TRAFFIC ASSIGNMENT MODEL FOR SIMULATION AND OPTIMIZATION OF ROAD NETWORK

BY

MD. JOBAIR BIN ALAM

A thesis submitted to the Department of Civil Engineering of Bangladesh University of Engineering and Technology, Dhaka in partial fulfillment of the requirements for the degree

of

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DECLARATION

I hereby declare that the research reported in this thesis was performed by me as a research project in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering from the Bangladesh University of Engineering and Technology (BUET) .

This thesis contains no material which has been accepted for the award of any other degree or diploma from any other institution. Further, to the best of my knowledge and belief, the thesis contains no material previously published or written by any other person, except when due reference is made in the text of the thesis.

July, 1992

(Md. Jobair Bin Alam)

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A thesis approved as to the style and content by:

Md. Mazharul Hoque

Dr. Md. Mazharul Hoque
Associate Professor
Dept. of Civil Engineering
BUET, Dhaka

:Chairman
(Supervisor)

M. F. Ahmed

Dr. M. Feroze Ahmed
Professor and Head
Dept. of Civil Engineering
BUET, Dhaka

: Member

Syed Ahmed

Mr. Syed Noor-ud-din Ahmed
Associate Professor
Dept. of Civil Engineering
BUET, Dhaka

:Member

Mr. Md. Nuruzzaman
Professor and Head
Dept. of Civil Engineering
B.I.T., Dhaka.

: Member
External

July, 1992

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ABSTRACT

Optimization of traffic and accurate assessment of traffic volume on different roads are very important in transportation planning. Optimization of traffic provides the advantage of best utilization of an existing facility. A balanced transport system, which ensures minimum user cost on every route, also depends on traffic optimization. The design of road layouts and pavements and analysis of alternative highway projects are based on an assessment of traffic volumes in a balanced condition.

This study attempts to make an independent approach in the field of traffic assignment. It computerizes a traffic assignment model and tends to combine mathematical analysis with subjective judgement in order to develop a method that is reliable and easy to use in road transport planning. The term 'subjective judgement' implies a choice in flow - travel time relationship and modelling of delays at road intersection. A procedure has also been developed to assess the impact of any new road link on traffic flow over an existing road network. Major features of the model include a computerized procedure for finding quickest route between any trip origin and trip destination in a road network, implementing an iterative procedure for the assignment of traffic and developing a method for the assessment of impact. The model was developed by remodelling Ford-Fulkerson's analytical algorithm of quickest route finding for computerization and capacity restraint traffic assignment algorithm. The impact was measured in terms of travel impedance viz. travel time and passenger car unit- minute . The

model is based on data of network structure and origin- destination (OD) matrix. It can be used to estimate the traffic volume on any road link should a change occur in the network structure or in the origin- destination (OD) matrix.

Statistical analyses showed that the result obtained from the model developed in this study agree very well with the practical situations. The model was applied for traffic analysis of the road network in metropolitan Dhaka. In particular, the effect of 'Pantha-path' extension, a new road under construction connecting Green road with Mirpur road, was studied. It was found that this new road will provide nearly nineteen percent reduction in overall travel time required by all the vehicles to travel within the study area at peak hour. Individually, the link travel-time reductions varied between 15 and 196 percent. A step wise procedure to obtain the future traffic volumes on different road links by using this model is presented to assist the user in the model's application.

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LIST OF NOTATIONS

C_p	Capacity of Particular Route
C_{ij}	Capacity of Link ij
C	Traffic Impedance
E	Income Elasticity
GDPC	Per Capita Growth Rate
l(i,j)	User Cost (in Time Unit) on Link (i,j)
L_p	Set of Links
N	Number of Lanes
PG	Population Growth Rate
P(j)	The Minimum User Cost (in Time Unit) from a Particular Origin to a Destination j
S_v	Service Volume
T	Balanced travel time
T_0	Free Flow travel Time
TGR	Traffic Growth Rate
TL	Truck Factor
t_p	Travel Time from Origin to Destination
t_{ij}	Travel Time on the Link ij
V	Assigned Volume
v/c	Volume to Capacity Ratio
w	Side Clearance Factor

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Transportation engineering involves a wide spectrum of activities related to planning, design, operation, control, management, maintenance and rehabilitation of multimodal facilities and services. Transportation facilities and services are needed for safe and efficient movement of people and goods and provide basic mobility as well as accessibility to places of work, business and recreation. Transportation services are related to social and economic opportunities which are vital to our standard of living and national economy. Some of the basic components of transportation include vehicles, fixed facilities (such as road links, intersections traffic control procedures) and their users. Interaction of these components create many problems such as traffic congestion, delay, accidents.

Dhaka's traffic system is predominantly road based. This road based transport modes can be classified in two major groups - private transport and public transport. Its traffic system can further be characterized with the dominance of low occupancy travel modes, such as rickshaws. The number of rickshaws in Dhaka city is about 125000 (Ahamed and Hoque, 1988). Results of studies on modal split of passengers in metropolitan Dhaka showed that non- motorized and motorized vehicles contributed nearly 80 percent of total trips. The huge number of rickshaws, together with indiscriminate

movement, and lack of proper traffic management and control aggravate the problems of traffic congestion, delay and accident. In metropolitan Dhaka traffic congestion causing long queues of vehicles are common scene . Traffic congestion, delay and accidents cause considerable problem to the society and has a crippling effect on national economy.

In many major cities of the world the problem of traffic congestion has been minimized by application of traffic management strategies (viz., one way system, traffic access control and reduction, reverse flow lane, traffic optimization). Such management strategies have potential in alleviating a lot of transport problems in metropolitan Dhaka and in other urban areas in Bangladesh. Optimization of the mixed mode traffic flow is very important in the context of improving overall traffic situation in Dhaka.

The management of road based transport system is a major problem area for passengers as well as freight movement in metropolitan Dhaka. The overall problem should be tackled through close coordination of land-use plan, traffic engineering and management strategies. The expert system developed in this research deals with estimation of traffic flow on different links of road network and thus helps to evaluate proposed alternative solutions. It will also help in optimization of traffic flow through road networks and thus provide a balanced traffic flow in the road system. A balanced

network is one where traffic is uniformly distributed over the network in such a way that user cost or travel time becomes minimum. The model developed in this research will be of help in improving traffic flow in road networks by ensuring a balanced flow pattern.

This research has been undertaken as an aid in mitigating problems in traffic operation and control in urban road networks through an expert system for traffic management and planning.

1.2 BACKGROUND OF THE STUDY PROJECT

Traffic optimization though extensively practiced, is still in its early stages. Standard methodologies for traffic optimization have not been established. Individual authorities have developed their own procedures to accommodate their needs. While some are too specific in domain definition, others are costly for general use.

Traffic estimation using optimization techniques have been extensively used in Australia, UK and USA. Advanced estimation methodologies mainly based on sophisticated computer modelling programs, have been developed. But these are highly costly and requires much time and sophisticated high capacity computers. They also require highly educated technical people to handle and interpret the methods and outputs [Taylor etal,1985]. A few of such

models are discussed in Chapter 2.

The prediction of traffic volume has been relatively neglected despite its many potential uses. The most obvious and direct use of traffic volume on different links is for the estimation of the benefits from alternate highway improvement projects. The second application is in the development of road users information system about quickest route for a particular time. This can be used in conjunction with telephone information system. The identification of potential problem areas in highway system could be accomplished by using optimization techniques. Much work need be done in this area to accommodate other planning steps in the model developed in this research to increase the extent of its application. It is expected that the combined model would be of great help to highway designers and national planners.

In our country no such study has been made. To make best utilization of our limited resources and to avoid misuse of fuel, manpower and time, traffic optimization and realistic traffic estimation are required in our country.

Traffic data are essential in nearly every step of the transport planning process. In highway investment (major maintenance, reconstruction or new constructions) a reliable estimates of future traffic volume is a key element. A method for the estimation of traffic volume on any link of urban road network is sought for in

this research.

