of the reduction of traffic congestion. The major contributor of CO is car. Though car use increases by 19 percent for rickshaw removal, the total peak period vehicle-hour demand of car reduces for increase in overall travel speed; as a result total CO emission rate reduces. Removal of rickshaw makes the increase rate of SO_x, NO_x, and CO from exponential type to linear type in future.

6.3.3 Impact on Demand for Other Modes

Rickshaw is the non-motorized part of the vehicular composition of urban Dhaka and posses a major modal share. For Greater Dhaka rickshaw provides 60% of total mechanized person trips (excluding walking) (DUTP-II, 1998). For central urban areas of Dhaka (study area of present research) rickshaw occupies 41% of modal share. If rickshaws are removed at a time or gradually, the people who depend on rickshaw will shift to other modes. The demand of rickshaws should be compensated by increasing the number of other modes. The analysis shows that if rickshaws are removed totally from main roadway links of the network, rickshaw users will shift to bus, auto-rickshaw and car. To compensate the rickshaws, the percentages of present amount of bus, auto-rickshaw and car have to be increased by 51%, 28% and 19% respectively. The comparative figure is shown in Figure 6.5.

Table 6. 1: Peak Period Total Travel Demand in the Conditions of With-rickshaw and Without-rickshaw Composition

Year	Population ('000)	Demand in Vehicle-km ('000)			Demand in Vehicle-hr ('000)		
		With-rickshaw	Without-rickshaw	% Reduction	With-rickshaw	Without-rickshaw	% Reduction
2002	6139	692.55	1345.26	48.52	45.05	59.50	24.28
2003	6415	735.73	1430.10	48.55	48.25	67.23	28.23
2004	6704	781.51	1515.07	48.42	51.73	76.17	32.08
2005	7005	831.98	1614.39	48.46	55.70	89.94	38.06
2010	7650	940.88	1865.24	49.56	65.20	120.00	45.65
2014	8354	1063.30	2126.08	49.99	77.40	170.40	54.57
2020	9123	1188.43	2370.22	49.86	95.73	252.50	62.09

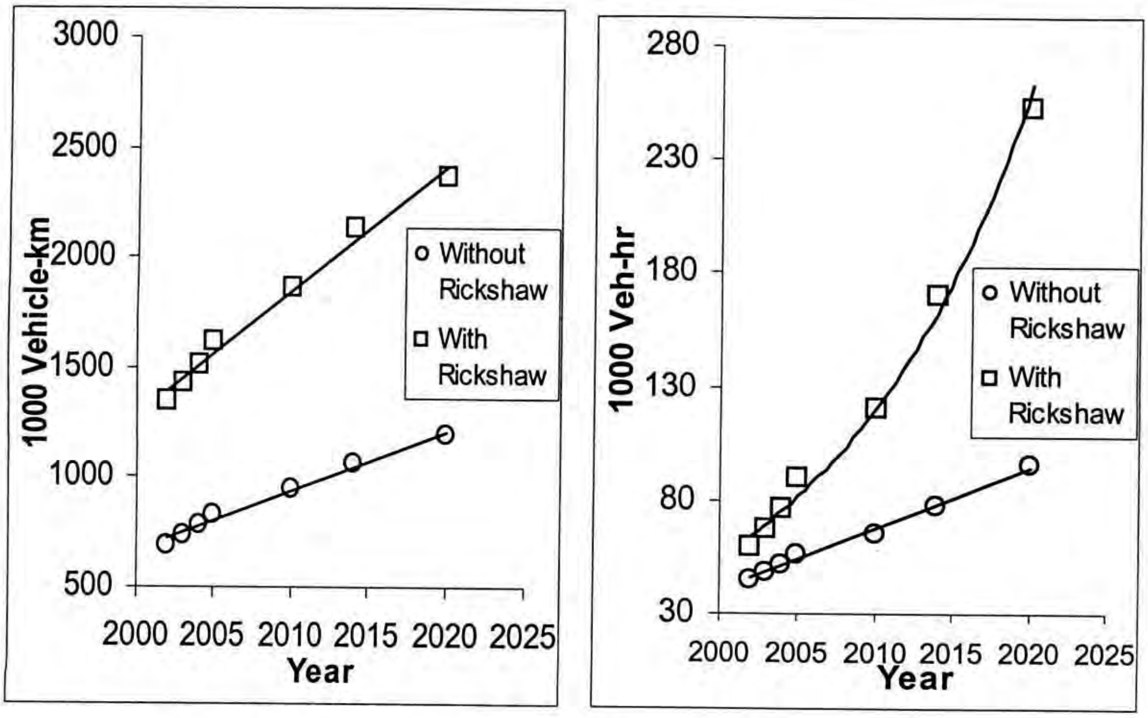


Figure 6. 1: Peak Period Total Vehicular Travel Demand

Table 6. 2: Peak Period Congestion Indices in the Conditions of With-rickshaw and Without-rickshaw Composition

Year	RCI			TRI			VCI			CSI		
	Without Rickshaw	With Rickshaw	% Reduction	Without Rickshaw	With Rickshaw	% Reduction	Without Rickshaw	With Rickshaw	% Reduction	Without Rickshaw	With Rickshaw	% Reduction
2002	1.25	2.53	50.69	1.51	5.67	73.45	1.43	2.26	36.97	23.17	226.51	89.77
2003	1.32	2.64	50.14	1.57	6.61	76.28	1.46	2.39	38.95	26.23	273.19	90.4
2004	1.39	2.82	50.56	1.65	7.87	79.02	1.48	2.49	40.58	30.35	340.32	91.08
2005	1.49	2.95	49.59	1.76	9.37	81.19	1.54	2.62	41.2	35.83	410.22	91.27
2010	1.69	3.43	50.73	2.07	19.50	89.37	1.69	2.92	42.12	51.63	937.27	94.49
2014	1.92	4.09	53.08	2.49	47.50	94.76	1.88	3.34	43.7	72.60	2460.90	97.05
2020	2.16	4.60	53.02	3.48	68.50	94.92	2.02	3.75	46.16	123.10	3574.50	96.56

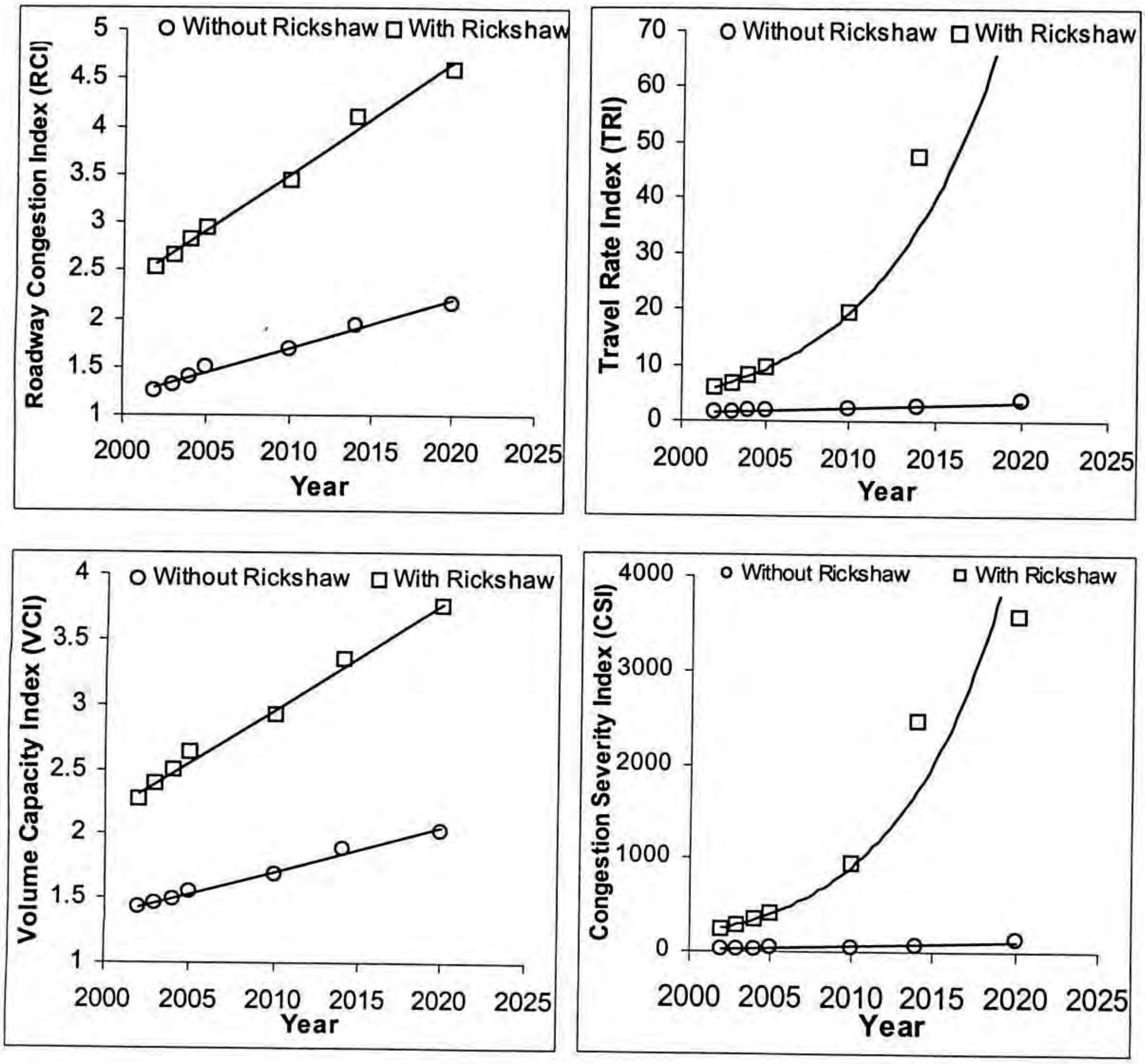


Figure 6. 2: Peak Period Congestion Indices

Table 6. 3: Peak Period Volume-Capacity Ratio and Average Speed in the Conditions of With-rickshaw and Without-rickshaw Composition

Year	% of Total Roadway Length with Average speed < 15 kilometer per hour			% of Total Roadway Length with Volume-Capacity Ratio > 1.25		
	Without Rickshaw	With Rickshaw	% Reduction	Without Rickshaw	With Rickshaw	% Reduction
2002	14	47	70.21	21	62	66.13
2003	15	48	68.75	25	65	61.54
2004	18	53	66.04	32	67	52.24
2005	21	56	62.5	36	73	50.68
2010	30	57	47.37	44	79	44.3
2014	39	61	36.07	54	82	34.15
2020	46	68	32.35	61	85	28.24

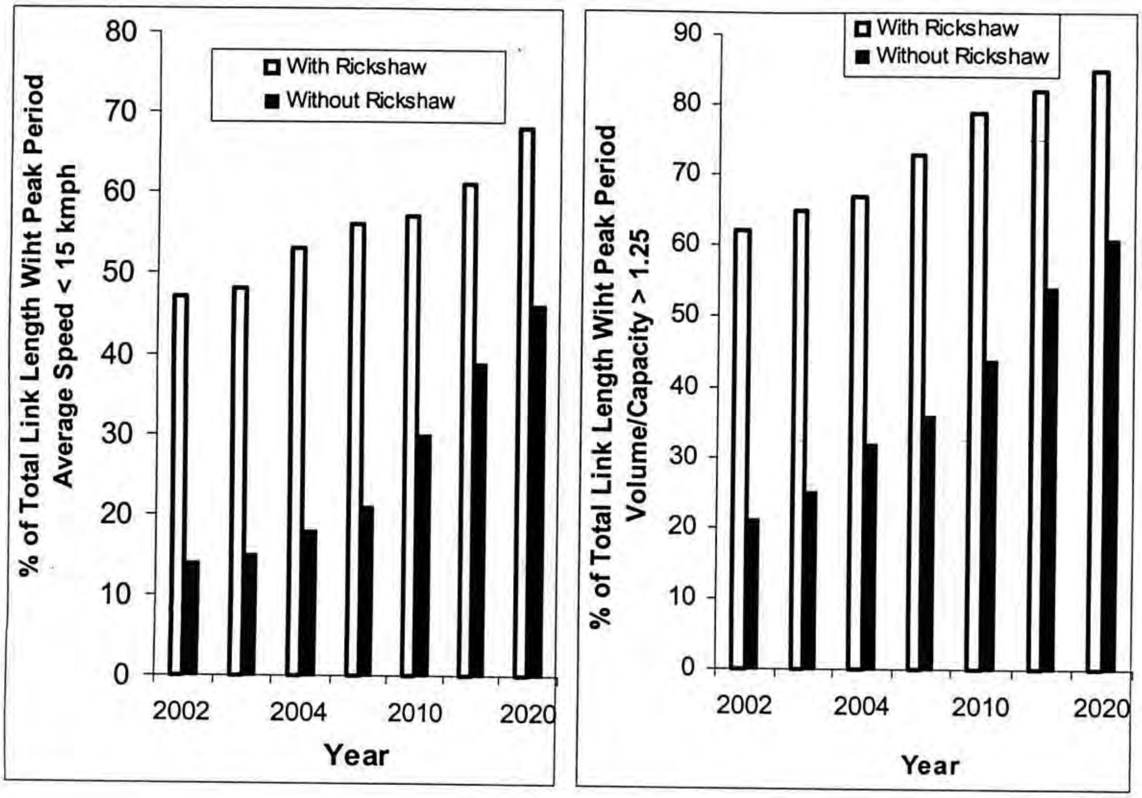


Figure 6. 3: Condition of Road Network in Peak Period in Terms of Average Speed and Volume-Capacity Ratio

Table 6. 4: Peak Period Emission Rates in the Conditions of With-rickshaw and Without-rickshaw Composition

Year	SO_2 ton/hr			NO_2 ton/hr			CO ton/hr		
	Without Rickshaw	With Rickshaw	% Reduction	Without Rickshaw	With Rickshaw	% Reduction	Without Rickshaw	With Rickshaw	% Reduction
2002	0.27	0.26	-3.85	0.83	0.79	-5.06	13.12	13.44	2.38
2003	0.29	0.3	3.33	0.9	0.92	2.17	14.02	15.29	8.31
2004	0.31	0.34	8.82	0.97	1.07	9.35	14.99	17.45	14.1
2005	0.33	0.41	19.51	1.05	1.3	19.23	16.1	20.92	23.04
2010	0.39	0.56	30.36	1.25	1.8	30.56	18.78	28.18	33.36
2014	0.46	0.82	43.9	1.5	2.66	43.61	22.3	40.82	45.37
2020	0.58	1.25	53.6	1.89	4.11	54.01	27.58	61.68	55.29