Traffic estimates can be made using various approaches depending on the type of area (urban or rural) and the methods to be used (projections or forecasts). In projection techniques historical record is projected or extrapolated to the target year using trend relationships. This technique can not be used when structural change occurs. `Structural change' means any change in traffic variables, any change in the network structure or configuration. Forecasting techniques are based on mathematical analysis of the situation at the time when it is required. Any change in this origin- destination data, land use pattern or network structure can be accommodated using this method. As forecasting technique can be mathematically defined, it is possible to computerize the procedure.

In an urban area, traffic forecasts or estimation of traffic on different road links are generally based on a four step (trip generation, trip distribution, modal split and traffic assignment) travel simulation process [Blunden, 1971]. The output of the process is estimated traffic volume on various links of the road network. To plan, manage and implement new projects this estimation is essential. Also to make best utilization the existing traffic facilities the traffic should be managed in such a way that the overall travel time becomes minimum. This will provide a balanced road network which will optimize traffic volume and reduce

congestion and delay to a minimum.

The complex nature and interrelations among traffic variables make it difficult to perform calculations and analyses of travel simulation process. Easy to use, fast enough to provide information and economical computer based simulation models are sought for by planners and engineers. Expert systems in Transport technology can be developed to solve traffic problems. This research work is an attempt towards developing an Expert System in transportation planning.

1.3 POTENTIAL OF EXPERT SYSTEM IN TRANSPORT PLANNING

Expert systems are interactive computer programs incorporating judgement, experience, rule of thumb, intuition and other expertise with mathematical analysis to provide knowledgeable advice about a variety of tasks and provide information about a solution or set of solutions. In many transportation engineering problems multi-objective decision making are involved. To extract the best decision and to compare different alternatives the potential is high for knowledge based expert system to become useful tools for the practicing transportation engineers.

The expert system developed in this research work is for large-scale transportation network design problems that are evaluated using multiple conflicting traffic flow criteria. More

specifically, the expert system addresses the design of single mode, fixed demand, discrete, equilibrium transport network. The term 'single mode' stands for passenger car unit (PCU) based analysis, 'fixed demand' stands for defined origin- destination matrix and 'discrete' stands for isolated groups of traffic. Output of the system is an equilibrium transportation network.

The expert system developed in this research attempts to estimate assigned traffic on different links under optimized or balanced condition using management strategies and evaluate their performance in terms of traffic impedance (travel time, travel cost etc).

1.4 SIGNIFICANCE AND OBJECTIVE OF THE STUDY

The purpose of this research is to develop a method or a procedure to estimate assigned traffic flow on different roads on urban area for a known trip distribution among origins and destinations. It can be useful to the Highway regulatory authorities to measure the adequacy of any road or assess the usefulness or requirement of construction of any new link.

The primary focus of this study was the design and testing of a comprehensive computerized method to estimate traffic volume on a particular link of urban road network. This thesis details the development of such procedure. This also describes some additional

uses of the computer model developed in connection with this research. One of the objectives of the research is to assess the traffic effectiveness of link road, between Green Road and Mirpur Road, which is now under construction.

The model developed has been based on a well defined and established mathematical technique. This proposed technique is reliable, well documented and flexible and also simple to use. Easily available microcomputers (IBM AT compatible) will be enough to handle all the mathematical calculations and graphical representations. The system has been programmed in TURBO C (MS-DOS System) for IBM-AT compatible microcomputers.

Specifically, the objectives of the study are to :

* Develop a computer model or expert system for traffic optimization in a system of road network.

* Develop a procedure for estimation of traffic flow on particular link using the above mentioned model.

* Investigate traffic effectiveness of link road between Green road and Mirpur road which is now under construction and thereby develop a general procedure to examine traffic effectiveness of any road.

1.5 ORGANIZATION OF THESIS

This thesis consists of nine chapters and three appendices. Chapter 2 discusses the literature review in the light of transportation studies in Bangladesh and other countries.

Chapter 3 addresses the problem of, and the overall methodology for, constructing the computer model. It also briefs about overall deign of study procedure.

Chapter 4 describes different components of road network system, their characteristics and ways to accommodate them in computer models. This chapter explains different techniques of representing components of road network and selects the best one for computerization.

Chapter 5 contains the analytical approach of the model. The mathematical programming method is also presented in this chapter.

Chapter 6 concerns about the computer model or expert system developed in this research. It provides the description of the model, its problems and limitations etc. It also presents the performance of the model, using data gathered for traffic analysis of Jamuna Bridge. Step wise procedure for implementation of the model is provided in this chapter.

Chapter 7 describes the data variables and their uses. This chapter deals with explanation of variables used in the model and techniques for collection of data for these variables.

The analysis of data is provided in chapter 8. Different types of application of the model are presented in this chapter. Ways to gather output information from the expert system developed.

Chapter 9 gives the summary and conclusion of the study. This chapter also provides probable problems, limitations and suggestions to overcome them during implementation of the model. It also makes some recommendations for future study in this field.

The data tables developed and analyzed in chapter 6,7 and 8 are presented in Appendix A. The program and corresponding flow-chart are given in Appendix B. Appendix C contains input and output data used to check validity of the model.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a review of literature on transport studies with particular emphasis on urban traffic modelling procedures. An extensive literature survey of the documents on relevant researches and studies done both within Bangladesh and abroad has been performed and some of them are abstracted in this chapter. A review of the literature reveals that only a limited research has been accomplished on the topic of road network modelling and assessing the performance on the context of urban roadways. Some ideas from this review study have been incorporated in the current study.

2.2 THE NATURE OF TRANSPORT STUDIES IN BANGLADESH

Before entering in the theme of the present study, it is desirable and informative to review the past transport studies in Bangladesh specially those relating the metropolitan Dhaka. This section summarizes those studies.

2.2.1 Planning and Policy Study

Though Dhaka is a very old city, detailed study and research based planning of the city is relatively new. The first study on road network planning, "Dhaka City Master Plan" was made in 1964. It

provided a detailed plan for future construction of roads in the metropolis. Another study was made on the economic and engineering feasibility of the "Dhaka bypass" in 1968. In this study along with recommendations for the design and construction of the road, some suggestions were made on traffic control and traffic management.

Baquee (1979) conducted a study regarding traffic problem in old Dhaka city. It was a comprehensive study on nature, cause and probable solution of congestion in old Dhaka city. In the study it was found that traffic congestion arises partly because the city road network was not designed to cope with new forms of road transport and their increasing numbers. Also traffic management has been neglected.

Baquee pointed out that some way of controlling the use of roads can 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 change in the landuse of pattern can improve the situation greatly.

Shankland Cox Partnership (1979) study : It is a comprehensive study on transport development in metropolitan Dhaka, emphasizing 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 considerations for rickshaw in road construction. Shankland Cox Partnership (1980) 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 are allowed to continue at the present rate without any restrictions, an increase in number in likely. On the other hand if rickshaws are eliminated from the metropolis the situation will create serious pressure on other modes of transport which are grossly inadequate at present and will also have impact on the general living conditions of the public as the travelling costs in general is likely to elevate. The most serious impact, however, will be the employment situation since a large number of people will be rendered jobless.

Jamuna Bridge Project, Phase II study, Feasibility Report, Volume V & VI - Economic and Traffic Studies (1989): The main elements of the study are macro and regional economic development, the transport system in terms of operating characteristics and unit costs, the forecasting of passenger and freight traffic, the study of road and rail ferries, the benefits to be derived from an electricity interconnector placed on the bridge, the investment and

maintenance costs of the bridge, and the environmental impact of the bridge structure on agriculture, fishing and river transport. The economic and traffic studies and the evaluation of the proposed Jamuna crossing have been approached in the context of the socio-economic and geo-graphical background of Bangladesh. In this study traffic assignment and optimization has been used to predict traffic volume. Traffic data collected for Jamuna Bridge feasibility study was used in this research project.

2.2.2 Traffic Management and Safety Study

Ahmed (1980) discussed different aspects of failure in traffic management and administration for Dhaka City. It found that existing transport facilities are not adequate to meet travel demand and mixed mode situation has resulted in traffic congestion and less safety. Suggestions for modifications of traffic management and policies has been made.

Hoque (1989) mainly dealt with different aspects of road safety. He identified several typed of road accidents in metropolitan Dhaka. He also pointed out their cause and recommended some remedial actions.

2.2.3 Studies on Urban Travel Pattern

Ara (1983) investigated the factors that are responsible for the selection of particular transport mode. In particular, it analyzed the travel behavior of a number of households from some particular localities in the metropolitan Dhaka. It was found that total family income is the most important factor in determining its members' choice of appropriate transport mode for different trip purposes. Other factors those influence selection of travel mode are age and sex, transport ownership pattern etc.

2.2.4 Studies on Urban Public Transport

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

AHSAN (1990) investigated the status of the public transport systems in Metropolitan Dhaka. Particular attention had been given to examine the necessity of a functional and cost effective "mass transit" system. It pointed out that the existing mass transit system needs to be expanded in terms of both fleet size and route network. It also recommended to improve maintenance facilities, stops and terminals layouts, the quality of services and

development of more advanced form of transit facility such as rapid transit system.

2.2.5 An Overview

In Bangladesh only a few studies have been made on the transport sector. Of them, however, the urban sector transportation is richer than the rural sector and 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, are mostly related to the transport inventory, traffic management and safety problems, and physical characteristics of different modes. None of them are related to traffic optimization from the view point of transportation planning. Also traffic forecasting and performance evaluation in terms of traffic engineering parameters has not been studied yet.

However, among these studies, only Baquee (1979) studied traffic congestion problem and made some recommendation in the context of traffic management and optimization. In the "Jamuna Bridge Project Feasibility Study" traffic optimization techniques have been used for whole national road network. Studies on traffic optimization and planning for urban traffic is yet to be made. Research in the field of travel synthesis in Bangladesh is conspicuously absent.

2.3 RESEARCH ON TRAFFIC PLANNING AND MANAGEMENT

Many studies have been done in different countries relating to urban travel behavior and its relation to socio-economic variables of urban dwellers. Some of them, which deals 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 are 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 is semi-independent centers or clusters of activities are provided with ready access of 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 diseconomics of over concentration. He emphasized on the need for traffic simulation modelling for the

design of large-scale urban development. He also suggested traffic optimization modelling as a tool for such process.

2.3.2 Choice of Travel Mode

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

1) Characteristics of Journey that includes:
    a) Journey time/length
    b) Journey purpose
2) Characteristics of traveller which includes
    a) income
    b) car-ownership
3) Characteristics of transport system which includes
    a) relative travel time
    b) relative travel cost
    c) relative level of service
    d) accessibility indices

For modelling 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 of

which only the current researches are discussed below.

Case and Latchford (1981) examined characteristic 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 into the organization and operation of conventional bus undertaking and privately operated 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, Berger and Stoulov (1988) investigated the transport situation in Quito, Ecuador and proposed a new planning and bus scheduling program for the city. Umigar, Sikdar, Khanna and Rana (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 these new technique offer traffic planners new and perhaps more approximate means for using computers in their work.

Young, Taylor and Gipps (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 Pavel Schonfeld (1984) studied and developed a macroscopic model for Traffic Simulation and Optimization for regional highway networks. It was applied to the Maryland Eastern Shore network, where heavy recreational traffic creates 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 are

infrequent.

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 MODELLING

All the road users are aware that traffic conditions vary widely over the road system. The situation in most of the cases are very unsatisfactory. Though everybody is concerned about the situation, their recommendations for its improvement vary from person to

person. Traffic modelling represents one method of resolving some of these conflicts. It is directed towards gaining an understanding how the traffic system operates. Models are, however, developed for many purposes such as traffic flow-volume relationship study, traffic management, traffic planning, load-use planning. 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 [Taylor et al, 1985]. 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 part 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 signalling, geometric design of road and fleet composition.

2.4.1 Comments on Transportation Modelling Systems

This is a relatively new field of study and only a little work on models and expert systems in transportation engineering had been done [Ritche et al, 1987]. 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 then are remain 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 designing traffic signal setting. 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, discrete equilibrium transportation network. The system was part of doctoral dissertation by Shein-I Tung in the Department of Civil Engineering at University of Washington [Ritche et al, 1987].

Some other expert systems on transportation operation, control and management are HERCULES, STREET-SMART are still under development.

TRANSTEP a transport demand model to predict traveller responses to transport policies and practices [Nairn,1984]. It is a flexible microcomputer based demand model suitable for the analysis of a variety of urban landuse/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 [Bolland et al 1979, Hall et al 1980, Van Vliet 1982]. It is useful for the analysis and evaluation of traffic management systems over relatively localized node networks [Young et al 1988].

MULATM 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 and 'slow points'. For an engineer or planner the 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 UK Department of Transport model intended for relatively small road networks, but which may contain complex traffic and pedestrian control techniques [Young et al 1988].

A comprehensive listing of transportation models can be found in Young, Taylor and Gipps (1988) and Radwan and Sadegh (1985).

2.5 DEFINITION OF FUNCTIONAL CLASSES OF HIGHWAYS

Roadways are functionally classified because planning and design of new roads and management of roads and traffic in existing network

depend on it. A network consists of different types of roadways. Parameters for capacity, traffic flow, and access control vary for different types of highways. The variations are much severe at intersections. The study project considers that the parameters remains same for the whole network under study. This in fact implies that the roads considered are of same type or the variation is very small.

The classical functional hierarchy of road systems in the context of urban development pattern is described by Russell (1968). This is depicted in figure 2.1.

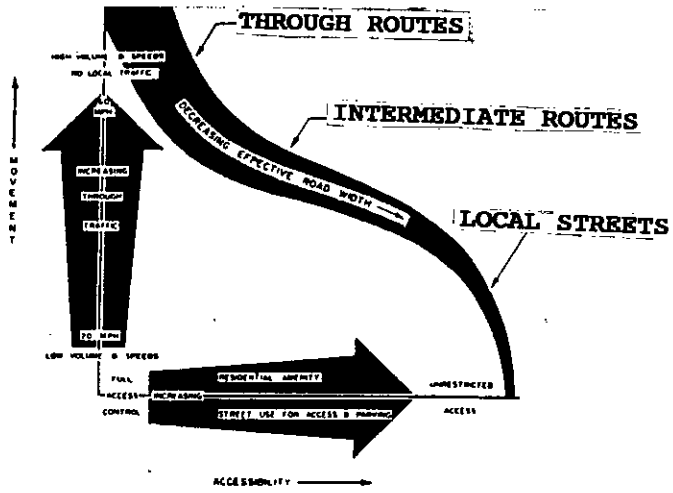

Figure 2.1 The classical hierarchy's view of the gradation of road functions. (Source : Russell, 1968)

The Melbourne Hierarchy of Roads Study (M.M.B.W. , 1981) adopted the following definitions, and urged that they can be adopted by

'all relevant agencies' to improve communications (Brindel, 1984):

Freeways : those roads with full access control and grade separated intersections, whose primary function is to service large traffic movements.

Primary Arterial Roads : those arterial roads whose functions is to form the principal avenue of communication for metropolitan traffic movements not catered for by freeways.

Secondary Arterial Roads : those roads which supplement the Primary Arterial Roads in providing for through traffic movement, to an individually determined limit that is sensitive to both roadway characteristics and abutting land uses.

Collector roads : those non - arterials roads which distribute traffic between the arterial roads and the local street system, which provide local connection between arterial roads and which provide access to abutting property.

Local Access streets : those street not being arterials or collectors, whose main function is to provide access to abutting property.

2.6 CONCLUSIONS

From the above review, it appears that the most transport studies in metropolitan Dhaka are related to the transport inventory and traffic management of urban transport situation. Some of them have dealt with mass transit system in the metropolitan area. There has

been no study on traffic planning and methods for traffic assessment and evaluation techniques. Information on parameters relating to the system development and performance evaluation techniques of the existing road network are not available in those literature. 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 new construction in road network is deemed important in providing guidelines for future policies investments and improvements in the existing road network.