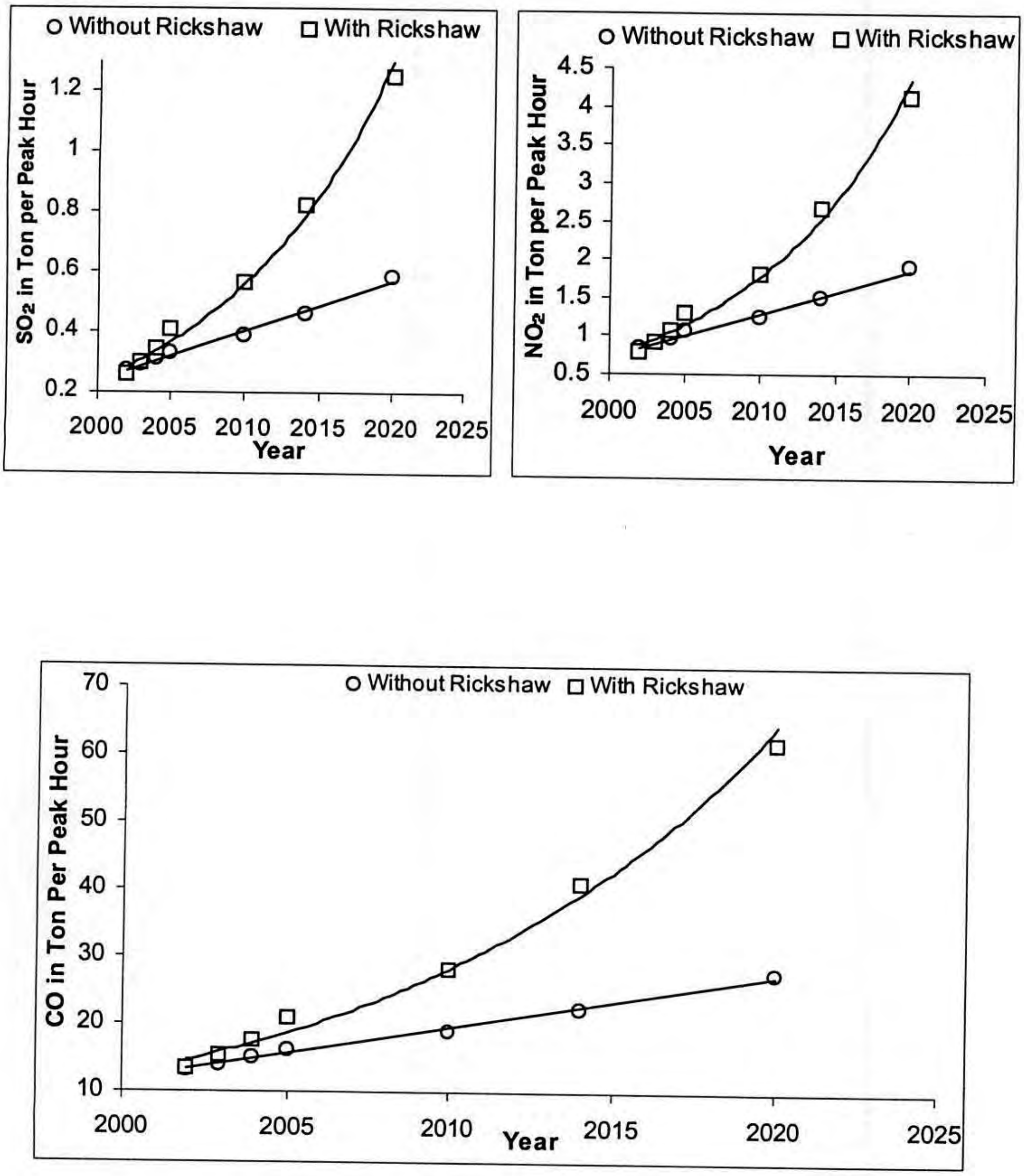


Figure 6. 4: Emission Rate of SO_2, NO_2 and CO in Peak Period

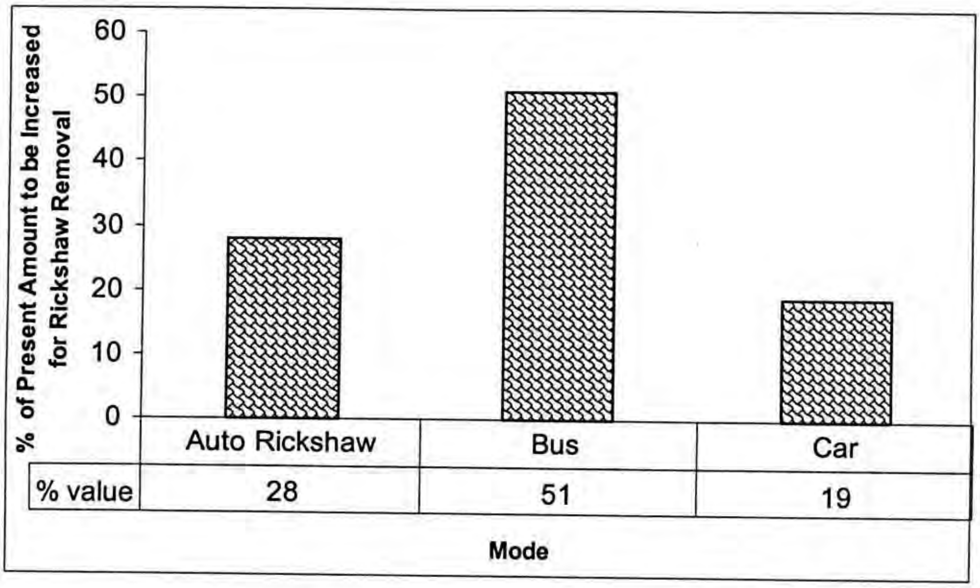


Figure 6. 5: Increase in Peak Period Demand of Other Modes for Rickshaw Removal

6.4 Elimination of Auto-Rickshaws from Main Road links of urban Dhaka

Auto-rickshaw is an important mode of transportation in Dhaka and in popularity it is next to rickshaw. Its main advantage is its small size and resulting easy accessibility to different narrow links of the city. But its inherent disadvantage is the use of two stroke engine, which causes serious air pollution. Considering the air pollution, the government of Bangladesh has already contemplated to ban it. This section describes the quantitative result of banning auto-rickshaws in Dhaka.

6.4.1 Impact on Traffic Congestion

Removal of auto-rickshaw from the road network of Urban Dhaka improves the traffic congestion. Table 6.5 shows that peak period travel demand, 1345,260 vehicle-kilometers and 59,500 vehicle-hours reduce to 1244,650 vehicle-kilometers (7.48% reduction) and 42,600 vehicle-hours (28.39% reduction) for the removal of auto-rickshaw from main roadway links of urban Dhaka. Figure 6.6 shows the changing pattern of peak period travel demand with time for with-auto-rickshaw and without-auto-rickshaw composition. The maximum portions of auto-rickshaw users shift to bus, which has on an average 33 times higher occupancy level than that of auto-rickshaw, for this reason the total peak period vehicle-km travel demand reduces for the removal of auto-rickshaw. The vehicle-hour demand reduces because of removal of congestion and increase in overall peak period travel speed. The figure 6.6 shows that the vehicle-hour demand curve is much steeper for with-auto-rickshaw composition than without-auto-rickshaw composition.

The removal of auto-rickshaw reduces the values of RCI, TRI, VCI and CSI from 2.53, 5.67, 2.26 and 226.5 respectively to 2.43, 5.19, 2.21 and 202 respectively. The comparative values of indices for different years in future are shown in the Table 6.6. The changing patterns of indices are shown in Figure 6.7. Removal of auto-rickshaws makes the changing pattern of TRI and CSI value from exponential to linear type that means traffic congestion will increase linearly rather than exponentially for removal of auto-rickshaw. Again the removal of auto-rickshaw reduces the values of indices by a smaller degree in comparison to that of rickshaw removal. The cause of this less reduction of congestion indices is the higher speed of auto-rickshaw than that of rickshaw. Average speed of auto-rickshaw is greater than that of bus but the inefficiency of this mode and thereby traffic congestion is only due to low occupancy level than bus.

6.4.2 Impact on Air Pollution

The main objection against auto-rickshaw is the air pollution. Auto-rickshaw uses two-stroke engine. The inherent disadvantage of two-stroke engine is the production of un-burnt fuel gas (Buyan, 2001). In this study, due to the lack of proper data to calculate emission rate of un-burnt fuel gas, it was not possible to estimate reduction of un-burnt fuel gas emission due to auto-rickshaw removal. The comparative reductions of SO_x, NO_x and CO are shown in Table 6.7 and Figure 6.8. It is seen that as major contribution of auto-rickshaw in air pollution is by SO_x and CO emission so removal of auto-rickshaw in the present year of 2002 reduces SO_x and CO emission rate by 26.92% and 34.82% of present values respectively, it also reduces the increase rate of emission in future. But the removal of auto-rickshaw increases the emission of NO_x. This is because of the shifting of a major share of auto-rickshaw users to bus and car, which produce higher rate of NO_x emission than auto-rickshaw.

6.4.3 Impact on Demand for Other Modes

Auto-rickshaw is another popular mode of transportation in urban Dhaka like rickshaw. In the present analysis it is found that auto-rickshaw shares 14 percent of total person trips of central urban portion of Dhaka. Its popularity is for its smaller size and easy access to different narrow roadway links. It provides better comfort in the form of better privacy. If auto-rickshaw is totally removed from road network of urban Dhaka, the auto-rickshaw users will shift to other modes like bus, car and rickshaw. From the analysis it is seen that if auto-rickshaw is removed totally, then to compensate the demands for auto-rickshaws the present amount of bus, car and rickshaw will have to be increased by 17%, 7% and 8% respectively.

Table 6. 5: Peak Period Total Travel Demand in the Conditions of With-Auto rickshaw and Without-Auto rickshaw Composition

Year	Population (1000)	Demand in Vehicle-km ('000)			Demand in Vehicle-hr ('000)		
		With Auto-rickshaw	Without Auto-rickshaw	% Reduction	With Auto-rickshaw	Without Auto-rickshaw	% Reduction
2002	6139	1345.26	1244.65	7.48	59.5	42.6	28.39
2005	7005	1614.39	1500.73	7.04	89.94	61.68	31.42
2010	7650	1865.24	1699.88	8.87	120	80.96	32.51
2014	8354	2126.08	2017.88	5.09	170.4	114.2	32.98
2020	9123	2370.22	2289.53	3.4	252.5	172.2	31.8

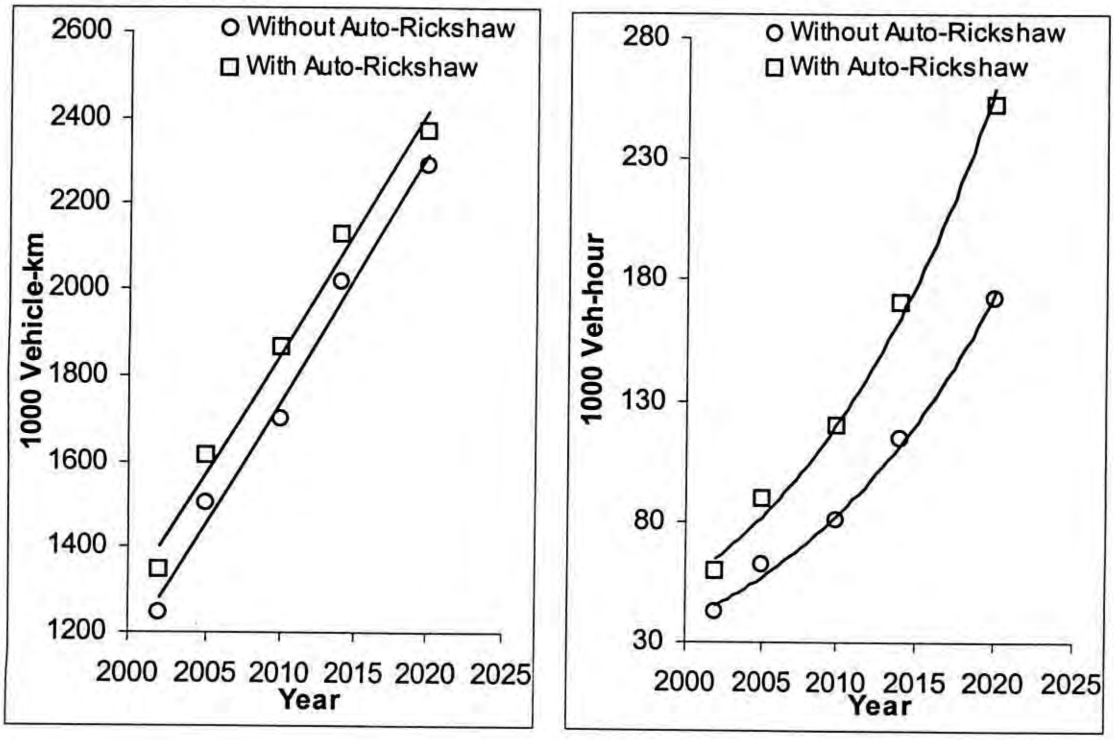


Figure 6. 6: Peak Period Total Vehicular Travel Demand

Table 6. 6: Peak Period Congestion Indices in the Conditions of With-Auto rickshaw and Without-Auto rickshaw Composition

Year	RCI			TRI			VCI			CSI		
	With Auto-Rickshaw	With out Auto-Rickshaw	% Reduction	With Auto-Rickshaw	With out Auto-Rickshaw	% Reduction	With Auto-Rickshaw	With out Auto-Rickshaw	% Reduction	With Auto-Rickshaw shaw	out Auto-Rickshaw	% Reduction
2002	2.53	2.45	3.22	5.67	5.19	8.56	2.26	2.21	2.27	226.5	202	10.47
2005	2.95	2.88	2.38	9.37	9.17	2.13	2.62	2.52	3.79	410	407	0.63
2010	3.43	3.23	5.87	19.5	14.9	23.58	2.92	2.8	4.26	937	708	24.41
2014	4.09	4.07	0.52	47.5	40.5	14.72	3.34	3.41	-2.26	2460.9	2050	16.7
2020	4.6	4.72	-2.58	68.5	60.6	11.62	3.75	3.81	-1.51	3574.5	3070.	14.09

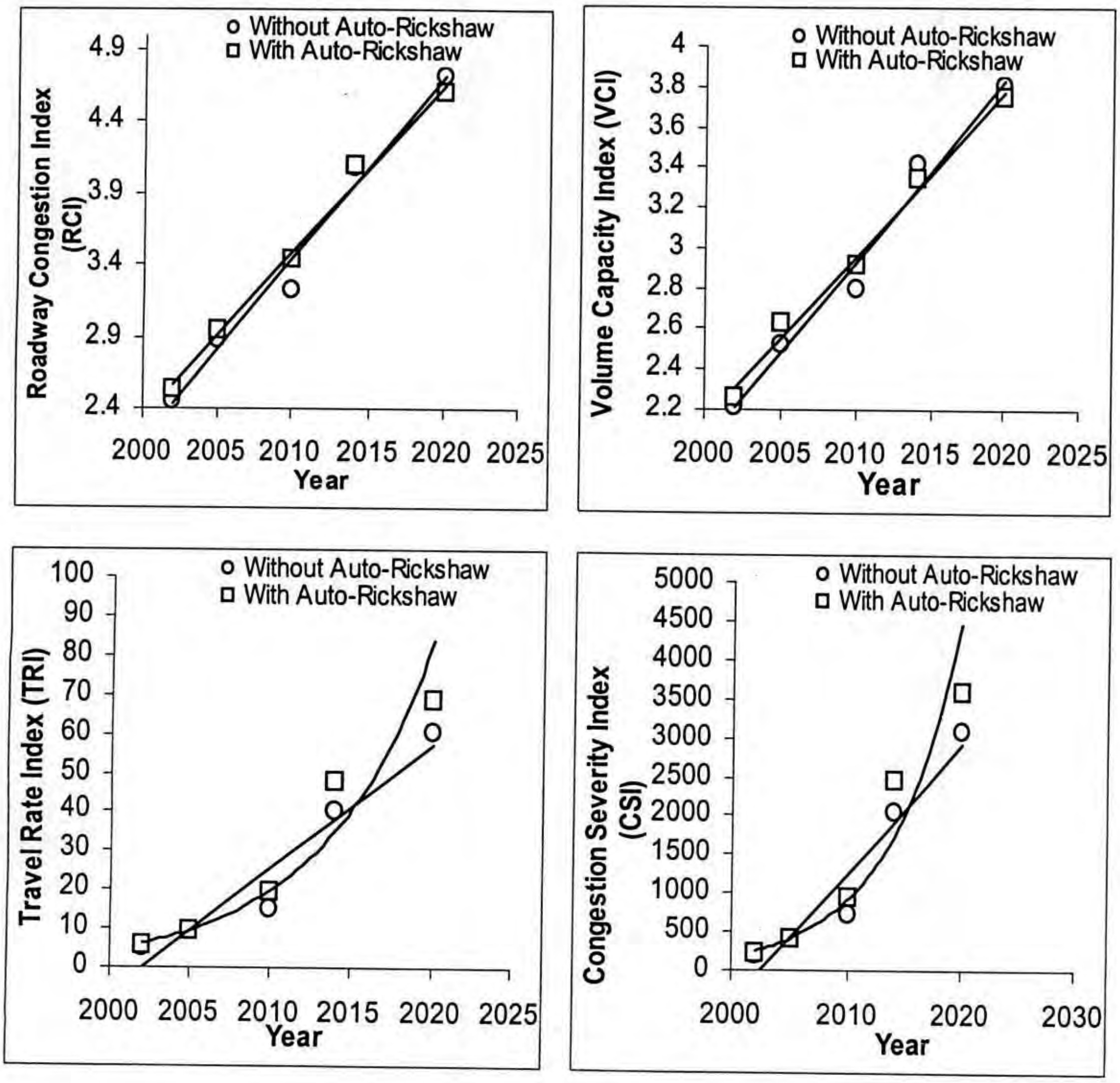
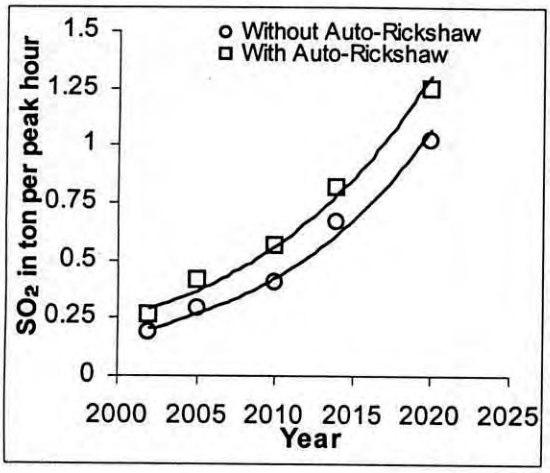
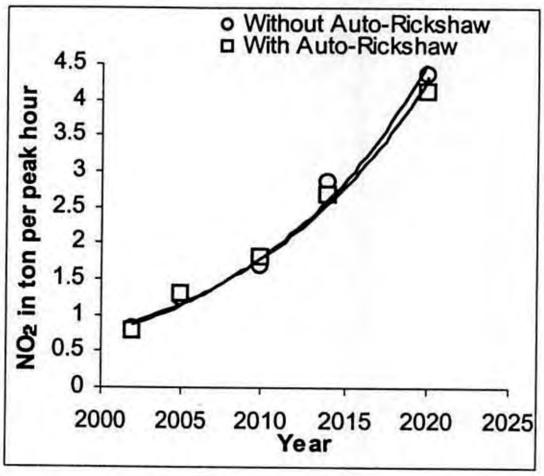


Figure 6. 7: Peak Period Congestion Indices

Table 6. 7: Peak Period Emission Rates in the Conditions of With-Auto rickshaw and Without-Auto rickshaw Composition

Year	SO_2 Ton/hr			NO_2 Ton/hr			CO Ton/hr		
	With Auto-Rickshaw	Without Auto-Rickshaw	% Reduction	With Auto-Rickshaw	Without Auto-Rickshaw	% Reduction	With Auto-Rickshaw	Without Auto-Rickshaw	% Reduction
2002	0.26	0.19	26.92	0.79	0.8	-1.27	13.44	8.76	34.82
2003	0.41	0.29	29.27	1.3	1.24	4.62	20.92	13.21	36.85
2004	0.56	0.4	28.57	1.8	1.69	6.11	28.18	17.74	37.05
2005	0.82	0.67	18.29	2.66	2.85	-7.14	40.82	29.61	27.46





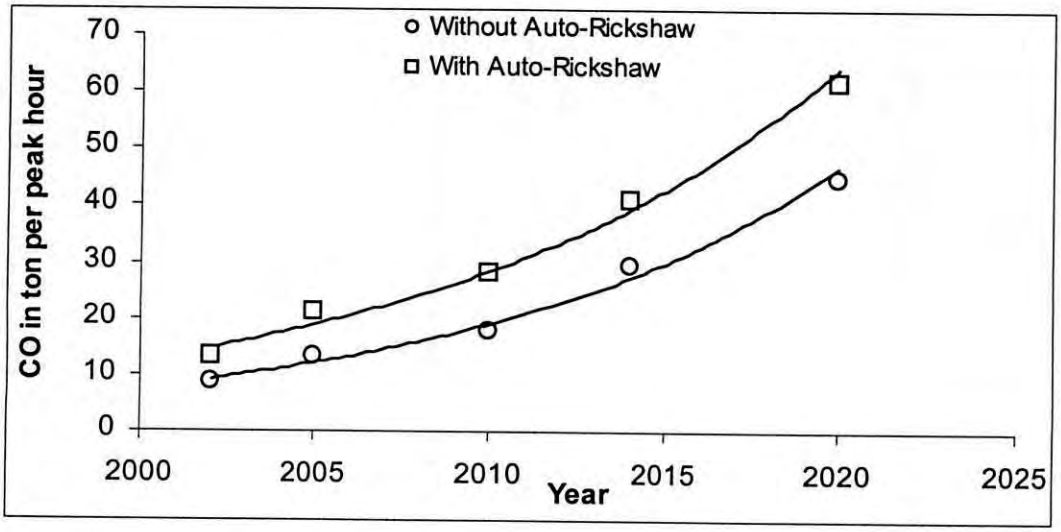


Figure 6. 8: Peak Period Emission Rates in the Conditions of With-rickshaw and Without-rickshaw Composition

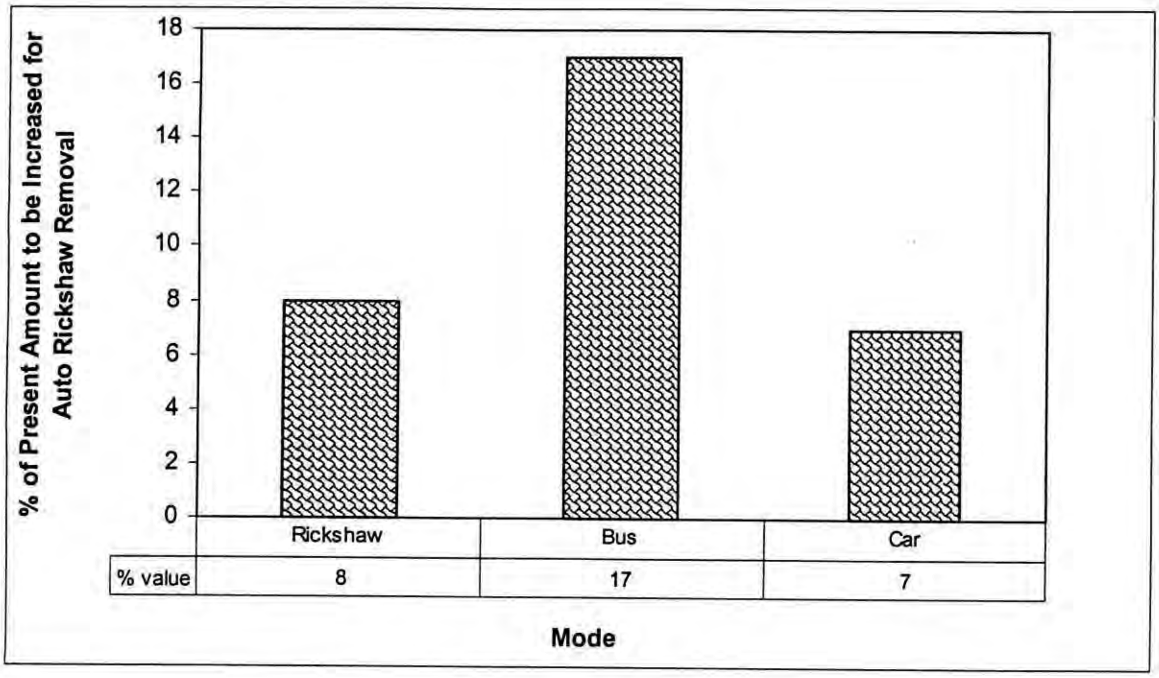


Figure 6. 9: Increase in Peak Period Demand of Other Modes for Rickshaw Removal

6.5 Effects of Road Network Improvement

Sometimes traffic congestion becomes exaggerated due to some physical deficiencies in the road network. Such physical deficiency may be the closer of some strategically important roadway links or reduction of effective roadway width creating bottlenecks to traffic flow. Simulation of present year peak period traffic in road network of Dhaka by DUTM shows that there are a number of missing or closed links and bottle neck points in the network. Rigorous study is deemed necessary to identify all bottleneck points and missing or closed links of the network. Improvement of road network refers to opening of closed roads, construction of missing links or widening of links creating bottlenecks. This section describes the benefits of such improvement of road network of Dhaka city by opening two closed roads and widening two bottleneck points in the network.

6.5.1 Identification of Network Deficiency and Bottlenecks

Analysis of the present situation of road network of Dhaka shows that there are two strategically important roadway links in the network which are closed in some way. One of such roads is 1.52 kilometer long "Pilkhana Road" through BDR Staff Quarter. This road is totally restricted for public use. The other is 0.465 kilometer long link behind

"Nagar Bhaban" from "Fulbaria Bus Stand" to "Banga Bazar Market", which is actually used as bus depot. These two roads are very important for their strategic positions considering travel patterns of zone to zone movement in the network. Closer of such roads compels the peak period traffic to redistribute in the network that creates congestion in other links. Again analyzing the peak period travel conditions, it is found that tremendous bottle necks are created in two places, one is at "Rampura DIT Road" near "Mailbag Bazar Intersection" and the other is at the junction of "Tongi Diversion Road" with "Dhaka-Mymensingh Road" near the office of "Survey of Bangladesh". It is seen that the peak hour travel time is around 33 times of free flow travel time at first place and around 30 times at second place, which are also supported by practical experience. Though the road links at above mentioned bottleneck points are actually very wide (6 lanes total in both directions) but in some portions, the roadway widths are occupied by roadside non-motor activities, which effectively reduce the overall capacity of links. The DUTM considers only the roadway widths effective for traffic movement, so it is easy to utilize the information of actual roadway width used by road traffic. An attempt has been made to evaluate the situation, which will happen if the above mentioned two closed roads are made open for public use and effective roadway widths are increased at the two major bottlenecks. The modified parts of the network are:

- Opening of 1.52 kilometer long "Pilkhana Road" through BDR Staff Quarter.
- Opening of 0.465 kilometer long link behind "Nagar Bhaban" from "Fulbaria Bus Stand" to "Banga Bazar Market"
- Increase to total 6 effective lanes from 4 actually effective lanes of "Mailbag Bazar Intersection" to "New Circular Road" and "Tongi Diversion Road"

6.5.2 Impact on Traffic Congestion and Air Pollution

Opening of such closed roads for public use changes the land-use pattern. Ignoring such land-use change, the changes in peak period total travel demand in vehicle-km and vehicle-hour are shown in Table 6.8. It shows that peak period total vehicle-km and vehicle-hr travel demand reduce from 59,500 vehicle-hours to 56,160 vehicle-hours (3.07% reduction) and 1345,260 vehicle-km to 1303,960 vehicle-km (5.61% reduction) respectively for such improvement of road network. The changing patterns of peak period demands in future are shown in Figure 6.10. It shows that such improvement of road network reduces sudden upslope of vehicle-hour demand curve; it means that such improvements not only reduces present year demand but also reduces the increase rate of peak period traffic congestion in future, because sudden upslope of demand curve is an indication of sudden increase in traffic congestion. It is seen that widening of effective roadway widths of the two proposed locations reduces the peak period travel time to free flow travel time ratio from 30 to4.6 and 33 to 5.9 respectively.

The reduction of congestion situation due to such improvements can be better perceived by observing the changes in congestion indices as shown in Table 6.9. The changing patterns of indices are shown in Figure 6.11. RCI, TRI, VCI and CSI reduce from 2.53, 5.67, 2.26 and 226.5 respectively to 2.37, 4.97, 2.17 and 192.7 respectively. The reduction of indices is greater than those for auto-rickshaw removal for the present year of 2002. The changing pattern of CSI value shows that such network improvement reduces average delay for some period of time only and the previous situation will retrieve after some period of time with the increase in population This is the inherent disadvantages of 'structural improvement' type of measure.

6.5.3 Impact on Air Pollution

With the reduction of peak period total demand and traffic congestion, the emission rates of SO_x, NO_x and CO also reduce for network improvement. The comparative values of emission rate are shown in Table 6.10. For the present year of 2002, SO_x, NO_x and CO emission rates reduce by 7.69%, 6.33% and 5.88% respectively. The changing pattern of emission rates are shown in Figure 6.12 and it is seen that such improvement in network prevents the sudden increase in emission rates in future. As the emission rates are functions of peak period vehicle-hour demand, the emission rates increase at the same rate as that of vehicle-hour demand rate increases and such improvements in road network reduce traffic congestion and prevent the sudden increase in peak period total vehicle-hour demand and emission rates in future.

Table 6. 8: Changes of Travel Demand for Network Improvement

Year	Population 1000	Total Demand in '000 Vehicle-hour			Total Demand in '000 Vehicle-km		
		Existing Condition	After Improvement	% Reduction	Existing Condition	After Improvement	% Reduction
2002	6139	59.50	56.16	3.07	1345.26	1303.96	5.61
2003	6415	67.23	62.92	2.54	1430.10	1393.77	6.42
2004	6704	76.17	70.79	2.11	1515.07	1483.1	7.06
2005	7005	89.94	80.11	2.19	1614.39	1578.98	10.93

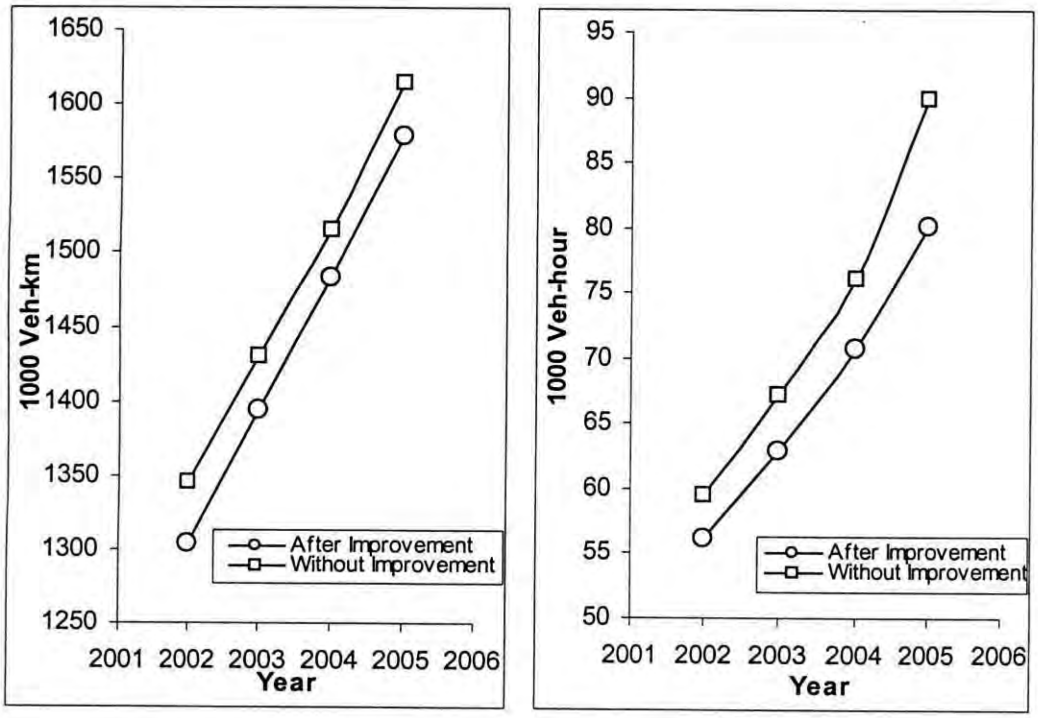


Figure 6. 10: Peak Period Total Vehicular Travel Demand

Table 6. 9: Changes of Congestion Indices for Network Improvement

Year	RCI			VCI			TRI			CSI		
	Existing Condition	After Improvement	% Reduction	Existing Condition	After Improvement	% Reduction	Existing Condition	After Improvement	% Reduction	Existing Condition	After Improvement	% Reduction
2002	2.53	2.37	6.17	2.26	2.17	12.37	5.67	4.97	3.98	226.5	192.7	14.9
2003	2.64	2.50	5.49	2.39	2.26	14.76	6.61	5.63	5.42	273.1	226.1	17.22
2004	2.82	2.61	7.43	2.49	2.34	14.79	7.87	6.71	6.15	340.3	280.8	17.49
2005	2.95	2.81	4.76	2.62	2.47	13.53	9.37	8.10	5.86	410.2	402.1	1.97

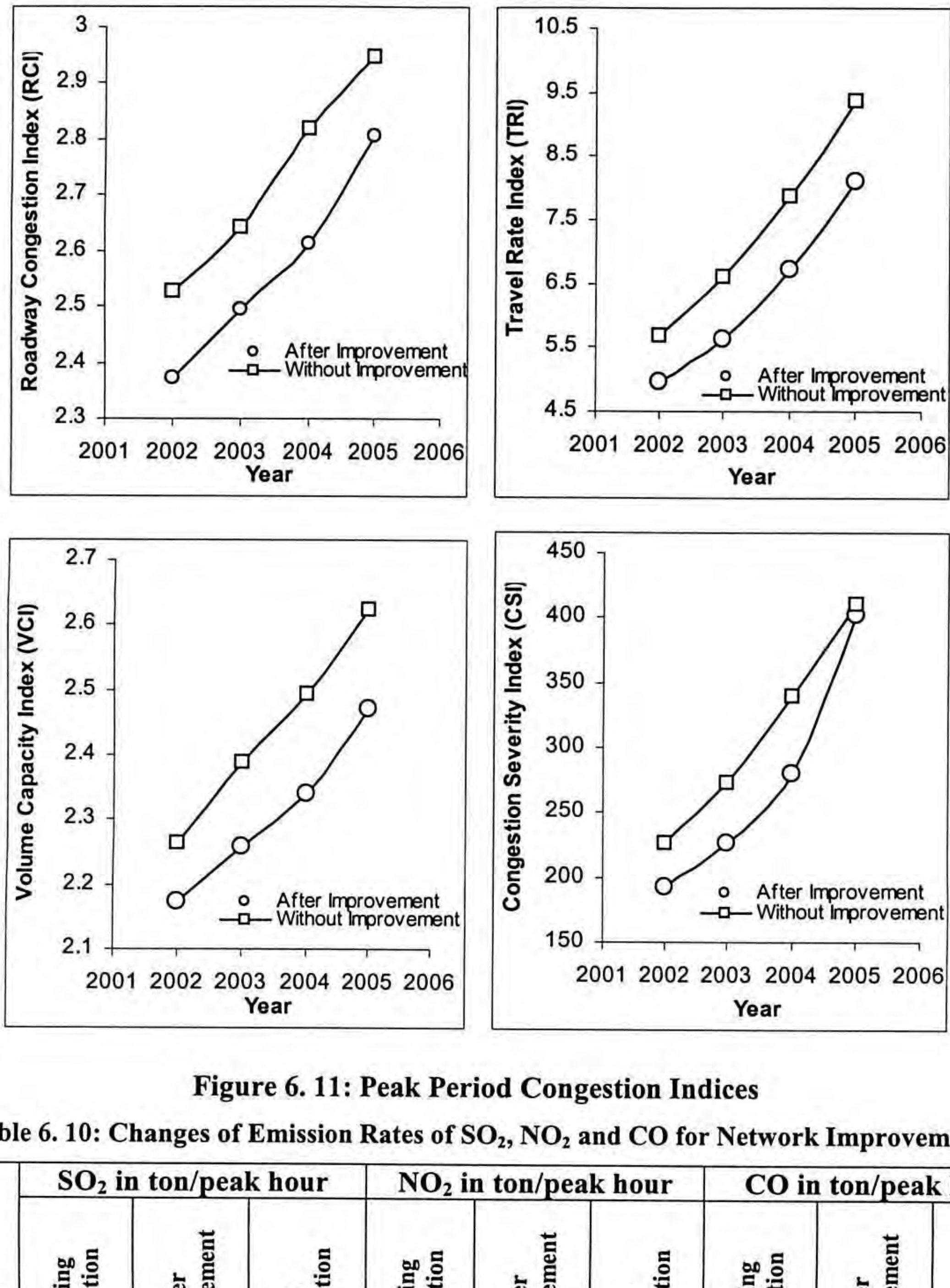


Figure 6. 11: Peak Period Congestion Indices

Table 6. 10: Changes of Emission Rates of SO_2, NO_2 and CO for Network Improvement