Traffic management and planning have become the focus of urban transport planning in the developing countries and this is reflected in the most literature available. Literatures discussed in this chapter is expected to provide guidance for traffic planning and management using computer aided optimization techniques in the present study.

CHAPTER 3

STUDY DESIGN AND METHODOLOGY

3.1 INTRODUCTION

Planning of urban roads has been a major focus of transportation engineering research. Most of the current researches in this area has been overviewed in chapter 2. In this research an effort has been made to develop computerized procedures to optimize traffic in a network and to assess the effectiveness of new links. By estimating traffic volume over new road links, the usefulness, the impact of such links and traffic congestion can be visualized and evaluated. A method has also been developed to find the quickest route from a particular trip origin node to a particular trip destination node.

This chapter is concerned with the overall study design and the methodological considerations. The study design is organized to include the underlying principle of the traffic optimization model, selection and description of the study area where the model was applied for analysis and the need for traffic and road data and their collection procedure.

3.2 STUDY DESIGN

Before entering into the theme of the study the total procedure should be briefed to give an overview and a clear understanding of the thesis. The following sections explains traffic optimization,

study area where this optimization model was applied and traffic survey for input data collection for the model.

3.2.1 Underlying Principle of the Study

Chapter 2 provides basic conception about the variables of traffic planning and management to optimize traffic flow through a road network. For optimization of traffic flow one of these variables should be chosen as independent parameter and the others are related to it by empirical relationships or equations. In this study travel time has been chosen as independent variable which is to be optimized. In the optimized condition, traffic flow in the whole network be balanced in such a way that travel time consumed by individual user and overall travel time consumed by all the vehicles using the system will be the minimum. Other variables such as flow volume, capacity, free flow travel time are incorporated in the model by relationships which are explained in section 3.3.

3.2.2 Selection of the Study Area

The study area, in which context the proposed model has been applied, includes an inner part of the Dhaka metropolitan area. This is shown in figure 3.1. It includes the area bounded by Mohamadpur, Dhanmondi, Shahbag and Farmgate has been selected for the application of the model. This zone is known as new Dhaka where roads were built in more planned way considering the demand of the inhabitants. This is predominantly a residential area which generates a large amount of traffic particularly at peak hours. It

also works as corridor for the traffic from Mirpur and Cantonment area towards central business area like Motijheel and Dilkusha commercial area. Safe, quick and organized movement of traffic in this zone is very important for the overall traffic movement of Dhaka city. The study area is shown in figure 3.1.

3.2.3 Traffic Surveys

The collection, analysis and interpretation of traffic data are vital element in traffic engineering profession. This section deals with traffic survey procedures used in this research.

3.2.3.1 Need for Traffic Data

Traffic engineers and planners need information about traffic for a variety of purposes such as managing road and traffic system and designing and implementing changes to it. The purposes for which traffic information is required can be summarized as follows [Allsop, 1984].

a) Monitoring - the collection of information about traffic condition prevailing at any time and as they change over time.

b) Forecasting - the use of information about the traffic as it is under present conditions as one of the inputs to a procedure for estimating what the traffic would be like under different conditions, either now or in future.

c) Calibration - the use of information to decide what values to give to one or more parameters in a theoretical or simulation model.

d) Validation - the checking of a theoretical or simulation model against information quite independent of any that has been used in its calibration.

3.2.3.2 Traffic Survey Processes Used in this Research

Traffic surveys were designed to gather information of all the trips made in the study area; these data are useful in assessing the adequacy of the transport facilities as well as in developing models of travel demand. The data required for this research are road inventory data and traffic data. Road inventory data includes road length, width, number of lanes, roadway condition etc. Details of this information is given in chapter 7.4. For traffic data small scale origin-destination (OD) survey was made. At the counting stations drivers were asked about their origin and destination within the study area. A trip generation and distribution model can be an alternative to this OD survey. For monitoring of existing system traffic volume and speed surveys were made. Volume counts were made at some counting stations uniformly distributed over the study area. For speed surveys, speeds of different vehicles on different links were measured and the average was taken as average running speed.

3.3 METHODOLOGY

3.3.1 Overview of Road Network Planning Methodology

Transportation plans must be coordinated with land use and other plans for the region. This plan must be undertaken continuously, so

that the long range plans as well as the immediate action programs can be modified to meet changing needs. As a result of these requirements, the transportation planning process has become known as 3C transportation planning process- continuing, comprehensive and coordinated transportation planning process [Morlok, 1978].

Planning must start with data that represent the region served by the transportation system. One of the first step of the process is gathering of data. These data provide the basis for identifying problems and help sharpen the specification of the known problems. Also they provide the basis for the development of the various models used to forecast future land use, determine travel patterns, and model the performance of various proposed changes in the transportation system.

3.3.2 Need For Improved Methodology

The current practice at the Dhaka City Corporation (DCC) to build new roads is based on City Development plan without considering traffic engineering aspects. It is also lacks theoretical background. For inter-district or regional roads foreign consultants follow their own methods which vary from project to project. Recognizing that the current procedure is outdated, very simplistic and lacking logical and engineering values to justify them, the proposed method will provide a means of assessing the requirement of new link and performance of the road transport network that is reliable, well-documented, flexible and based on input factors which can be easily obtainable.

3.3.3 Methodology Developed for the Study

This section describes the methodology used for development of the model for traffic optimization. At first the scope of the developed model and then the basic features are explained.

A clear distinction should be made about the nature of the traffic planning methodologies. They are divided two separate groups : 1) Those that address the planning problem as a network analysis, based on traditional four-step process. They require enormous data and sophisticated computer resources. 2) The simple, easy-to-use planning based on deterministic method which lacks logical background. Deterministic approach uses some pre-determined coefficients and relationships which are extracted from past trend.

The proposed method seeks a suitable `middle ground' between these two types of processes using network analysis and traffic assignment techniques. Though sophisticated mathematical and computational analysis are included using computer, the complications have been reduced using some assumptions and thus reducing the amount of data and computer resources requirement. Easily available microcomputers such as IBM-AT compatible are enough to execute the program.

The result of Morf and Houska study [Morf and Houska, 1958] suggest different traffic planning models for different functional classes of roadways. The functional classification of roadways has already

been describe in earlier chapters. The proposed method is, however applicable to all the functional classes with light modification in data structure.

Figure 3.2 shows recorded Annual Average Daily Traffic (AADT) on Road no I-65 of Indiana state from 1950 to 1982. During 1970-71 a new parallel road was built. In this figure it is seen that flow of traffic is reduced drastically when the new roads are constructed. This is based on data collected by Indiana Department of Highways (IDOH), USA. The problem is how an engineer or planner can assess this effect at the planning stage before the construction of the road. The process developed in this research will provide an opportunity for the planners to assess traffic volume over any new or improved links before the implementation of the project.

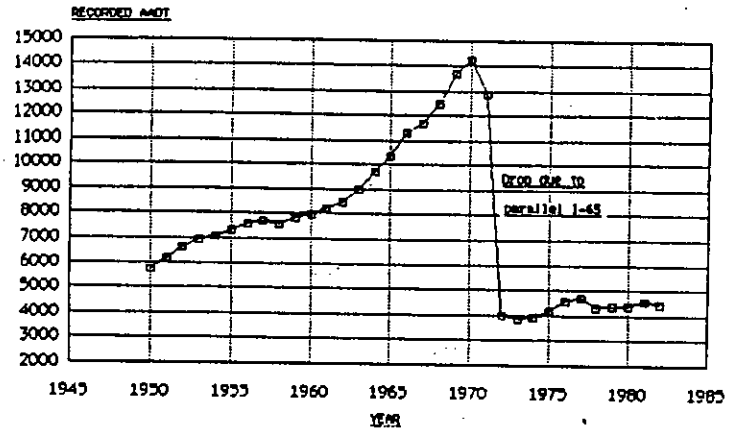

Fig. 3.1 Drop in traffic demand due to construction of new road
Source : Saha, S.K, 1986

The methodology used consists of three features :

- Finding of quickest route
- Implementation of traffic assignment model
- Choice of critical time.