Year	SO_2 in ton/peak hour			NO_2 in ton/peak hour			CO in ton/peak hour		
	Existing Condition	After Improvement	% Reduction	Existing Condition	After Improvement	% Reduction	Existing Condition	After Improvement	% Reduction
2002	0.26	0.24	7.69	0.79	0.74	6.33	13.44	12.65	5.88
2003	0.3	0.28	6.67	0.92	0.85	7.61	15.29	14.27	6.67
2004	0.34	0.32	5.88	1.07	0.98	8.41	17.45	16.17	7.34
2005	0.41	0.36	12.2	1.3	1.14	12.31	20.92	18.44	11.85

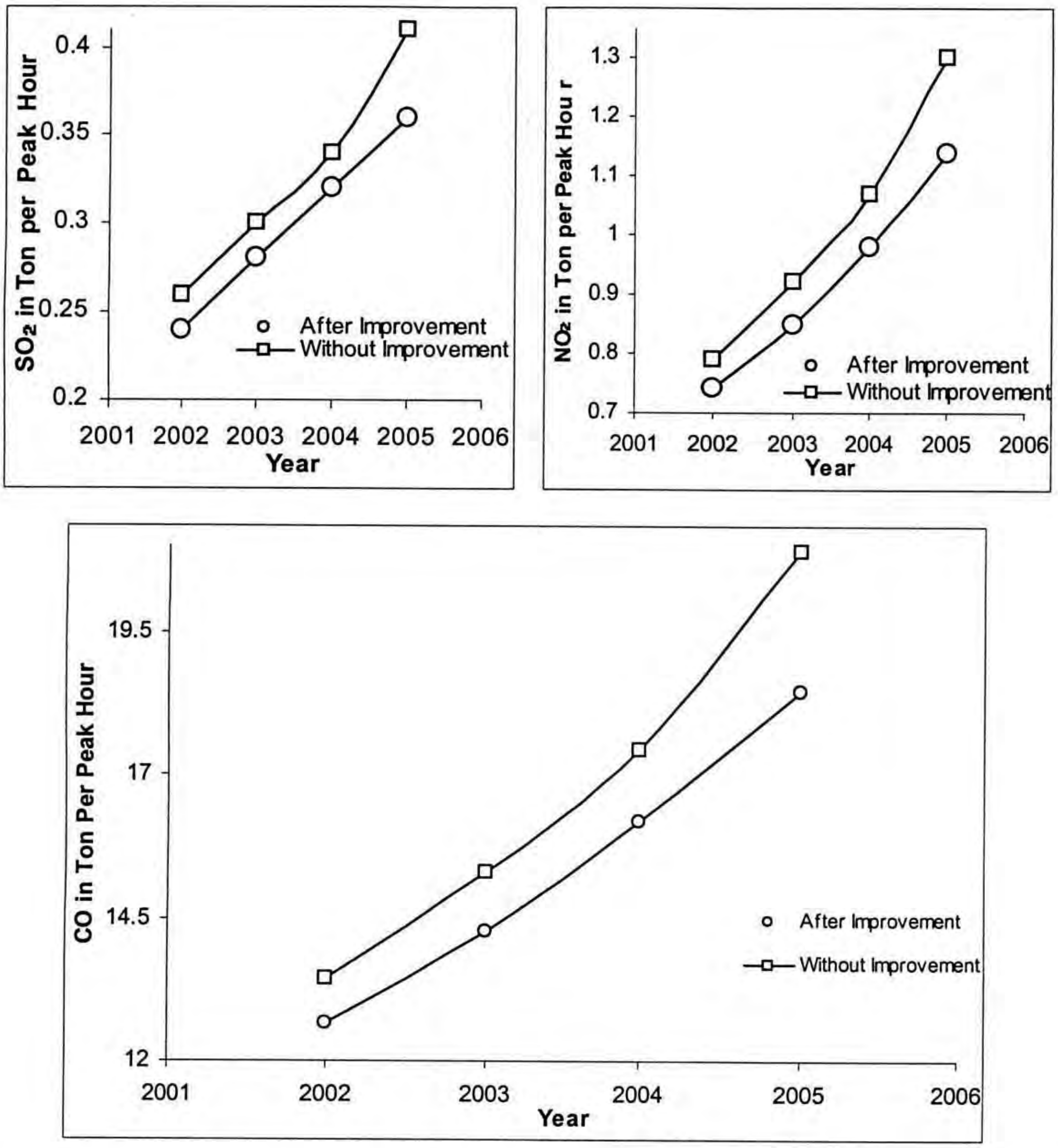


Figure 6. 12: Changes of Peak Period Emission Rates for Network Improvements

6.6 Effects of Improvement of Bus Services

The term 'mass transit' indicates the public transportation modes, which have higher occupancy level compared to other private modes of transportation. For urban areas of Dhaka, all types of bus services are considered as 'mass transit'. From a study (Jaigirdar, 1998) on urban Dhaka, it is seen that average occupancy of bus (Double-decker bus, Normal bus, Mini-bus, Para transits such as maxi, rider etc all), rickshaw, auto-rickshaw and car are 40, 0.6, 1.2, and 1.3 respectively, where as the PCU of bus, rickshaw, auto-rickshaw and car are 3, 0.5, 0.75, and 1.0 respectively. It is seen that although rickshaw occupies around one sixth of roadway space of that of a bus, rickshaw carries around one sixty sixth passenger of that of a bus. Similarly auto-rickshaw and car are also less efficient in passenger carrying capacity than bus. So increase in modal share of bus in urban area will definitely reduce number of vehicle on road. This section describes the benefit of improvement of bus service in Dhaka and scope of such improvements.

6.6.1 Impact on Traffic Congestion

Table 6.11 shows the peak period total vehicular travel demands for different modal shares of bus and Figure 6.13 shows the changing pattern of peak period vehicular travel demand with changes in modal share of bus in Dhaka. It is seen that peak period vehicular travel demand reduces exponentially with the increase in modal share of bus.

The picture of peak period congestion reduction becomes clear by comparing the changing rate of indices with increasing modal share of bus, as shown in Table 6.12 and Figure 6.14. The equations of peak period congestion indices as functions of modal share of bus are:

$$RCI = 3.926 * \exp(-0.0174 * (\%\ of\ modal\ share\ of\ bus)) \quad (6.1)$$

$$VCI = 2.85 * \exp(-0.0102 * ((\%\ of\ modal\ share\ of\ bus)) \quad (6.2)$$

$$TRI = 11.05 * \exp(-0.0265 * (\%\ of\ modal\ share\ of\ bus)) \quad (6.3)$$

$$CSI = 741.73 * \exp(-0.0436 * (\%\ of\ modal\ share\ of\ bus)) \quad (6.4)$$

All of these indices reduce exponentially with the increase in percentage of modal share of bus. The improvement of congestion situation with increase in modal share of bus is due to the overall reduction of peak period vehicular travel demand and at the same time reduction of number of other modes of travel on road.

6.6.2 Impact on Air Pollution

It is seen that for urban areas of Dhaka, peak period emission (SO_x, NO_x and CO_x) rates are functions of both the number and staying period of vehicles on road. Increase in modal share of bus reduces the total number as well as staying period (due to increase of average speed of peak period traffic flow) of vehicles on road network. So it is clear that the improvement of bus service will definitely reduce peak hour pollution rates. The values of peak period emission (SO_x, NO_x and CO) rates for different modal share of bus is shown in Table 6.13 and the changing patterns of emission rates are shown in Figure 6.15. The relationships between emission rates and modal share of bus are:

$$SO_2 \text{ Emission per Peak Hour} = 0.3001 * \exp(-0.0134 * (\% \text{ of modal share of bus})) \quad (6.5)$$

$$NO_2 \text{ Emission per Peak Hour} = 0.6303 * \exp(-0.0033 * (\% \text{ of modal share of bus})) \quad (6.6)$$

$$CO \text{ Emission per Peak Hour} = 35.537 * \exp(-0.0363 * (\% \text{ of modal share of bus})) \quad (6.7)$$

It is seen that peak period emission rates reduce exponentially with the increase of modal share of bus. The reason of this exponential reduction of emission rates is the exponential reduction of traffic congestion in terms of reduction of total vehicular demand (in term of vehicle-hour) with the increase of modal share of bus.

6.6.3 Scope of Improvement of Bus Services in Urban Dhaka

The discussions of above two sections clarify that one of the major ways to reduce traffic congestion and consequent air pollution is the increase of modal share of urban bus service. It is important to determine the way or scope of the improvement of the modal share of bus. As described in chapter three and four, three types of modal attributes influence urban people in modal choice. These attributes are speed, cost and comfort. Attempts have been made in this study to determine the scope of increase in modal share of bus by changing speed, cost and comfort. The graphical representation of influence of these attributes on modal share of bus is shown in Figure 6.16. If the modal share of bus is designated as 'B', the changes of speed, cost and comfort as percentage of base year value (base year values of speed, cost and comfort are 9 kmph, 2 taka per hour and 0.1 respectively) are designated as 'x', 'y', 'z' respectively, then the relationship between 'B' and the attributes are as follows:

$$B = 0.00007x^3 - 0.0132x^2 + 0.9743x + 38.303 \quad (6.8)$$

$$B = 38.23\, e^{-0.008y} \quad (6.9)$$

$$B = 37.044\, e^{0.0015z} \quad (6.10)$$

These equations express the modal share of bus in terms of speed (x), cost (y) and comfort (z) for urban areas of Dhaka. The elasticity of demand is the rate of change of demand changing rate with respect to particular attribute. Now if elasticity of modal share of bus is calculated individually and elasticity for speed, cost and time are designated as E_x, E_y and E_z, then,

$$E_X = \frac{\frac{\partial B}{B}}{\frac{\partial x}{x}} = \frac{\partial B}{\partial x} * \frac{x}{B}$$

or $E_X = (0.00021\,x^2 - 0.0264\,x + 0.9743) * x / B$

or $E_X = (0.00021\,x^3 - 0.0264\,x^2 + 0.9743x) / B$ (6.11)

$$E_y = \frac{\frac{\partial B}{B}}{\frac{\partial y}{y}} = \frac{\partial B}{\partial y} * \frac{y}{B}$$

or $E_y = -0.008\,y$ (6.12)

$$E_z = \frac{\frac{\partial B}{B}}{\frac{\partial z}{z}} = \frac{\partial B}{\partial z} * \frac{z}{B}$$

or $E_z = +0.0015\,z$ (6.13)

The attributes are expressed as percentages of base year value, in the above expressions. Here it is found that the elasticity of any attribute is a function of that attribute. To determine the sensitivities of individual attributes, if a 10% increase of all attributes are considered, then the values of corresponding elasticity are: $E_X = 0.156$; $E_y = -0.08$; $E_z = 0.015$. Here it is seen that speed is the most sensitive attribute, the people of urban areas of Dhaka are more concern about travel time than travel cost or comfort. So to increase the modal share of bus, improved bus service should be ensured that provides higher speed and thereby less travel time.

Table 6. 11: Relationship between Modal Share of Bus and Peak Period Vehicular Travel Demand

Modal Share of Bus	Peak Period Vehicular Travel Demand	
	'000 vehicle-hour	'000 vehicle-km
34	45.54	1161.7
57.39	29.87	770.73
63.15	25.26	639.09
66.59	22.86	567.71
68.8	21.54	526.07

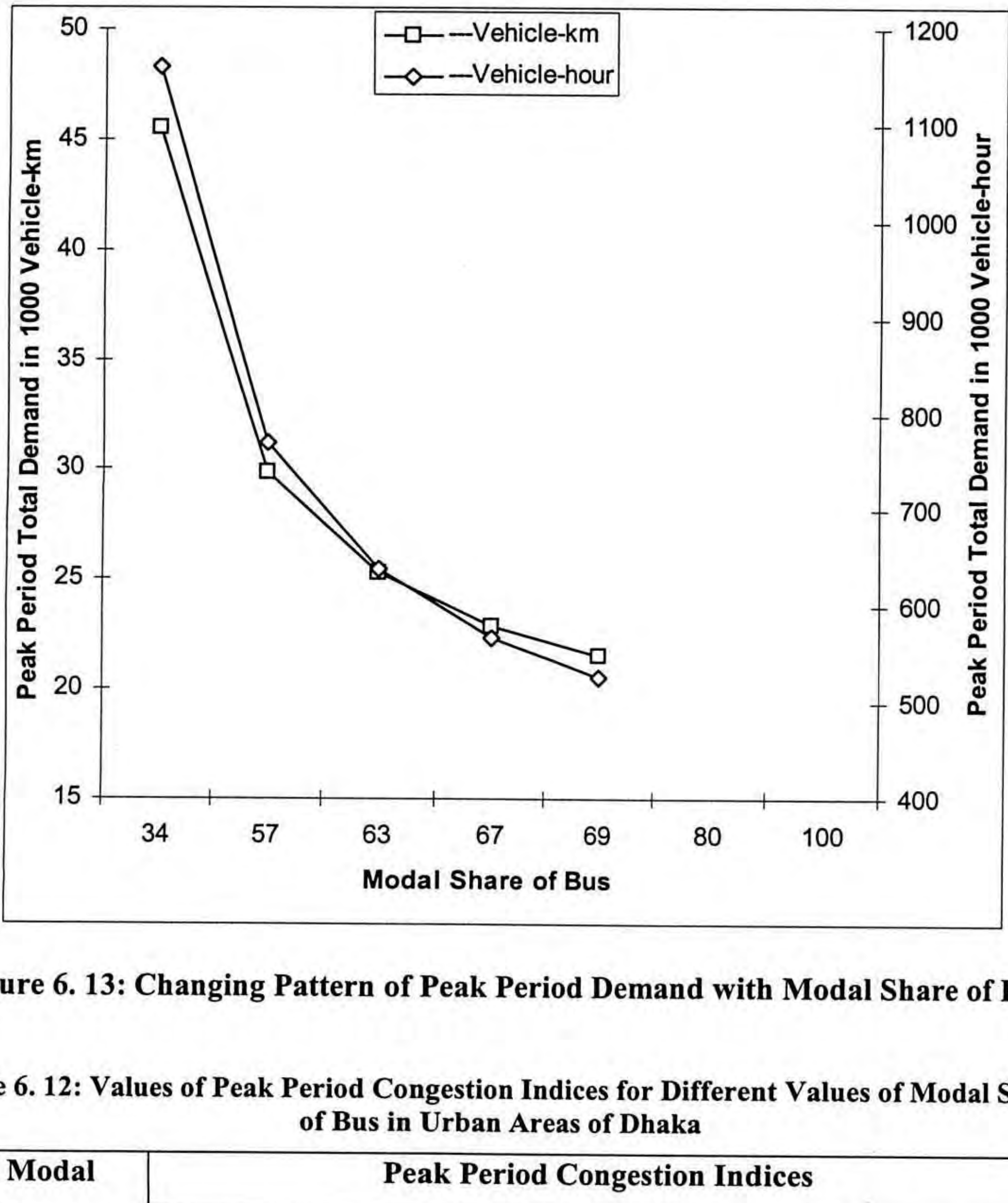


Figure 6. 13: Changing Pattern of Peak Period Demand with Modal Share of Bus

Table 6. 12: Values of Peak Period Congestion Indices for Different Values of Modal Share of Bus in Urban Areas of Dhaka

Modal Share of Bus	Peak Period Congestion Indices			
	RCI	TRI	VCI	CSI
34	2.13	4.43	2	160.7
57	1.52	2.51	1.62	69.07
63	1.33	2.12	1.49	50.52
66	1.22	1.86	1.44	38.79
68	1.14	1.75	1.39	33.82

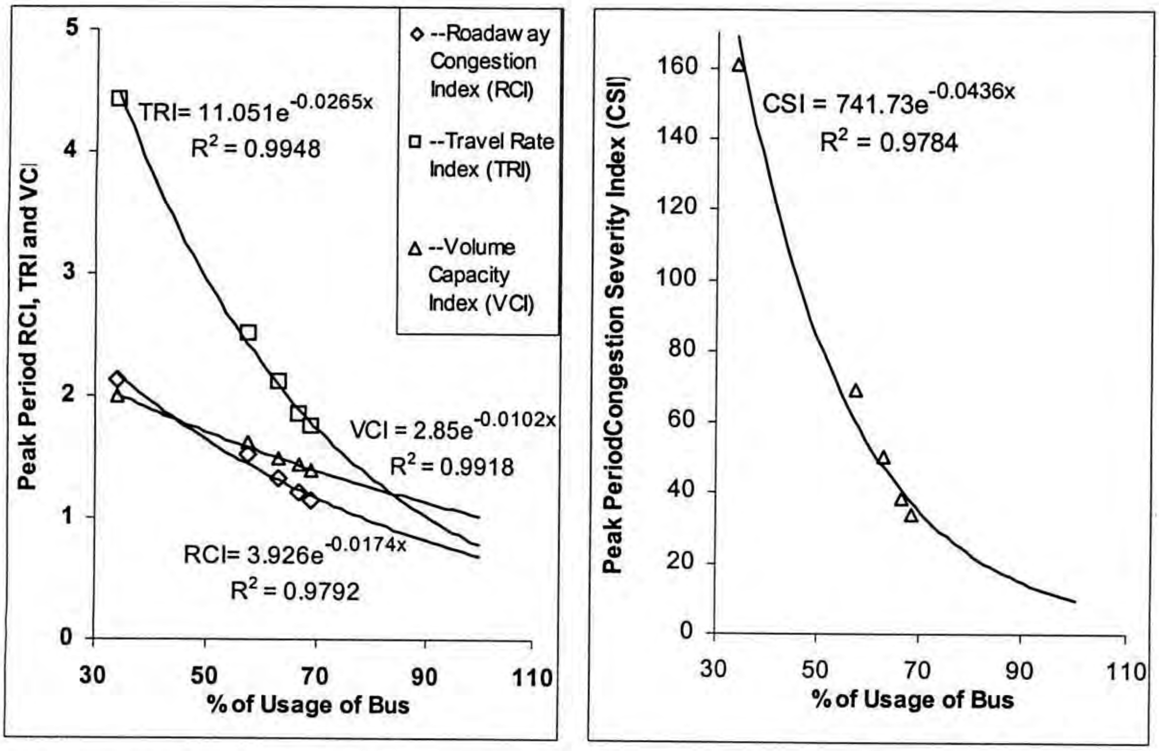


Figure 6. 14: Peak Period Congestion Indices for Different Modal Share of Bus

Table 6. 13: Peak Period Emission (SO_2, NO_2 and CO) Rates for Different Modal Shares of Bus in Urban Areas of Dhaka

Modal Share of Bus	Peak Period Emission Rate in Ton/Hour		
	SO_2	NO_2	CO
34	0.19	0.56	9.96
57.39	0.14	0.53	4.97
63.15	0.13	0.51	3.7
66.59	0.12	0.5	3.05
68.8	0.12	0.5	2.72
34	0.19	0.56	9.96

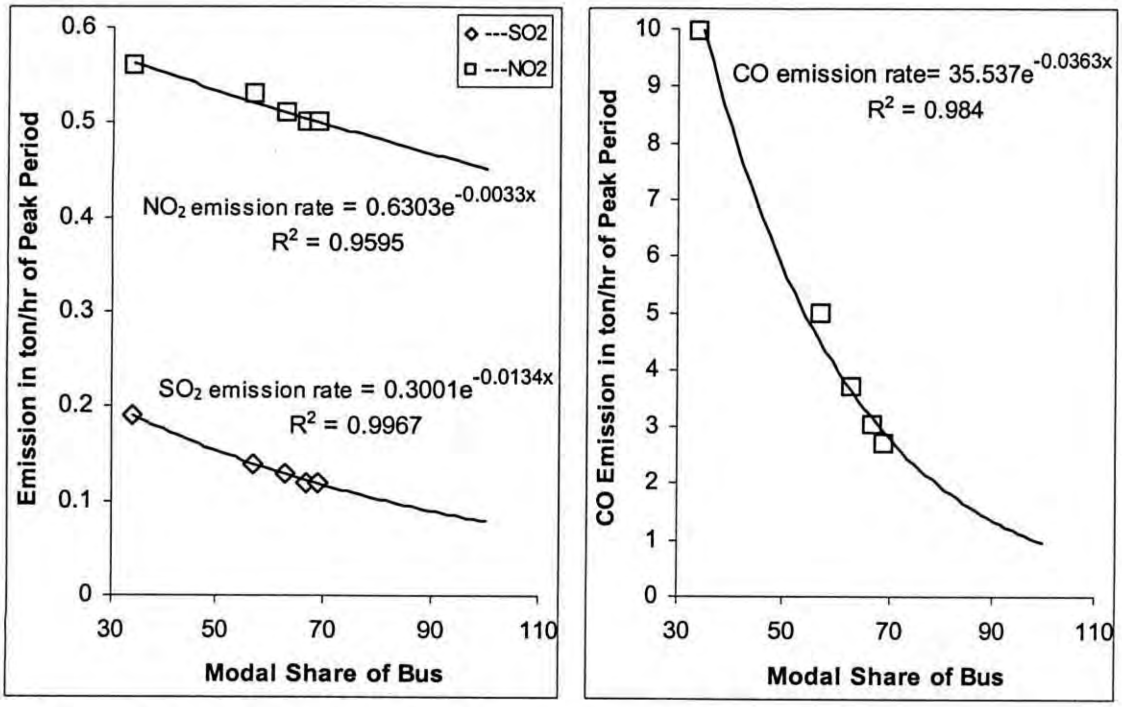


Figure 6. 15: Peak Period Emission rates for different Modal Shares of Bus

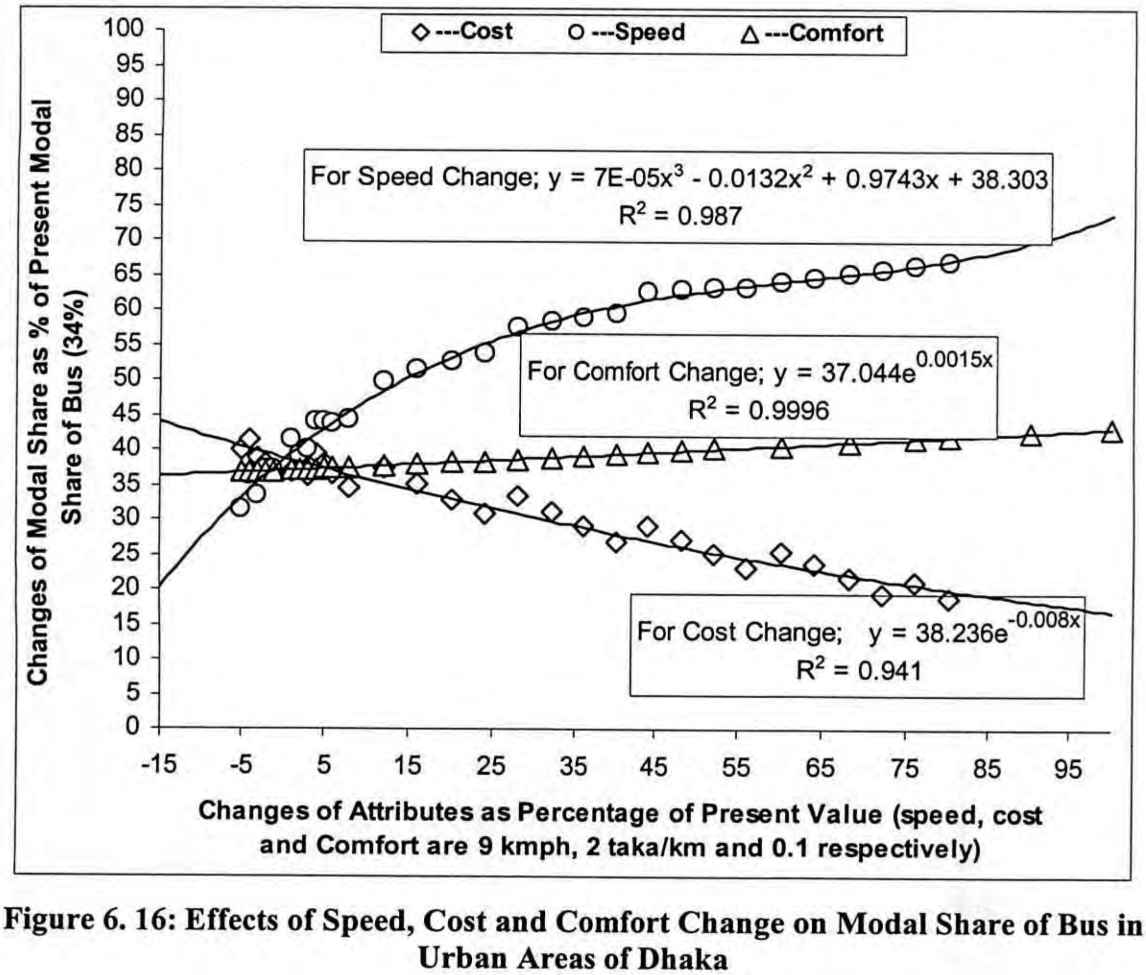


Figure 6. 16: Effects of Speed, Cost and Comfort Change on Modal Share of Bus in Urban Areas of Dhaka

6.7 Incorporation of Intra-city Rail Service

Although a part of national railway line lies within Dhaka, there is no intra-city rail service in Dhaka. Incorporation of a new mode in Dhaka like intra-city rail service is likely to reduce modal share of road traffic modes and alleviate traffic congestion thereby. This section describes the quantitative benefit of incorporation of an intra-city rail service within Dhaka along the existing rail line.

6.7.1 Selection of Rail Route and Service

An intra-city rail service has been considered from Uttara to Kamalapur. It connects 15 analysis zones. The Connecting zones are Uttara sub-region (TAZ no 01), four zones of Gulshan sub-region (TAZ no. 17, 18, 19, 20), five zones of Central Metropolitan sub-region (TAZ no 33, 34, 35, 36, 54), two zones of Eastern Metropolitan sub-region (TAZ no. 28, 55) and three zones of Dhanmondi-Farmgate sub-region (TAZ no.37, 38,39). The connecting route is a part of existing rail line as shown in the map in Appendix. For analysis it is considered that the intra-city rail service will provide speed, same as that of car (20 kilometer per hour), comfort is considered as half of that of car (0.5) and cost is considered as same as that of bus (2 taka per kilometer). Analyses have been done without considering long term land-use changes for incorporation of intra-city rail service in the city transportation system.

6.7.2 Impact on Traffic Congestion

Total peak period vehicular road travel demand of the whole road network reduces from 1345,260 vehicle-km to 1330,560 vehicle-km and 59,500 vehicle-hours to 58,480 vehicle-hours for incorporation of intra-city rail system in urban Dhaka. This is citywide short term network effect. The rail line considered here is a single line that connects Uttara to Kamalapur, so effect of this small part on the overall city network may not be pronounced. If a particular zone is considered, such as Uttara (TAZ no. 01), total peak period generated person-trip is 8,910. If the proposed rail service starts then total 796 person-trips divert to rail. The corresponding percentage diversion of road traffic to railway is 9%. This is the overall diversion of peak period traffic from Uttara but actually the proposed rail lines gives the connection of Uttara with other 14 zones only and if only the rail connected zones are considered, then out of total 1,471 peak period person-trips (from Uttara to other 14 rail connected zones only) from Uttara, 796 are diverted to rail, which is 54% diversion.

Similarly if two individual roads, New Airport road and Dhaka-Mymensingh road (which are parallel to the proposed rail line) are considered rather than the whole network, it is seen that incorporation of such rail mode reduces peak hour traffic volume from 6294 PCU to 6063 PCU, that means 4% reduction of peak hour traffic volume on New Airport road and 7809 PCU to 6870 PCU, that means 12% reduction of peak hour traffic volume on Dhaka-Mymensingh road. Average speed of traffic flow varies with the fourth power of volume-capacity ratio; [($t_1/t_0 = 1+0.15*(\text{Volume/Capacity})^4$; t_1 is the actual travel time and t_0 is the free flow travel time], so 4% reduction of peak period traffic volume increases peak period average speed of Airport road by 6% and 12% reduction of peak period traffic volume increases peak period average speed of Dhaka-Mymensingh road by 40%.

The diversion of traffic from roadway to railway depends on a number of factors. As railway is a rigid type of traveling mode, the major factors influencing rail use is the accessibility to railway. So, only incorporation of rail mode will have a little value unless appropriate access modes are available. In this study the average speed of access mode is taken as 9 kilometer per hour and it is seen that increasing of access mode speed from 9 to 15 kilometer per hour increases the diversion of traffic of Uttara (TAZ no. 1) from roadway to railway from 796 person-trips to 872 person-trips, thus percentage of diversion increases from 54% to 59%.

Incorporation of a new mode, like railway creates diverted traffic (changing route), transferred traffic (changing mode), shifted traffic (changing origin-destination) and induced traffic (generated after the changes in the system take place). In this analysis only diverted and transferred traffic are taken into account by the DUTM, so further rigorous study is necessary in this regard.

6.7.3 Impact on Air Pollution

Effects of incorporation of the rail line in network on peak period air pollution are shown in Table 6.14. These are the overall network effects. Table 6.14 shows that although the reduction of air pollution is lower at present, the effects become more positive in future. This is due to the long term effect of rail. Actually the short term effect of such a single rail line may be small, again in this analysis, changes in land-use pattern due to starting of rail mode are not considered, so the result of present analyses may underestimate the actual effect of incorporation of rail in city transportation network.

6.7.4 Impact on Demand for Other Modes

In this analyses a single rail line is considered, which connect Uttara to Kamalapur. The TAZs in between Uttara and Kamalapur, like Gulshan and Central Metropolitan areas are connected to this rail line by access links. The average speed of rail is considered as 20 kilometer per hour and average speed of access mode is considered as that of bus, 9 kilometer per hour. The comparative amounts of peak period travel demand satisfied by individual modes are shown in Table 6.15 and 6.16. If overall citywide network is considered, then for the year of 2002 the reductions of total peak period travel demand in vehicle-hour of Rickshaw, Auto-rickshaw, Car and Bus as percentage of present value are 1.82%, 1.74%, 2.24% and 1.37% respectively and in vehicle-kilometer 0.98%, 1.06%, 2.12% and 1.09 respectively. But for a single TAZ, Uttara (TAZ no. 01), which is directly connected to the rail line, it is seen that 9% of total peak hour trips (in PCU) is shifted to rail and the reduction of modal share of Rickshaw, Auto-rickshaw, Car and Bus as percentage of present value are 10.35%, 9.27%, 12.84% and 5.1% respectively.

Table 6. 14: Effect of Incorporation of Intra-city Rail on Peak Period Total Air Pollution in the Network

Year	Population In 1000	SO_2 in Ton/Hour		NO_2 in Ton/Hour		CO in Ton/Hour	
		With Rail	Without Rail	With Rail	Without Rail	With Rail	Without Rail
2002	6139	0.25	0.26	0.78	0.79	13.24	13.44
2005	7005	0.4	0.41	1.27	1.3	20.4	20.92
2010	7650	0.54	0.56	1.74	1.8	27.37	28.18
2014	8354	0.79	0.82	2.58	2.66	39.58	40.82
2020	9123	1.19	1.25	3.93	4.11	59	61.68

Table 6. 15: Share of Total Peak Period Vehicle-hour Demand by Different Modes in the Network

Mode	2002		2005		2010		2014		2020	
	With Rail	Without Rail	With Rail	Without Rail	With Rail	Without Rail	With Rail	Without Rail	With Rail	Without Rail
Rickshaw	304334	309965	411272	422349.1	517987	536248.6	679181	705202.3	926167.7	943365.2
Auto-Rickshaw	25818	26276.3	37721.5	38614.3	49575.3	51069.7	69555.5	71917.1	102636.9	107444
Bus	2387.3	2442	4088.6	4213.9	5759.2	5963.6	8662.8	8977.9	13533.2	14175.6
Car	16734	16965.7	26514.1	27215.8	35894	36952.4	52685.2	54249.6	78757.3	82266.8

Table 6. 16: Share of Total Peak Period Vehicle-km Demand by Different Modes in the Network

Mode	2001		2005		2010		2014		2020	
	With Rail	Without Rail	With Rail	Without Rail	With Rail	Without Rail	With Rail	Without Rail	With Rail	Without Rail
Rickshaw	1589592	1605359	1851288	1881293	2145424	2148007	2398902	2437049	2667440	2698605
Auto-Rickshaw	256064	258796.1	310048.3	311581.4	361138.2	364133.1	410915.6	414202.7	459555.7	467464.6
Bus	30712.8	31378.9	42641.4	43409.3	52407.6	53228.2	62287.8	63232.1	72519.4	73578.9
Car	251580	254344	306073.3	309828.6	355246.1	358448.9	400946.4	407207.8	445807.1	449583.5

6.8 Comparison among Evaluated Planning Options

In this study five types of planning options were evaluated for alleviating peak period traffic congestion and air pollution. Parametric analyses of the selected options were discussed in the foregoing sections.

The first option considered was the elimination of rickshaws from the main roadway links of urban Dhaka. It was seen that the removal of rickshaw significantly improved the situation. The average delay per kilometer travel in peak period reduced by 89.77% and average peak hour delay rate (ratio of actual travel time and free flow travel time) reduced by 73.45% for removal of rickshaw. It also reduced the increasing rate of traffic congestion and delay for increase in city population. Removal of rickshaw reduced the emission rate of CO by 2.38% and reduced the increasing rate of emission of SO_x, NO_x and CO in future for the increase in city population. But the removal of rickshaws increased the demands of other modes. It increased peak period demand of bus by 51%, auto-rickshaw by 28% and car by 19%. So to keep the mobility level constant after removal of rickshaw, numbers of other individual modes should be increased accordingly.

The second option considered was the withdrawal of two-stroke engine driven auto-rickshaws from the city streets. This option improved the situation but to a lesser degree than the option of rickshaw removal. The average delay per kilometer travel in peak period reduced by 10.47% and average peak hour delay rate (ratio of actual travel time and free flow travel time) reduced by 8.56% for removal of auto-rickshaw. It also reduced the increasing rate of traffic congestion and delay for increase in city population. It reduced the emission rates of SO_x and CO by 26.92% and 34.82% respectively. It also reduced the increase rates of emission of SO_x, NO_x and CO for the increase in city population. Banning of auto-rickshaw is easier to implement than banning of rickshaw right now and the government of Bangladesh has already contemplated to implement this option.

The third option considered was the improvement of road network of Dhaka. Analysis was performed by opening two closed roads (Pilkhana road and road behind Nagar Bhaban from Fulbaria to Banga Bazar market) and increasing effective roadway widths of two bottlenecks (Malibagh bazar moar and Tongi Diversion road) in the road network. It was seen that the peak period total demand in vehicle-km reduced by 5.61% and in vehicle-hour reduced by 3.07%. The average delay per kilometer travel in peak period reduced by 14.9% and average peak hour delay rate (ratio of actual travel time and free flow travel time) reduced by 3.98% for such improvements. It also reduced the increasing rate of traffic congestion and delay for increase in city population. Such improvements in the network reduced emission rates of SO_x, NO_x and CO by 7.69%, 6.33% and 5.88% respectively. It also reduced the increase rates of emission rates of SO_x, NO_x and CO for the increase in city population.