Finding of quickest route

For quickest route finding, method described by Ford and Fulkerson was modified for the purpose of computerization. The method discussed by Ford and Fulkerson is analytical in nature and suitable for small network. It was modified to make it adaptable to computer and to use it for large networks. The method for finding quickest route by this method is discussed in greater detail with specific example in chapter 5. This will help in understanding of the model.

Traffic Assignment

Problem usually occurs when assigning trips to a roadway network. In practice a balance exists between travel costs and flows. A particular route between an origin and a destination is selected by a trip maker so that the perceived travel cost is approximately the minimum for the existing traffic condition.

A variety of techniques for traffic assignment are available. They are discussed in detail in chapter 5 (Section 5.4). The simplest one is all-or-nothing assignment. However, the explanatory power of such a model is too low to provide reasonably accurate estimates of

traffic flow.

All or nothing assignment results in a link with favorable cost, the link which costs minimum, attracting a considerable number of trips while links with unfavorable cost attract only few trips. In practice this would result in the originally favorable link becoming overloaded, a situation which would not occur in real life [Salter, 1976].

The problem of overloading is somewhat tackled by introducing capacity-restraint assignment to roadway networks by taking into account the relationships which exists between travel time required and flow on a roadway. The capacity restraint assignment technique can be implemented in various ways. The procedure to be developed first make a complete all-or- nothing assignment to the network using free flow travel time. The journey cost usually measured in time is then updated on the basis of flow assigned to it and the procedure to repeated for several iterations until link cost show a limited change on each iteration.

The capacity restraint model used in Federal Highway Administration (FHWA) computer program is applied in iterative manner. The adjusted link speed or its associated travel impedance (time) is computed by using the following capacity restraint functions:

$$T=T_0*[1+0.15*(\frac{V}{C})^4]$$

where T = balanced travel time

To = free flow travel time

= observed travel time at capacity times 0.87

V = assigned volume

C = capacity

[Federal Highway Administration,1965]

Choice of Critical Time

The choice of critical time for traffic optimization is another important issue. Generally the travel time during low level of traffic volume (that is, off-peak period), traffic optimization is not required. Individual can use any route according to his choice and none of the roads will be congested. The question of optimization arises when traffic volume is high and roads become congested. Generally the peak hour volume on most of the roads occur at the beginning and ending of office hours because of work trips. It was therefore decided to get an inventory of the peak hour traffic volume. The period chosen as critical time for traffic optimization was from 7-30 A.M. to 9-30 A.M. and from 1-30 P.M. to 3-30 P.M. The peak hour traffic volume data were collected from continuous count program. A total of 25 stations were chosen for this purpose.

Details of the analytical procedure, model development and data collection are presented in the chapters 4, 5 and 7 respectively.

3.4 AN OVERVIEW

A brief description of the study design has been presented in this chapter. These are included in the section of selection of study area and the description of traffic data items and their collection procedure. The underlying concept and principle features of the methods developed in the study are also provided in this chapter.

CHAPTER 4

ROAD TRANSPORT SYSTEM COMPONENTS

4.1 INTRODUCTION

As the study is basically concerned with the optimization of traffic through a road network, it is essential to have a clear idea about components of transportation system, particularly about components of road network. This chapter describes the components, techniques for their representation and quantification for their computerization.

Provisions are made for accommodating the traffic between many origins and destinations by linking the paths together, allowing the options in the choice of routing and hence the places reached. Thus two components of paths results - way link and way intersection. Links are paths in which the traffic is contained to flow through a particular route as in the case of railway track or highway. Flows on two links can be merged together and a single flow can be separated to follow two or more distinct paths at an intersection [Morlok, 1978].

Another component of transportation system is terminal. At terminals traffic enjoys the opportunity of being transferred from one vehicle or container to another.

The way links, way intersections and terminals of transportation systems are often referred to as fixed facilities, since they are fixed in location (unlike vehicle or containers).

The final necessary component of transportation system is an operation plan. Most transportation systems are very large, consisting of hundreds and thousands of elements. Thousands of distinct movements of traffic can occur in a single day. It is essential that traffic facilities be operated in such a way that traffic flowing through them can be accommodated and traffic is routed via appropriate links and intersections through the system to the final destination. All of these requires substantial coordination of the activities of each of the components. The set of the procedure by which this is done is termed as operation plan. Two other types of components might be separately identified: the maintenance subsystem and the information and control subsystem.

4.2 ROAD TRANSPORT SYSTEM COMPONENTS

Transportation system exists in order to provide facilities for safe movement from one place to another. A traveller desires to be transferred from one particular place, the origin, to another, the destination. For road transport this facility is provided using road network and vehicle.

The main components of transportation system are object and path in

which the object moves. The object is that which is to be moved and the path is the location in space along which it flows.

The object moves in some type of vehicles. The vehicle gives the object mobility on the particular type of path employed and which can be propelled on that path. The vehicle is identified as a third functional component. The interaction among these basic components of transportation system is illustrated in Fig. 4.1.

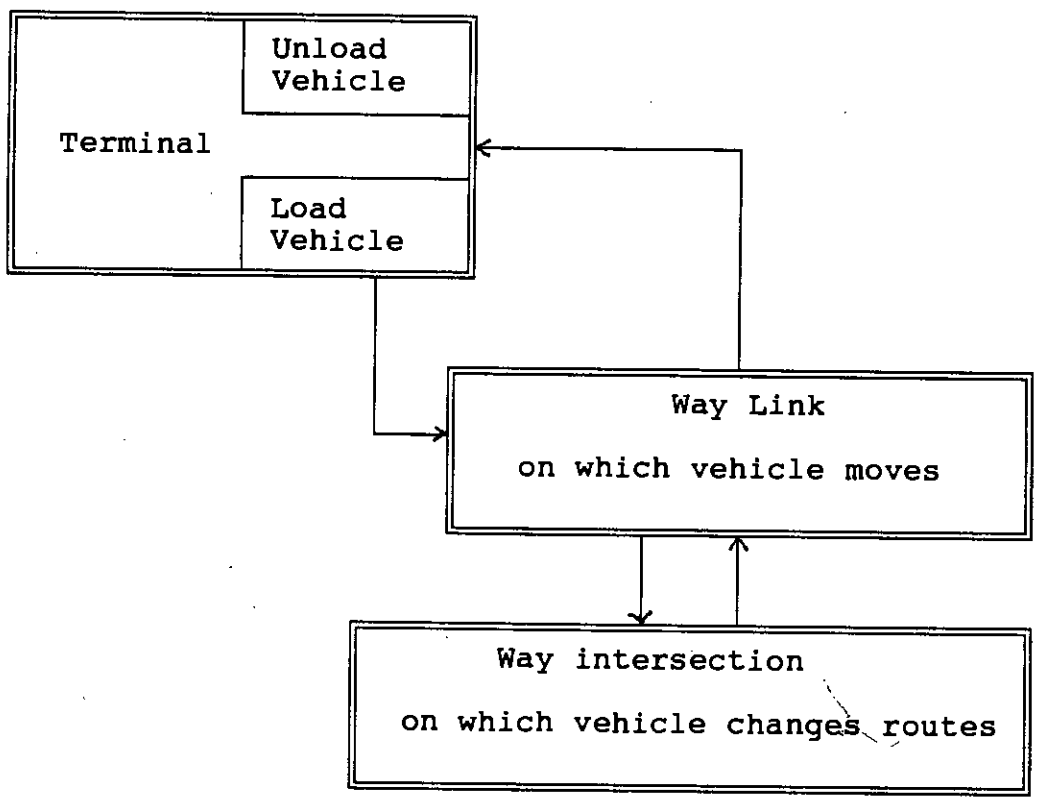

Figure 4.1 Transportation system components
Source : Morlok,1978

4.2.1 Road Network

A network is a mathematical concept that can be applied to describe quantitatively transportation system and other systems which have spatial characteristics.