The fourth option considered was the improvement of existing mass transit system of the city. It was seen that traffic congestion in terms of peak period network average delay per kilometer travel, delay rate, volume-capacity ratio etc all reduced exponentially with the increase in modal share of bus. The emission rates of SO_x, NO_x and CO also reduced exponentially with increasing modal share of bus. For the increase of modal share of bus average speed of bus or travel time was the most sensitive parameter. With only 2% increase in average speed of bus, modal share of bus increased by 6.7%; peak period network average delay per kilometer travel, delay rate, volume-capacity ratio etc. reduced by 5%, 2% and 5% respectively and corresponding SO_x, NO_x and CO emission rates reduced by 3%, 1% and 4% respectively.

The fifth and last planning option analyzed in this study was incorporation of an intra-city rail service from Uttara to Kamalapur connecting fifteen TAZs. The Connecting TAZs were Uttara sub-region (TAZ no 01), four zones of Gulshan sub-region (TAZ no. 17, 18, 19, 20) and five zones of Central Metropolitan sub-region (TAZ no33,34,35,36,54), two zones of Eastern Metropolitan sub-region (TAZ no. 28, 55) and three zones of Dhanmondi-Farmgate sub-region (TAZ no.37, 38,39). The analyses were conducted without considering long term land-use pattern change, which was beyond the scope of the study. Although overall network effect of such a line connecting only 15 TAZs out of 90 TAZs was relatively low, it was seen that it diverts 54% of total peak period generated road trips of Uttara zone. Such a rail transit system increased average peak period speed of Airport road by 6% and for Dhaka-Mymensingh road it increased peak period average speed by 40%. In facts these are the short term effects of railway and in the long run, overall land-use and corresponding travel pattern will experience a significant change for such intra-city rail service. However, note that, easy access to such rail service is very important Full utilization of such intra-city rail service can not be achieved unless suitable access mode to railway is provided.

6.9 Summary

This chapter described the result of parametric studies of five alternative planning options. Using Dhaka Urban Transportation Model (DUTM), the evaluations were made mainly from the traffic congestion and air pollution reduction perspective. The analyses were conducted to measure resulting traffic congestion and air pollution caused by implementation of the planning options and to compare them with base-line situations described in Chapter 5. The options considered in this study were removal of rickshaws, removal of auto-rickshaws, improvements of road network, improvements of city bus service and incorporation of intra-city rail service. It was seen that removal of rickshaws and auto-rickshaws improved both traffic congestion and air pollution situation but other modes would have to be increased accordingly to keep the mobility level unchanged. Improvement of road network by opening closed roadway links and removing bottlenecks to flow reduced traffic congestion and resulting air pollution significantly. Increase in modal share of bus reduced traffic congestion and air pollution but it required providing high speed city bus service. Incorporation of intra-city rail service diverted a significant amount of road traffic from nearby zones of rail transit service and reduced traffic congestion and resulting air pollution.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This study was motivated by the severe traffic congestion and environmental pollution situation prevailing in Dhaka city. Although there exist plethora of opinions regarding improvement of the situation, only few detailed analytical studies had been done on the issue. Due to the lack of scientific and engineering basis, most of the measures undertaken in order to improve the situation, failed to produce desired result. In fact, to improve the situation a comprehensive planning is required incorporating various planning options and analyzing their impacts. The aim of this study was to evaluate some alternative planning options to alleviate traffic congestion and consequent air pollution of Dhaka city. To evaluate the consequences of alternative planning options, an urban transportation modeling system for Dhaka, named as Dhaka Urban Transportation Model (DUTM), was developed. The DUTM incorporated 154 km^2 area of central urban portion of Dhaka, which is divided into 90 DCC wards and contains a total present population of 61,38,526. The road network of main roadway links of the area having total length of 350 km was considered in the analysis. To measure the performance of transportation system and quantify traffic congestion, four types of congestion indices were used, which include Roadway Congestion Index (RCI), Travel Rate Index (TRI), Volume Capacity Index (VCI) and Congestion Severity Index (CSI). These indices estimate citywide aggregate measure of traffic congestion. For air pollution emission rates of SO_x, NO_x and CO caused by traffic were selected for analysis. These indices and pollution rates were used to estimate baseline situation and to evaluate five alternative options, which included removal of rickshaw, removal of auto-rickshaw, network improvement, improvement of bus service and incorporation of intra-city rail service. The impacts of the planning options were compared with the baseline situation to measure their effectiveness for the planning period up to 2020. It is to be noted here that these analyses considered recurrent traffic congestion and resulting air pollution during peak period. Details of analyses results were presented in the earlier chapters. On the basis of the analyses, summary of findings and recommendations for future probable research study are presented in the following sections.

7.1.1 Findings of the Study

Baseline situation analysis: Analyses for past, present and future years were performed under business as usual situation without altering the transportation system components, (except for socio-economic variables changing with time) and termed as baseline analysis. From the baseline analyses, it was found that for the year of 2002, the peak period total vehicular travel demands on the selected road network were 13,45,260 vehicle-km and 59,500 vehicle-hours. Total peak period travel demand both in terms of vehicle-km and vehicle-hour were increasing exponentially with the increase in city population and by 2020 total peak period vehicle-km travel demand would be 2.6 times of that of the year 2002 at the same time total peak period vehicle-hour demand would be 7.73 times of that of the year 2002. For the year of 2002, 62% of total roadway length of urban Dhaka had to carry peak hour traffic with volume-capacity ratio greater than 1.25 and by 2020 it would be 85%. For the year of 2002, 47% of the total roadway length of urban Dhaka had peak hour average travel speed less than 15 kilometer per hour within which 51 percent (24 percent of total) had less than 5 kilometer per hour and by 2020, 68% of the total roadway length would carry peak period traffic with average speed less than 15 kilometer per hour within which 85 percent (58 percent of total) would have less than 5 kilometer per hour.

The value of RCI was 2.53 at the year of 2002 and by 2020 it would be almost double (4.60). The value of TRI was 5.67 at the year of 2002 and by 2020 it would be almost 12 times (68.53). The value of VCI was 2.26 at the year of 2002 and by 2020 it would be almost 1.66 times (3.75). The value of CSI was 226.51 at the year of 2002 and by 2020 it would be almost 16 times (3574.54). It was seen that travel time related measures (TRI, CSI) were increasing exponentially with the increase in city population, which also indicated that traffic congestion and resulting delay were increasing exponentially with time.

The peak period emission rate of SO_2 was 0.26 ton per hour at the year of 2002 and it would be 1.25 ton per hour by 2020. The peak period emission rate of NO_2 was 0.79 ton per hour at the year of 2002 and by 2020 it would be 4.11 ton per hour. The peak period emission rate of CO was 13.44 ton per hour at the year of 2002 and by 2020 it would be 61.68 ton per hour. Since emission rates of the pollutants were functions of total vehicle hour demand so those emission rates were also increasing exponentially with the increase in city population.

7.1.2 Impacts of Alternative Planning Options

Considering the present traffic congestion and resulting air pollution situations of Dhaka city and their degrading rates, five planning options were selected in this study and their effectiveness in reduction of traffic congestion and consequent air pollution were evaluated. The effects of individual implementation of five alternative planning options were found as follows:

(1) Removal of Rickshaw: The elimination of rickshaws from the main roadway links (links selected for present study) reduced 48.52% of peak period total vehicle-km demand and 24.28% of peak period total vehicle-hours demand for the year of 2002. Such rickshaw elimination made the increase rate of peak period total network demand from exponential to linear type. It reduced the percentage of total roadway length carrying peak hour traffic with volume-capacity ratio greater than 1.25, from 47% to 14% for the year of 2002 and from 85% to 61% for the year of 2020. It reduced the percentage of total roadway length carrying peak hour traffic with average speed less than 15 kilometer per hour, from 62% to 21% for the year of 2002 and from 68% to 46% for the year of 2020.

For the year of 2002, peak period values of RCI, TRI, VCI and CSI reduced 50.69%, 73.45%, 36.97% and 89.77% respectively for removal of rickshaws. It reduced the increase rate of RCI and VCI and made the increase rate of TRI and CSI from exponential to linear type. Although removal of rickshaw increased SO_x and NO_x emission rate of the year 2002 by 3.80% and 5.06% respectively, it reduced the increase rates of emission rates and by 2020 it would reduce SO_x and NO_x emission rates by 53.60% and 54.00% respectively. For 2002 it reduced CO emission rate by 2.38% and by 2020 it would be reduced by 55.29%.

But the removal of rickshaws from the network increased the demand for other modes. Such removal of rickshaws, without altering the peak period total travel demands, would only be possible if the total amount of auto-rickshaw, bus and car could be increased by 28%, 51%, and 19% respectively.

(2) Removal of Auto-rickshaw: The elimination of auto-rickshaws from the main roadway links (links selected for present study) reduced 7.8% of peak period total vehicle-km demand and 28.39% of peak period total vehicle-hours demand for the year of 2002. Such auto-rickshaw elimination reduced the increase rate of peak period total network demand.

The peak period values of RCI, TRI, VCI and CSI of the year of 2002 reduced by 3.22%, 8.56%, 2.27% and 10.47% respectively for the removal of auto-rickshaws. It reduced the increase rate of RCI and VCI and made the increase rate of TRI and CSI from exponential to linear type. For the year of 2002, peak period emission rates of SO_2 and CO reduced by 26.92% and 34.82% respectively for the removal of auto-rickshaw. It also reduced the increase rates of SO_2 and CO in future.

The removal of auto-rickshaws from the network increased the demand for other modes. Such removal of auto-rickshaws, without altering the peak period total travel demands, would require increasing the amount of rickshaw, bus and car by 8%, 17%, and 7% respectively.

(3) Improvements of Road Network: Analyses of peak hour situations of the year of 2002 showed that there were a number of bottleneck points and missing links in the network. A rigorous study is required to identify all bottleneck points and missing links. In this study two major bottleneck points and two closed links were identified to estimate the effects of their improvements. One of the bottleneck points was at "Rampura DIT Road" near "Mailbag Bazar Intersection" and the other was the junction of "Tongi Diversion Road" and "Dhaka-Mymensingh Road". It was seen that the peak hour travel time was about 30 times higher than that of free flow travel time at those two places. Among the two closed links one was "Pilkhana Road" through 'BDR Staff Quarter' and the other was behind "Nagar Bhaban" from "Fulbaria Bus Stand" to "Banga Bazar Market". It was seen that although those two links were practically existed, those were completely closed for free movements of traffic. Analyses were made by increasing total effective roadway width of two bottleneck places and opening two closed roads for free movements of traffic. It was seen that such improvements of road network reduced total peak period vehicle-km travel demand by 5.61% and vehicle-hours travel demands by 3%. The values of RCI, TRI, VCI and CSI reduced by 6.17%, 12.37%, 3.98% and 14.90% respectively for such improvements. For such improvements, the peak period emission rates of SO_2, NO_2 and CO reduced by 7.69%, 6.33% and 5.88% respectively. Improvement of road network also reduced the increase rate of peak period total travel demand, congestion indices and emission rates of pollutants.

(4) Improvement of City Bus service: At present, modal share of bus in central urban portion of Dhaka is 34% and it was seen that peak period total vehicular travel demands, both in terms of total vehicle-km and total vehicle-hours reduced exponentially with the increase in modal share of bus. The values of RCI, TRI, VCI and CSI also reduced exponentially with the increase in modal share of bus. In addition to exponential reduction of traffic congestion, pollution rates also reduced exponentially with increasing modal share of bus. In an attempt to analyze the scope of improving modal share of bus, it was seen that average speed of bus was the most sensitive parameter. The modal share of bus increased with increasing bus speed. So to increase the modal share of bus higher speed of bus should be ensured. It was seen that with 2% increase in average speed of bus, modal share of bus increased by 6.70%, peak period network average delay per kilometer travel, delay rate, volume-capacity ratio reduced by 5%, 2% and 5% respectively and corresponding SO_x, NO_x and CO emission rates reduced by 3%, 1% and 4% respectively.

(5) Incorporation of Intra-city Rail Service: An intra-city rail service from Uttara to Kamalapur, connecting fifteen TAZs were considered in this study. The Connecting TAZs were Uttara sub-region (TAZ no 01), four zones of Gulshan sub-region (TAZ no. 17, 18, 19, 20), five zones of Central Metropolitan sub-region (TAZ no. 33, 34, 35, 36, 54), two zones of Eastern Metropolitan sub-region (TAZ no. 28, 55) and three zones of Dhanmondi-Farmgate sub-region (TAZ no. 37, 38, 39). The analyses were made without considering long term land-use pattern changes. It was seen that incorporation of such an additional mode diverted a significant portion of road traffic and reduced traffic congestion on different roadway links. It was seen that for a particular zone of Uttara, it diverted 54% of total peak period generated road trips, thereby increased average peak period speed of Airport road by 6% and average peak period speed of Dhaka-Mymensingh road by 40%. It was also found that for such intra-city rail service, the access to rail service was very important. Full utilization of such intra-city rail service would not be effective unless suitable access mode to railway could be provided.

(6) Remarks on the Selected Planning Options: Evaluations of five alternative planning options reveal that removal of rickshaw is highly beneficial. But in this case, the major portion of rickshaw users shifts to bus. In order to keep the mobility level unchanged after removal of rickshaw, bus service should be improved and the number of buses should be increased by 51 percent. Removal of auto-rickshaw reduces air pollution and traffic congestion but demands the increase of other modes accordingly. Within the road network, there exist a number of bottleneck points and missing or closed links. Improvements of bottleneck points and opening of closed links or construction of missing links will reduce both traffic congestion and resulting air pollution. In this connection it is important to identify all bottlenecks and the missing links in the network. Increase in modal share of bus reduces the number of vehicle on the roads and thereby reduces traffic congestion and resulting air pollution. Maximum increase in modal share of bus can be achieved by increasing the speed of bus service. Incorporation of intra-city rail service diverts road traffic towards it and thereby reduces road traffic congestion and resulting air pollution. For such intra-city rail service, the access to rail service is important. For effective use of intra-city rail service, location of railway stations should be carefully selected to give better access of people to rail service from different zones and convenient access mode should be provided.

7.2 Recommendation for Future Research

This study was undertaken to develop a transportation planning tool for Dhaka city and evaluate a few planning options. In this regard a transportation model has been developed for Dhaka city. Considering the demand and supply structure as well as characteristics of associated variables, there exist many other options to improve the situation. Also considering the complex relationships among associated variables, further study is deemed necessary to improve the model. In this connection a couple of research directives are suggested below.

In this study the area wide network effects of different alternative planning options are evaluated. Any changes in transportation system have a long term impact on land-use pattern. Further study considering the land-use pattern changes for the planning options are necessary.

This study dealt with the mobility aspects of traffic congestion but the economic aspects of traffic congestion are also very important. Further study regarding the economic aspects of traffic congestion is deemed necessary.

In this study only recurrent traffic congestion had been considered. But non-recurrent traffic congestion is also very common in urban transportation network. Further study considering non-recurrent traffic congestion is required to be analyzed.

This study evaluates the incorporation of intra-city rail service, which connects only 15 TAZs. Further study is necessary to determine scope and effects of city wide rail service.

For trip generation model of this study a multiple regression type model is used. Further study regarding the trip generation incorporating category analysis according to socio-economic classes and transportation characteristics is required to enhance the scope of the model.

REFERENCES

Ahsan, H.M. (1990). "A Study of Mass Transit in Metropolitan Dhaka", M.Sc. Thesis, Department of Civil Engineering, BUET, Dhaka.

Ahmed, K.A. (1980). "Traffic Problems in Dacca City." Local Government Institute, Dhaka.

Ahmed, S.M. and Hoque, M.M. (1988). "Transportation and Traffic in Dhaka- Review of the Past, Present and Outlook for the Future." Proceedings, Seminar on Dhaka 2000 Ad, IEB.

Alam, J.B. (1992), "Traffic Assignment Model for Simulation and Optimization of Road Network" M.Sc. Thesis, Department Of Civil Engineering, BUET, Dhaka.

Alam, J.B., Jaigirdar, M. A. and Rahman, M.H. (2000), "Level of NO_x, SO_x, CO and SPM Pollution in Dhaka City and Their Possible Consequences", Bangladesh Environment 2000, an Outcome of ICBEN, BAPA (Bangladesh Poribesh Andolon)

Alam, J.B., Jaigirdar, M. A. and Rahman, M.H. (2000), "Air Quality in Dhaka City", Journal of Pollution Research, Enviromedia.

Alam, J.B., Jaigirdar, M. A. and Rahman, M.H. (1999), "Analysis of Behavioral Value of Travel Attributes and Their Implications on Urban Transport Policies", Journal of Civil Engineering, I.E.B., Vol. CE 27, No. 1, 1999.

Ara, H. (1983). "Socio-Economic Correlates of Urban Travel Pattern: A Study in Dhaka City." M.Sc. Thesis, URP, BUET.

Bangladesh Bureau of Statistics (BBS) (1991, 1996, 1999), Statistical Year Book of Bangladesh, Dhaka Reproduction Documentation and Publication Wing, BBS.

Bartone, E; Branstein, J; Eigen, J. (1994) "Urban Management Program toward Environmental Strategies for Cities", World Bank Technical Report.

Bates et al, (1989) "Building a Strategic Model for Edinburgh"; PTRC Summer Annual Meeting, Summer C, 1989.

Barwell, I. (1978). "Review of Appropriate Technologies for Road Transport in Bangladesh." Bangladesh Planning Commission.