As already mentioned, road network consists primarily of two elements - links and nodes. Nodes represents particular points in space and links are line connecting these nodes. A link is defined by the nodes which exist at its ends. [Morlok, 1978]

The network can be represented in the form of a map where direction of traffic flow is shown using arrows (Fig. 4.2). Figure 4.2(a) shows nodes and links of a typical network. It also shows time required to travel from the home node to other nodes and in parenthesis predecessor nodes are given where the home node is node 1. Figure 4.2(b) shows the procedure for selection of minimum path which is explained in section 4.2.2. In addition to this graphical form there are other ways of representing networks. Two important ones are the connection matrix and node-link incidence matrix. [Blunden,1971].

The connection matrix for network shown in Fig. 4.2 is given in table 4.1.

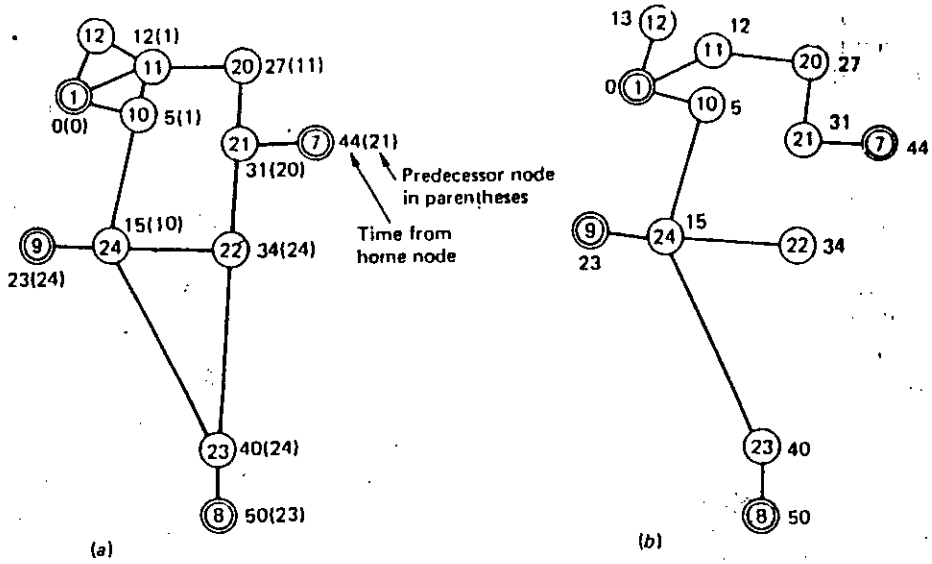

Figure 4.2 (Example network)

Table 4.1 Connection matrix of the network shown in Figure 4.2.

	Destination node												
Origin Node		1	7	8	9	10	11	12	20	21	22	23	24
	1	0	0	0	0	5	12	13	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	13	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	10	0
	9	0	0	0	0	0	0	0	0	0	0	0	8
	10	5	0	0	0	0	12	0	0	0	0	0	10
	11	12	0	0	0	12	0	5	15	0	0	0	0
	12	13	0	0	0	0	5	0	0	0	0	0	0
	20	0	0	0	0	0	15	0	0	4	0	0	0
	21	0	13	0	0	0	0	0	4	0	11	0	0
	22	0	0	0	0	0	0	0	0	11	0	21	19
	23	0	0	10	0	0	0	0	0	0	21	0	25
	24	0	0	0	8	10	0	0	0	0	19	25	0

In this matrix, rows and columns are the nodes of the network. A zero is placed in the cell corresponding to two nodes if there is no direct connection, in the form of link, between them. By convention zero is placed in the diagonal cells with same node in the row and column. Row number indicates origin and column number indicates destination. For flow from node 1 to node 10 the amount

will be placed in the Cell (1,10) and the direction of movement is from 1 to 10. For flow from node 10 to node 1 the corresponding cell will be (10,1). [Blunden, 1971]

Node-link incidence matrix is another way of representing road network. Here nodes makes individual rows and link makes columns of the matrix. Positive sign is placed corresponding to node which starts the link and negative sign is placed corresponding to node which ends the link. Table 4.2 shows node-link incidence matrix for the same network. The columns link destination and rows are node destination.

Table 4.2 Node-link incidence matrix

	Links for traffic flow															
		1-10	1-11	1-12	7-21	8-23	9-24	10-11	10-24	11-12	11-20	20-21	21-22	22-23	22-24	23-12
Nodes of origin	1	+1	+1	+1												
	7				+1											
	8					+1										
	9						+1									
	10	-1						+1	+1							
	11		-1							+1	+1					
	12			-1						-1						
	20										-1	+1				
	21				-1							-1	+1			
	22												-1	+1	+1	
	23					-1								-1		+1
	24						-1		-1						-1	-1

For advantage of computerization connection matrix form is used in

the model developed. Connection matrix provides easier representation facility, better understanding of the data stored and easier mathematical analysis implementation facility.

In addition to description of the spatial characteristics of transportation system, the network concept is used extensively to describe such characteristics as capacity, travel lime, flow volumes on various elements. The association of all these characteristics only with links or arcs is done primarily for mathematical reason and ease of analysis without any simplification of the network.

The problem of travelling through intersection can be solved in two ways, one is to include the travel time in the time spent travelling along one of the links or arcs leading into or out of that intersection. Another option is to divide the intersection itself into distinct links or arcs. In the model developed the first method is employed. A fixed time delay for intersection crossing was considered. This fixed time is the sum of red-time plus yellow-time per cycle at signalized intersection. The encountering of red signal was considered on probability basis. It was assumed that the user will encounter red signal at half of the intersections he passes through.

4.2.2 Network Analysis

A transport system is represented as a network in order to describe the individual components of the transportation system and their relationship with one another. Some of the most important characteristics of the system are travel time and cost.

This can be illustrated by reference to figure 4.2, which is the actual main road network. Average travel times in minutes are given on all links. The travel time from node 1 to node 8, via links (1,10), (10,24), (24,23), (23,8) is

$$5 + 10 + 25 + 10 = 50 \text{ min.}$$

There are other possible paths such as (1-11-20-21-22-23-8). Thus in giving origin to destination times or costs, it is important to specify the path used. In more general mathematical terms we can express this as follows, designating the path of interest p and the set of links or arcs comprising it Lp. [Morlok, 1978]

$$t_p = \sum_{ij \in L_p} t_{ij}$$

where tp - time from origin to destination

Lp - set of links

tij = time on link (i,j)

ij = Lp means ij included in the set of Lp.

In transportation engineering, another term is quite common - the least total travel time. In the context of person travel, most people select the route which minimizes total journey time. Here, the problem is essentially one of finding the path through the network having the minimum sum of certain costs (or times) associated with individual links which make up the path. Such a path is termed as minimum path or best path.

For this purpose a simple and elegant procedure - called tree building has been prepared. It is an application of a general mathematical procedure called dynamic programming. The procedure is explained in Chapter 5. This chapter describes analytically the example shown in Fig. 4.2(a) and 4.2(b), to find the path through this network, which has a minimum total time from node 1 to other nodes. The starting node is termed home node.

Starting at node 1, comparing the cost of traversing the links which emanate from that node, the link with minimum time gives the node to be selected. In this case node 10 is selected.

In the second step, it compares the time from the node 1 to all the nodes which can be reaches by travelling over one and only one additional link beyond a node to which the best path has been found (including the home node), of course the nodes which has already been reached will not be included because the minimum path to those nodes have already been selected. In this case, this step involves

comparing the times to node 12 (reached from node 1), node 11 (reached from node 1 and 10) and node 24 (reached from node 10). In this way the best path from the home node to the node of minimum time is 11 and the corresponding time is 12 minutes. Node 11 is labeled with (1 and 12). The third step involve extension of the procedure and thus repeating the above explained process for the whole network.

In performing analysis for finding minimum time paths, it is rather desirable to place the information in tabular form. Such a presentation is given in Table 4.3.