Baquee, L. (1979). "A Study of Traffic in Old Dacca City." An MURP. Thesis, Department of Urban and Regional Planning, BUET.

Ben Akiva, M.E. and Lerman S.R. (1985), Discrete Choice Modeling: Theory and Application to Travel Demand, MIT Press, Mass., USA.

Bhuiyan, A.A., (2001), "Urban Environment and Automobile Pollution- an Overview" Workshop on Urban Transport Development Strategy for Dhaka Metropolitan Area, January, 2001, GDTPCB, Dhaka City Corporation, Dhaka.

Bruton, M.J. (1974). "The Spirit and Purpose of Planning." First Edition. Hutchingson & Co. London, U.K.

Case, D.J., Latchford, J.C.R. (1981). "A Comparison of Public Transport in Cities in South East Asia." Study Report. World Bank.

DCC (2001), "Ward Details", Annual Report of Dhaka City Corporation.

"Dhaka Metropolitan Development Plan" (DMDP, 1995-2015)", RAJUK (Rajdhani Unnoyon Kotripokho), 1997.

DITS (Greater Dhaka Metropolitan Area Integrated Transport Study), (1993), Mid Term Report, Prepared by PPK Consultants, Delcan International and Development Design Consultant (DDC), Dhaka.

DSM, (2001), "Urban Transport Development Strategy", Workshop on Urban Transport Development Strategy for Dhaka Metropolitan Area, January, 2001, GDTPCB, Dhaka City Corporation, Dhaka.

DUTP (Dhaka Urban Transport Project), Phase II (1998), Draft Final Report, Prepared by PPK, Mot MacDonald and Development Design Consultant (DDC), Dhaka.

FHA, "Highway Performance Monitoring System; Mobility Goal in Performance Plan", (http://www.fhwa.dot.gov/policy/fhwapprt.htm#mobility)

Fielding, G.J. and Anderson, S.C. (1983). "Public Transit Performance Evaluation- Application to Section 15 Data." Transport Research Record 947.

Firdous, G.M. (1984). "A Study on the Problems of Bus Transport in Dhaka City." An MURP Thesis, Department of Urban and Regional Planning, BUET, Dhaka.

Flavin and Christopher (1994), "Storm Warning: Climate Change Hits the Insurance Industry," World Watch. November/December 1994, p.11.

Gallaghar, R. (1992), "Rickshaws of Bangladesh", University Press Limited, ISBN 9840511823.

Greenstein, J., Berger, L. And Strulov, A. (1988). "Public Transport Problems and Solutions in the Historical Center Of Quito." Proceedings of the International Conference on Road and Road Transport Problems. Icort-88, New-Delhi, India.

Gupta, T.K.D. (1980). "The Role of Rickshaw in the Economy of Dhaka City." An MURP Thesis, Department of Urban and Regional Planning, BUET, Dhaka.

Hafiz, K.G., (2001) "Urban Planning Strategies and Transport Programs in Dhaka Metropolitan Areas." Workshop on Urban Transport Development Strategy for Dhaka Metropolitan Area, January, 2001, GDTPCB, Dhaka City Corporation, Dhaka.

Hearty, M.J. (1980). "Public Transport in Kingston, Jamaica and its Relation to Low Income Households." TRRL Supplementary Report- 546.

Herur, A, (2001) "Operation and Management of Urban Transport Systems", Workshop on Urban Transport Development Strategy for Dhaka Metropolitan Area, January, 2001, GDTPCB, Dhaka City Corporation, Dhaka.

HGAC (1998), "Congestion Management System", Houston-Galveston Area Council (HGAC), May 1998.

Highway Capacity Manual (HCM), (1994), Special Report 209, Third Edition, Transportation Research Board, National Research Council, Washington, D.C. 1994.

Hossain, A. B. (1996), "Effect of Non-Motorized Transport on the Performance of Road Traffic in Metropolitan Dhaka, Department of Civil Engineering, BUET.

Hoque, M.M. (1981). "Traffic Accidents in Dacca- A Study on Road Safety." Department of Civil Engineering, BUET, Dhaka.

Hoque, M.M. (1986). "Traffic Accidents in Dhaka." Proceedings of 13th ARRB/5th REAA Conference In Australia, Vol. 13, No.2.

Hoque, M.M. and Alam, J.B. (2002), "Strategies for Sustainable Transportation in Bangladesh", KODATU-X, LOME

ICF (1997), "Opportunities to Improve Air Quality through Transportation Pricing Program", ICF Incorporated, 9300 Lee highway, Fairfax, Virginia, September 1997.

Jadaan, K.S. (1988). "Operation and Performance of Public Transport in a Rich Developing Country." Proceedings Of 14th ARRB Conference, Vol. 14, Part 3.

Jaigirdar, M. A. (1998), "Environmental Impacts of Improved Bus Service of Dhaka City", M.Sc. Thesis, Department of Civil Engineering, BUET, Dhaka.

Khan, S. A., (2001), "Urban Development Strategy for Dhaka Metropolitan Area", Workshop on Urban Transport Development Strategy for Dhaka Metropolitan Area, January, 2001, GDTPCB, Dhaka City Corporation, Dhaka.

Kiwan, M.S.A.A. (1988), "Pedestrianization in Dhaka City", An MURP thesis, Department of Urban and Regional Planning, BUET, Dhaka.

Mallinckrodt, A.J. (2001),"A Multimode Regional Congestion Index" AJM Engineering, USA.

Mallinckrodt, A.J (2001),"The Best Evidence on HOV Lane Effectiveness" AJM Engineering.

Matson, T.M., Smith, W.S. and Hurd, F.W. (1955). "Traffic Engineering." Mcgraw-Hill Civil Engineering Series.

Maunder, D.A.C. and Fouracre, P.R. (1983). "Specialized Bus Service in Three Third World Countries." TRRL Supplementary Report- 811.

Meyer D. & Miller E.J. (1984), "Urban Transportation Planning : A Decision-Oriented Approach", McGraw-Hill Series in Transportation, ISBN0-07-041752-0.

Monayem, M. A., (2001)" Evaluation of Traffic Operation Conditions on Two Urban Arterials in Metropolitan Dhaka." M.Eng. Thesis, Department of Civil Engineering, BUET, Dhaka.

Morlok, E.K. (1978). "Introduction to Transportation Engineering and Planning." International Student Edition, Mcgraw-Hill Book Company, U.S.A.

Nagari, A.T.M.H, (2001) "Strategic Transport Planning for Dhaka Metropolitan Area", Workshop on Urban Transport Development Strategy for Dhaka Metropolitan Area, January, 2001, GDTPCB, Dhaka City Corporation, Dhaka.

NCHRP Report 398, (1997); "Quantifying Congestion"-Final Report and user's Guide National Cooperative Highway Research Program Project 7-13, National Research Council.

Ortuzar, J. De and Willumsen, L.G. (1995), "Transport Modeling", J. Wiley & Sons Ltd., USA.

Owen, W. (1966). "The Metropolitan Transportation Problem." The Brookings Institution, Washington D.C., Revised Edition.

Quium, A.S.M. (1995). "Dhaka Metropolitan Development Plan, Review of Structures, and Urban Area Plans, Sub Sector: Transport", the paper was presented at a national seminar on Dhaka Metropolitan Development Plan, Dhaka.

Radwan, A.E. and Sadegh, H. (1985). "Assessment of Software for Traffic Signal Analysis in Microcomputer Applications within the Urban Transport Environment." Abkowitz ,M.D. (Ed) ,ASCE, New York.

Richie, S.G. and Harris, R.A. (1987). "Expert Systems for Civil Engineers: Technology and Application." Edited By Maher, M.L., International Student Edition, Mcgraw-Hill Book Company.

Rosenbaum, A.S. and Koenig, B.E. (1997). "Evaluation of Modeling Tools for Assessing Land Use Policies and Strategies", EPA420-R-97-007, Final Report-August 1997.

Salter, R.J. (1983). "Highway Traffic Analysis and Design." Revised Edition. The Macmillan Press Ltd., London, U.K.

Sheffi, Y. (1996), Network Analysis, McGraw Hill Book Company, USA.

Shankland Cox Partnership (1979). "Consultancy Report on Transport, Dhaka Metropolitan Area Integrated Urban Development Project."

Shrank and Lomax, (1998). "Urban Roadway Congestion", an annual series since 1988, latest is research report 1131-9, Texas Transportation Institute, 1998, http://mobility.tamu.edu

Shrank and Lomax, (1999). "The 1999 Annual Mobility Report-The information for Urban America", http://mobility.tamu.edu

Sharma, S.K. (1985). "Principles, Practice and Design of Highway Engineering." S. Chad & Company Ltd., New-Delhi, India.

Sharma, V.P., Kanchan P.K. And Nanda P.K. (1988). "Software Development for Computerization of Basic Features of National Highway." Proceedings of the International Conference on Road and Road Transport Problems. Icort-88, New-Delhi, India.

Starkie, D.N.M, (1976) "Transportation Planning, Policy and Analysis", Pergamon Press, Urban and Regional Planning Series, Volume 13, First Edition 1976.

Stewart, R.D. (1975). "The Effects of Carbon Monoxide on Humans", Annual review of Pharmacology, Vol. 15, pp.409-423.

TDM Encyclopedia, (2000) Victoria Transport Policy Institute, Victoria, Canada.

The Road Information Program (2001), "Struck in Traffic"; May 2001, Washington, D.C.20036; www.tripnet.org

The 1999 Annual Mobility Report & Annual Report of Texas Mobility Study-2001 (http://mobility.tamu.edu).

Umigar, F.S., Sikdar, P.K., Khanna, S.K. and Raan, P.S. (1988). "Performance Based Policy Framework for Ownership Options in Urban Bus Transit Management." Proceedings of the International Conference on Road and Road Transport Problems. Icort-88, New-Delhi, India.

Urban Roadway Congestion Annual Report, (1998). Sponsored by Department of Transportation in California, Colorado, Kentucky, Minnesota, New York, Oregon, Pennsylvania, Texas and Washington, 1998; (http://mobility.tamu.edu)

Victor, D.J. (1979). "Alternatives for Improving Transportation." Advanced Course on Urban Transport Management, Lecture Notes. Department of Civil Engineering, Indian Institute of Technology, Madras, India.

Wohl, M. And Martin, B.V. (1968). "Traffic System Analysis for Engineers and Planners." Mcgraw-Hill Book Company, U.S.A.

World Bank (1986). "Urban Transport. A World Bank Policy Study." Washington D.C., U.S.A.

Yi-Chin Hu and Paul Schonfeld (1984). "Simulation and Optimization of Regional Road Network." Journal of Transportation Engineering, ASCE, Vol. 110 No 4, July 1984.

Young, W. (1986). "Traffic, Statistics and Microcomputers." Workshop Paper, Monash University, Australia.

Young, W., Taylor, M.A.P., Gipps, P.G. (1988). "Microcomputer in Traffic System Design." Seminar Proceedings, Department of Civil Engineering, Monash University, Australia.