Table 4.3 Minimum Time Path for network shown in fig. 4.2

Node	Predecessor node	Cost in Time, mins
1	0	0
10	1	5
11	1	12
12	1	13
24	10	15
9	24	23
20	11	27
21	20	31
7	21	44
22	24	34
23	24	40
8	23	50

Such procedure of finding minimum paths in a network are undoubtedly the most widely used in network analysis tools [Morlok,

1978]. This can also be used to find path which has minimum cost.

This type of information on the characteristics of a network which relate to movements between all pairs of nodes can be usefully presented in a matrix form which is very similar to a connection matrix. Table 4.4 shows the minimum path travel time from each node to each other node as a possible destination.

Table 4.4 Matrix of minimum time path for node 1 as home node

	To node				
From node		1	7	8	9
	1	0	44	50	23
	7	44	0	55	51
	8	50	55	0	43
	9	23	51	43	0

Another important feature is that the best path through a network, regardless of the criterion used, often depends upon time of the day. In the case of highway networks travel time on any link is influenced significantly by volume of traffic on that link, the travel time increases with the increase in volume. During the middle of the night or early morning hours the volume may be quite low everywhere, and thus result in particular travel times on links and hence a particular minimum path from any origin to any particular destination. When traffic builds up as in a peak commuter travel period, certain links may be much more heavily used then others and hence their travel times may increase

proportionately much more than the travel times on other links. This may change the relative travel times among various links such that another path between the same origin and destination becomes the minimum travel time path. Thus the best path through a network can in fact be a function of time of a day. Accordingly the analysis for a particular time may not be valid for other times. For the analysis done in this research two most congested period were selected - morning peak form 7-30 A.M. to 9-30 A.M. and afternoon peak from 1-30 P.M. to 3-30 P.M.

Another aspect of network analysis, which is very important, is capacity. For finding capacity of individual links the following equation is used.

Service volume or capacity [Highway Capacity Manual, 1965]

$$Sv = 2000 * N * v/c * W * TL$$

where N = No of lanes

v/c = volume to capacity ratio depending on level of service

W = side clearance factor

TL = Truck factor

If there is only one possible path on which vehicles can flow, then the capacity of that path is simply the capacity of the link with least capacity. Mathematically it can be expressed as

$$C_p = \min_{ij \in L_p} \{C_{ij}\}$$

Where C_p = Capacity of the route

C_{ij} = Capacity of link ij.

In the case where the traffic can flow over many possible routes from the origin to the destination of interest, the problem becomes much more complex. It has been solved mathematically considering the limiting effect of other links on the earlier links of the path. This is explained in Chapter 5. In this chapter the basic elements of network analysis are explained.

4.2.3 Road Transport Vehicles

Vehicles of different types require different amounts of road space because of variation in size and function. In order to allow this in capacity measurements for roads and functions, traffic volumes are expressed in passenger car units (PCU's) [Ministry of Transport, Scottish development Department, 1966].

The different composition of road space by different types of vehicles can be expressed by a common standard. It is called PCU, passenger car unit. The PCU depends on vehicle speed and road design. PCU allows consideration of relative effects of various classes of vehicles by the use of appropriate multiplying factors.

There is an international standard of PCU where the motor car has been considered as one unit. Other vehicles are the expressed in relation to the standard car unit. PCU's for urban areas in Western countries are typically [E. Davis,1968]

Car	1.0
Truck/Buses Lorries	3.0
Motor cycle	0.75
Bi-cycle	0.33

The methods proposed by IRC (Indian Road Congress) and RHD (Roads and Highways Department, Bangladesh) also considered slow moving vehicles (like rickshaws,vans etc.) in addition to the vehicles listed above. PCU used by IRC (India) and RHD (Bangladesh) are given in Table 4.3 and 4.4 respectively.

Table 4.3 PCU provided by Indian Road Congress (IRC) [Source: Sharma,1988]

Vehicle	PCU
BUS/MINIBUS/ TRUCK	3
CAR	1
RICKSHAW/VAN	1.5
BABY-TAXI/MOTORCYCLE/BI CYCLE	0.5

Table 4.4 PCU provided by Roads and Highways Department (RHD), Bangladesh [Source : Shankland Cox, 1979]

Vehicle	PCU
BUS/MINIBUS/TRUCK	3
CAR	1
RICKSHAW/VAN/ BY-CYCLE	0.5
BABY-TAXI/MOTORCYCLE	1

4.3 SUMMARY

This chapter describes all the basic elements required for network analysis. Transportation systems involves too many components and variables. This chapter includes only those required by the model developed in this research. This will help in understanding the analysis procedures, the model and its input and output data.

CHAPTER 5

MATHEMATICAL PROGRAMMING METHODS

5.1 INTRODUCTION

The objective of this chapter is to provide a background understanding on the mathematical programming techniques used in the research. In chapter 4, different elements of road transport system and various ways of their representation were explained. This chapter describes how a transport system can be defined in a network form and how a mathematical programming approach may be used for its optimization.

5.2 REPRESENTATION OF A TRANSPORT SYSTEM

A landuse/transport system may be represented by a spatial array of land-use zones overlaid with a network representing the transport system. Such a system is shown diagrammatically in Fig. 5.1.

At macroscopic level extended zones do exhibit a great deal of homogeneity and permit the land use plan of most cities to be divided into some twenty to fifty major zones which permit business centers, industrial estates, residential areas to be characteristically defined. However, irrespective of the absolute analysis is to be undertaken, it is convenient to consider its activity to be concentrated at a point usually known as zone

centroid.

As specified in the earlier chapter there is no difficulty in specifying the transport network either geometrically or numerically, for in numeric form it is simply a two dimensional array of links and nodes of diagrammatic one.

For analytical purposes it is very convenient to specify the transport network in matrix form. This may be done by constructing a two dimensional inter-nodal link matrix or a node-link matrix. An example network is shown in figure 5.1 and its node-link matrix is given in table 5.1.

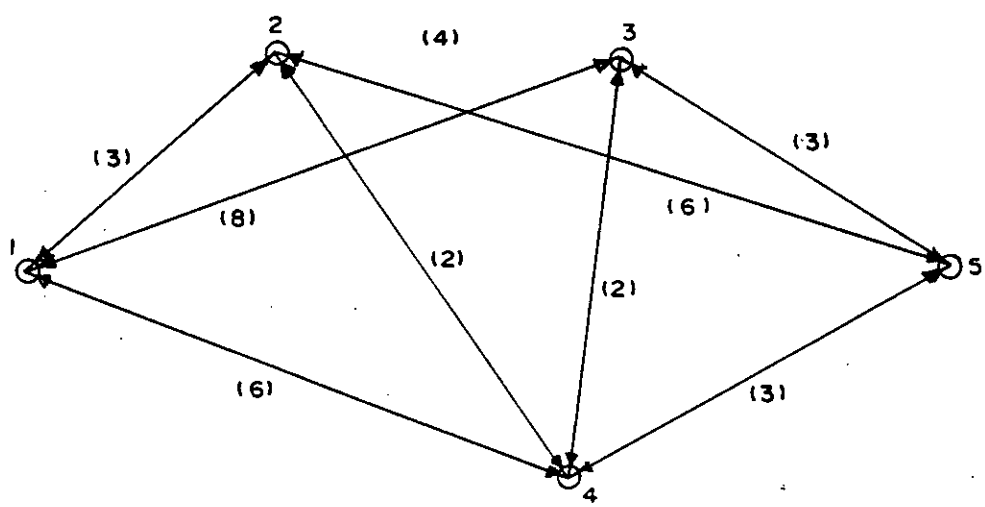

Figure 5.1 Example Network

Table 5.1 Node-link matrix for network shown in figure 5.1

		To node				
From node		1	2	3	4	5
	1	0	3	8	6	0
	2	3	0	4	2	6
	3	8	4	0	2	3
	4	6	2	2	0	3
	5	0	6	3	3	0

The elements of an array of this type may be used also to specify the length, travel time, capacity or cost of links of the network.

5.3 TRANSPORT IMPEDANCE AND TRAFFIC FLOW

The impedance of a transport element or system of elements which forms a network to conveniently measured by a suitable function which is synonymous with the "difficulty of traveling" over the link or progressing through the network. The time or cost of making journey provides a simple and sufficient measure of transport impedance.