APPENDICES

APPENDIX-A

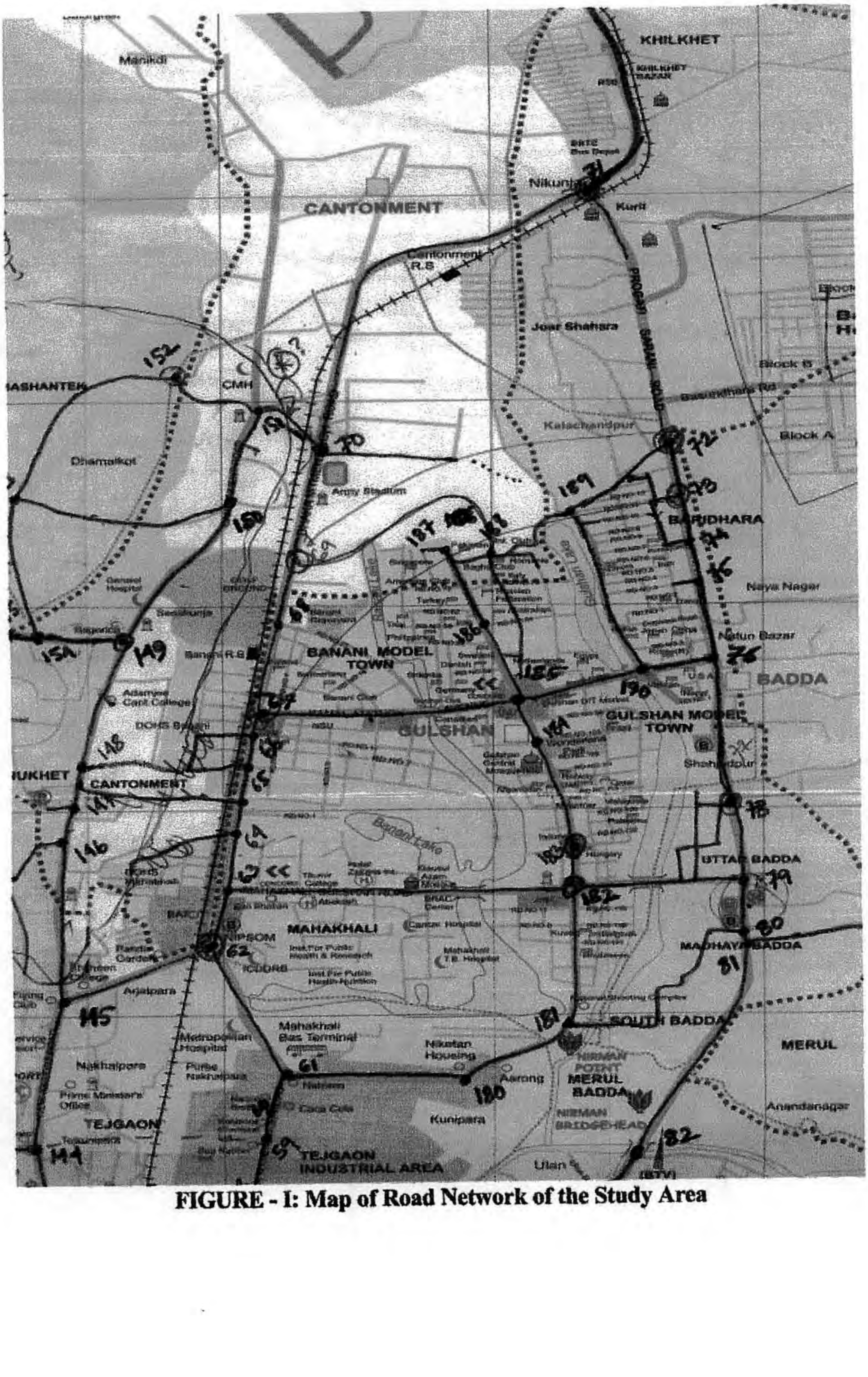


FIGURE - I: Map of Road Network of the Study Area

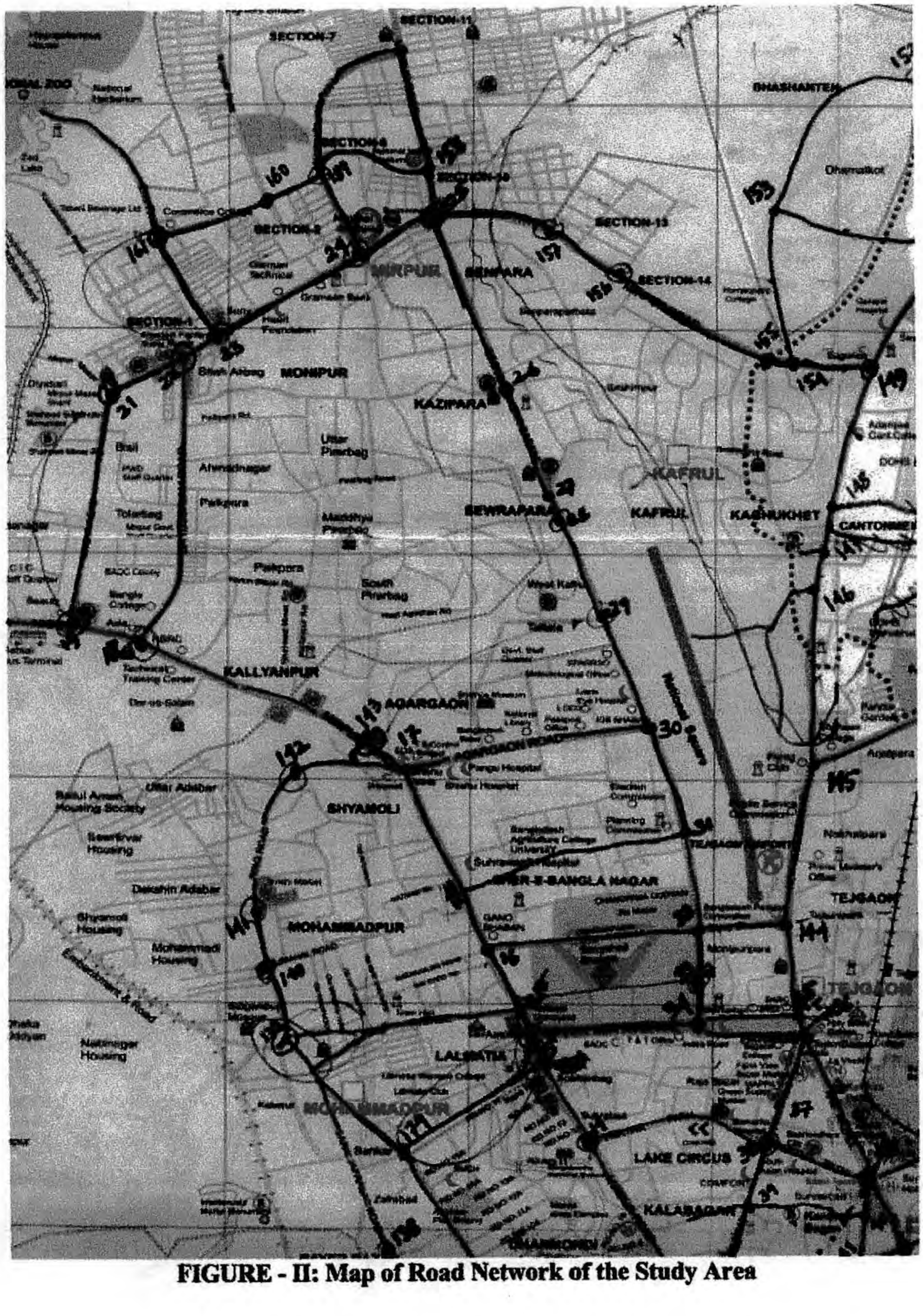


FIGURE - II: Map of Road Network of the Study Area

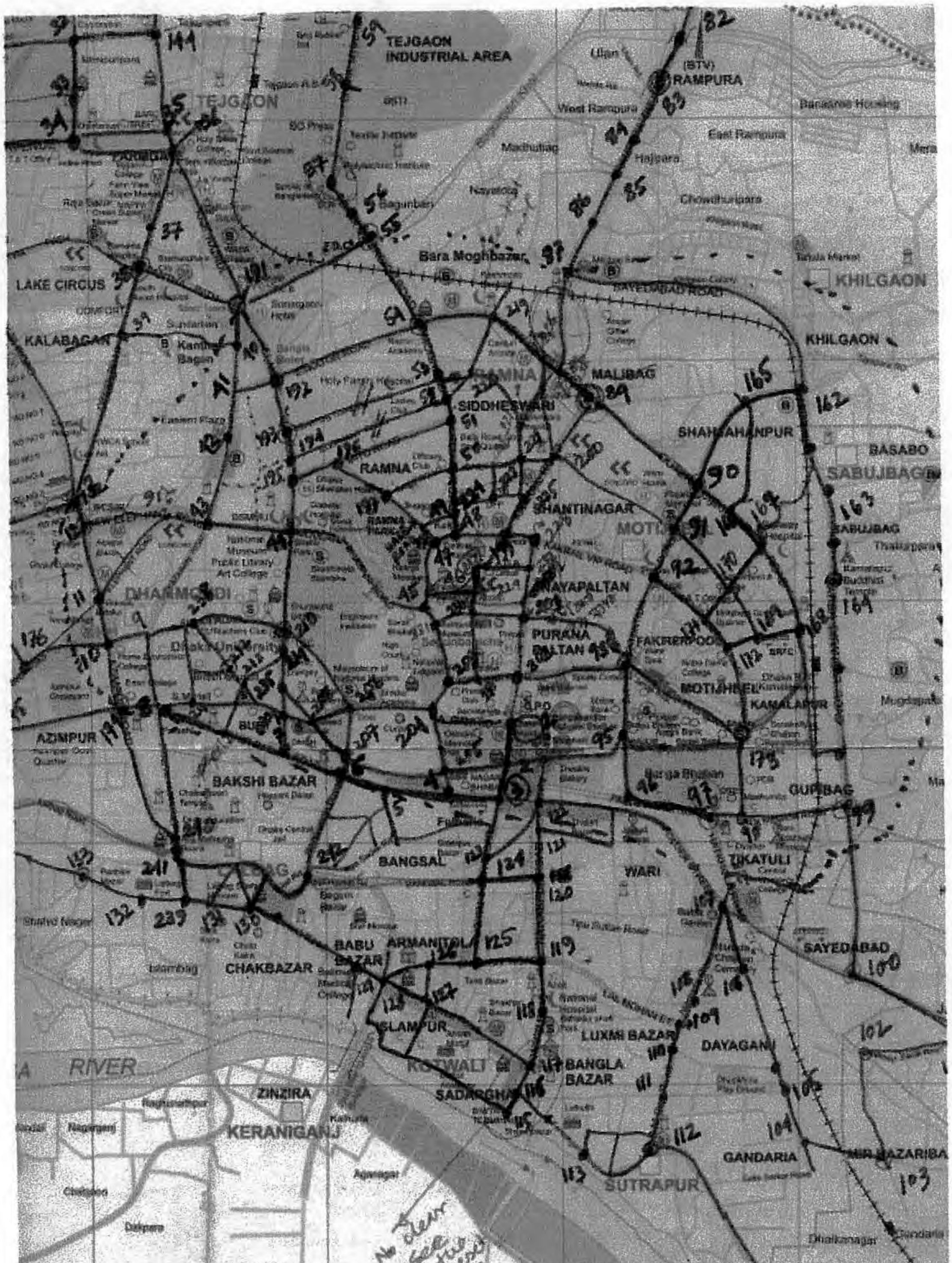


FIGURE - III: Map of Road Network of the Study Area

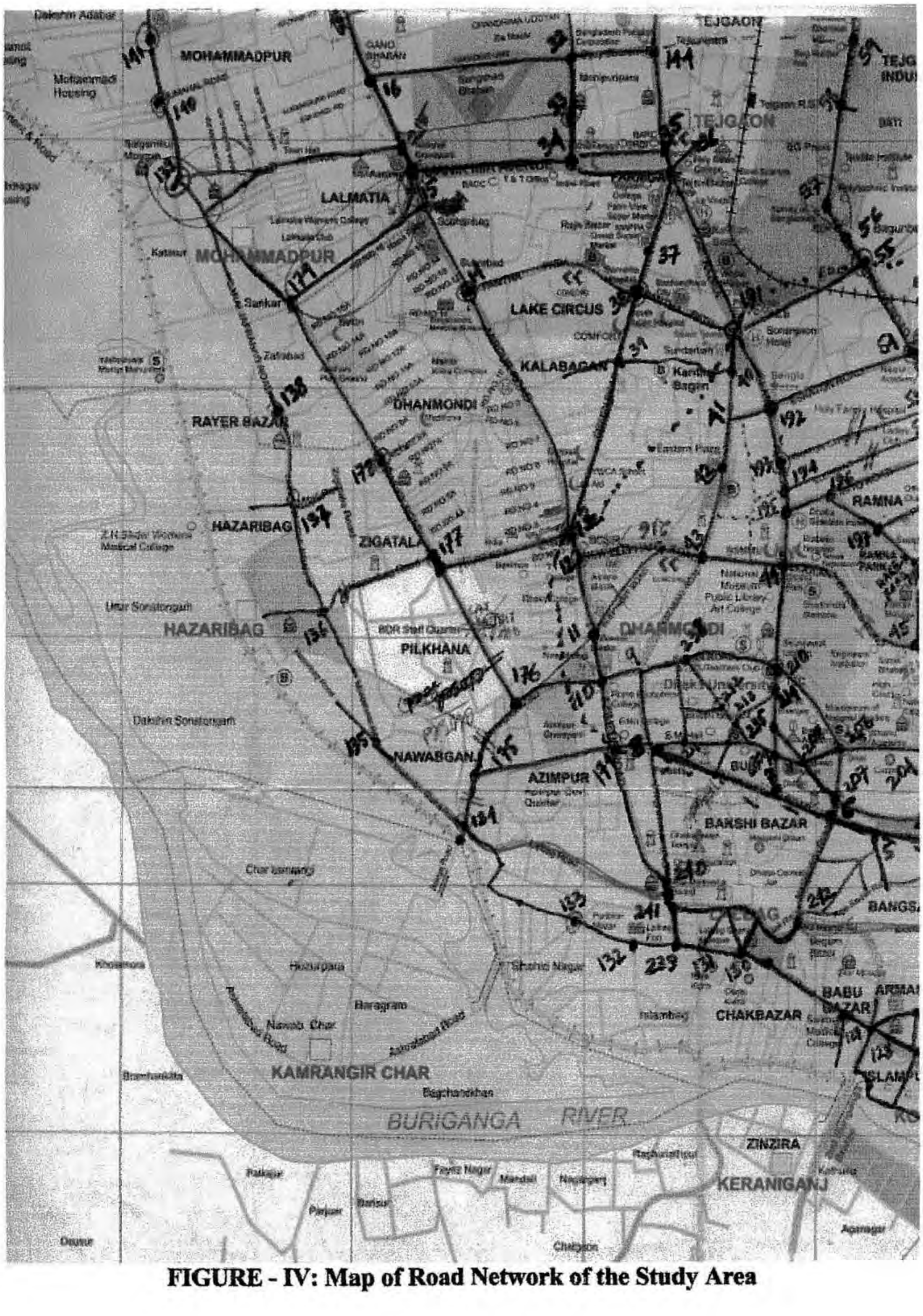


FIGURE - IV: Map of Road Network of the Study Area

APPENDIX-B

TABLE-I: Employment Shares of Individual TAZs within Sub-region

Sub-Region	Employment as % of Total Regional Employment	TAZ Number	Employment as % of Total Sub-Regional Employment
A	25	30	9.14
		31	9.14
		32	30.9
		33	2.34
		34	2.78
		35	2.78
		36	4.22
		53	8.33
		54	6.78
		56	15
		57	8.56
B	25	58	1.92
		59	1.92
		60	1.39
		61	4
		62	2.29
		63	2.13
		64	7.79
		65	2.68
		66	6.17
		67	5.03
		68	5.03
		69	2.03
		70	3.69
		71	3.41
		72	7.08
		73	2.01
		74	7.75
		75	3.91
		76	2.44
		77	4.87
		78	2.52
		79	2.2
		80	2.45
		81	0.87
		82	6.42
		83	4
		90	4
		58	1.92

TABLE-II: Employment Shares of Individual TAZs within Sub-region

Sub-Region	Employment as % of Total Regional Employment	TAZ Number	Employment as % of Total Sub-Regional Employment
C	12	7	0.75
		9	3.47
		10	2.54
		11	18.6
		12	18.6
		13	2
		14	6.99
		41	4.52
		42	14.8
		43	7.6
		44	3.87
		45	3.87
		46	1.96
		47	4.51
		48	5.88
D	4	2	13.9
		3	37.6
		4	5.29
		5	15.1
		6	5.34
		8	7.97
		15	14.8
E	4	17	8.69
		18	8.69
		19	34.9
		20	27.2
		21	20.5
F	4	1	1
G	13	22	9.3
		23	9
		24	6.8
		25	7.5
		26	7.5
		27	4.9
		28	8.8
		29	5.7
		55	8
		84	4.3
		85	5.3
		86	6
		87	5.6
		88	5.3
		89	5.9

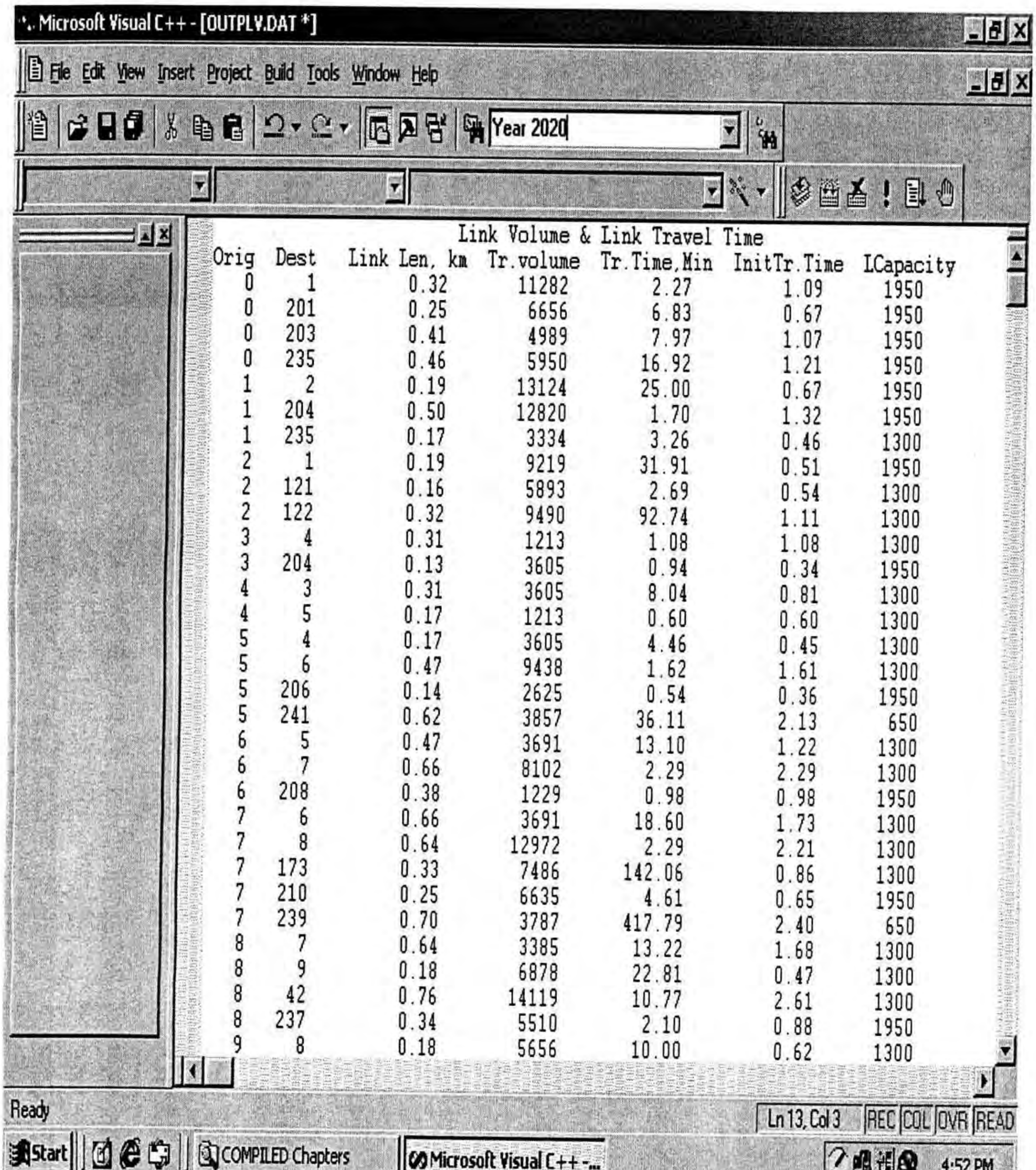
TABLE-II: Employment Shares of Individual TAZs within Sub-region

Sub-Region	Employment as % of Total Regional Employment	TAZ Number	Employment as % of Total Sub-Regional Employment
C	12	7	0.75
		9	3.47
		10	2.54
		11	18.6
		12	18.6
		13	2
		14	6.99
		41	4.52
		42	14.8
		43	7.6
		44	3.87
		45	3.87
		46	1.96
		47	4.51
		48	5.88
D	4	2	13.9
		3	37.6
		4	5.29
		5	15.1
		6	5.34
		8	7.97
		15	14.8
E	4	17	8.69
		18	8.69
		19	34.9
		20	27.2
		21	20.5
F	4	1	1
G	13	22	9.3
		23	9
		24	6.8
		25	7.5
		26	7.5
		27	4.9
		28	8.8
		29	5.7
		55	8
		84	4.3
		85	5.3
		86	6
		87	5.6
		88	5.3
		89	5.9

TABLE-III: Employment Shares of Individual TAZs within Sub-region

Sub-Region	Employment as % of Total Regional Employment	TAZ Number	Employment as % of Total Sub-Regional Employment
H	13	52	8.4
		16	6.8
		37	26
		38	16
		39	16
		40	4.7
		49	7
		50	7
		51	8.6

APPENDIX-C



Link Volume & Link Travel Time

Orig	Dest	Link Len, km	Tr.volume	Tr.Time,Min	InitTr.Time	LCapacity
0	1	0.32	11282	2.27	1.09	1950
0	201	0.25	6656	6.83	0.67	1950
0	203	0.41	4989	7.97	1.07	1950
0	235	0.46	5950	16.92	1.21	1950
1	2	0.19	13124	25.00	0.67	1950
1	204	0.50	12820	1.70	1.32	1950
1	235	0.17	3334	3.26	0.46	1300
2	1	0.19	9219	31.91	0.51	1950
2	121	0.16	5893	2.69	0.54	1300
2	122	0.32	9490	92.74	1.11	1300
3	4	0.31	1213	1.08	1.08	1300
3	204	0.13	3605	0.94	0.34	1950
4	3	0.31	3605	8.04	0.81	1300
4	5	0.17	1213	0.60	0.60	1300
5	4	0.17	3605	4.46	0.45	1300
5	6	0.47	9438	1.62	1.61	1300
5	206	0.14	2625	0.54	0.36	1950
5	241	0.62	3857	36.11	2.13	650
6	5	0.47	3691	13.10	1.22	1300
6	7	0.66	8102	2.29	2.29	1300
6	208	0.38	1229	0.98	0.98	1950
7	6	0.66	3691	18.60	1.73	1300
7	8	0.64	12972	2.29	2.21	1300
7	173	0.33	7486	142.06	0.86	1300
7	210	0.25	6635	4.61	0.65	1950
7	239	0.70	3787	417.79	2.40	650
8	7	0.64	3385	13.22	1.68	1300
8	9	0.18	6878	22.81	0.47	1300
8	42	0.76	14119	10.77	2.61	1300
8	237	0.34	5510	2.10	0.88	1950
9	8	0.18	5656	10.00	0.62	1300

FIGURE : Interface of Output File of DUTM