The performance of a network is measured by overall traffic impedance which can be defined as the total time required by all the vehicles travelling through the network. It can be shown mathematically

$$Total\text{-}Traffic\text{-}Impedance, C = \sum_{ij \in L_p} t_{ij} * V_{ij}$$

Where i= Origin node

j= Destination node

t_{ij} = Travel time required on link ij

V_{ij} = Traffic volume on link ij

L_p = Set of links of which ij is an element

The impedance of transport element depends on flow along it. At low flows the impedance of the traffic element has its lowest value. As the flow rises the impedance increases, slowly at first and as the maximum flow level in approached the impedance rises rapidly. In the steady state situation it is asymptotic to the saturation flow ordinate as shown in figure 5.2.

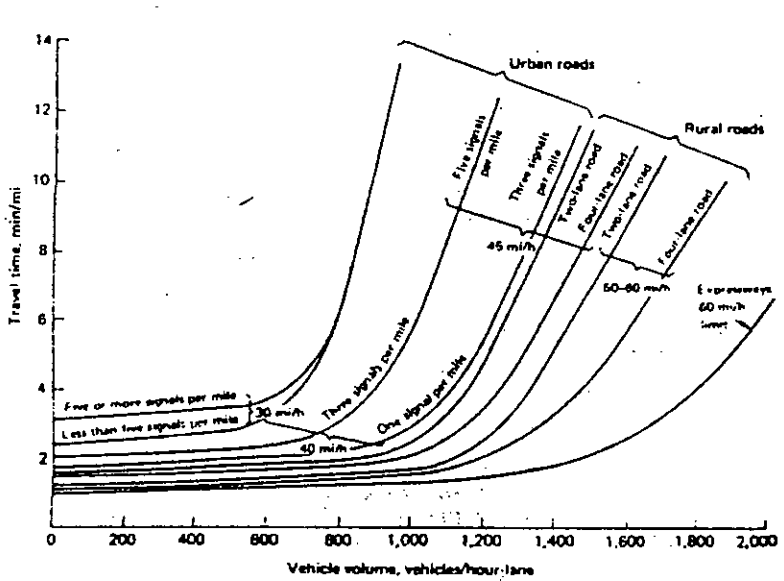

Figure 5.2 Travel Time- Flow relationship [Source : Morlok,1978]

Transport impedance depends on:

a) The zero flow travel time

b) The level of service factor

<u>The travel time/flow relationship for a finite length of road</u>

There is no complete theoretical explanation of the relationship between saturation flow and speed. The interaction between travel-time and flow arises from the disturbance due to the speed distribution resulting from faster vehicles catching up slower ones and being required to wait until passing or lane-changing is possible or in the case of single-lane or crowded lane conditions, being prevented from passing at all. On this basis there is a queuing mechanism at work. Figure 5.2 provides some useful information on queuing mechanism. These information and a number of well defined characteristics which can be stated from these experimental plots are listed below.

a) At zero flow the intercept on the travel-time axis is well defined and in the case of road traffic represents the reciprocal of the mean of the tree speed distribution.

b) In the steady state the delay is asymptotic to the situation flow ordinate.

c) The curve itself is monotonically increasing and the more "smooth" the flow situation the smaller the resulting travel time at least until saturation in imminent.

From these observations we may write the travel time t per unit distance may be written as

$$t = t^0 \left[\frac{1-(1-j)*y}{1-y} \right]$$

t^0 = zero flow travel time

y = q/s the ratio of flow to saturation flow

j = level of service factor as a function of the factors causing variability in the flow situation i.e parked vehicles, minor intersection, pedestrian crossing and so on. When j = 0 then t = t^0, no queuing at all.

In the absence of authentic data it seems appropriate in making initial evaluations or theoretical assessments to assume the values shown in Table-5.2 for the parameters of the travel time, flow equation.

Table 5.2 J-value and Capacity of different types of roads [Source: Blunden, 1971]

Condition	t^0 min/mile	j value	Saturation flow
Motorways	0.8-1.0	0-0.2	2000 /lane
Multilane urban arterials	1.5- 2.0	0.4-0.6	1800/lane
Collector roads	2.0-3.0	1.0-1.5	1800 in total width

5.4 MATHEMATICAL PROGRAMMING METHODS

This section provides with a background for the understanding of linear programming as network flow algorithms. It was already pointed out how land use/transport system may be defined in network form. Mathematical programming approach may be used for its optimization.

In this chapter the application of linear programming approach in will be discussed for shortest path and maximum flow problems.

Although the shortest path and maximum flow problem can be set up as linear programs, their special format permits their solution by "Combinational labelling algorithms".

5.4.1 Shortest Path Algorithm

There is number of good algorithms for determining the shortest path through a network. The most elegant and perhaps most useful is the one described by Ford and Fulkerson. It will best serve the

user in his exploration of the scope and application of this methodological device [Blunden,1971]. The method is described below.

The network shown in Figure 5.1 is considered. The number on the links represent their length either in distance or time units. The principal concern is to find the shortest path from a particular origin to a particular destination. This is done by labelling the whole network in a way explained below.

The labelling algorithm consists of finding a `label'-- a two-element set for a node, which is the other end of the link (i,j), where link (i,j) has emanated from an already labelled node, i. The label is written [i,p(j)] where i is the node from which the current node j is labelled, and p(j) is the shortest path from the origin to j.

The origin may be labelled [-,o] and the next node to be labelled is found by determining the j for which

$$p(j) = \min_{i \epsilon x}[p(i) + \min_{j \epsilon \bar{x}}(l(i,j))]$$

where x and $\bar{x}$ are the subjects of the universal set of nodes N

which lie to either side of the section (known is a cut) which divide the labelled and unlabelled nodes at any stage.

Example

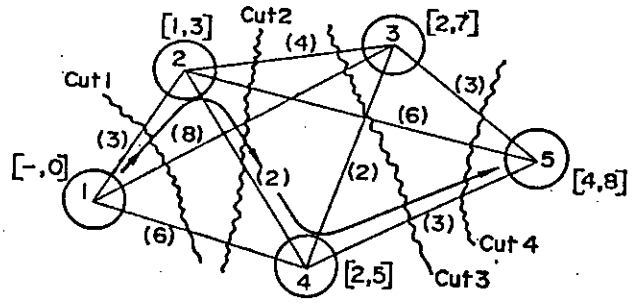

Figure 5.2 (Source : Blunden, 1971)

In this example node i is labelled [- ,0] starting with cut 1, the only node in x is node 1 and possible $\overline{x}$ we 2,3,4.

p(1) = 0

From

$$\min_{j \in \overline{x}}(l(i,j))$$

we get,

$$\min_{j=2,3,4}[l(1,2), l(1,3), l(1,4)]$$

ie, min (3,6 or 8)

ie, 3 or 1(1,2)

Therefore j = 2 and p(2) = 3 and node 2 is labelled as, (1,3)

For cut 2.

$$p(j)=\min_{i=1,2}\begin{bmatrix} p(1)+\min_{j=3,4}[l(1,3),l(1,4)] \\ p(2)+\min_{j=3,4,5}[l(2,3),l(2,4),l(2,5)] \end{bmatrix}$$

$$p(j)=\min\begin{bmatrix} 0+6^{l(1,4)} \\ 3+2^{l(2,4)} \end{bmatrix}$$

$$=3+2^{l(2,4)}=5$$

i = 2 j = 4 p(j) = 5

Label of node 4 is (2,5)

For cut 3

$$p(j)=\min_{i=1,2,4}\begin{bmatrix} p(1)+\min_{j=3}[l(1,3)] \\ p(2)+\min_{j=3,5}[l(2,3),l(2,5)] \\ p(4)+\min_{j=3,5}[l(4,3),l(4,5)] \end{bmatrix}$$

$$p(j)=\min\begin{bmatrix} 0+8^{l(1,3)} \\ 3+4^{l(2,3)} \\ 5+2^{l(4,3)} \end{bmatrix}$$

$$=3+4^{l(2,3)}=7$$

[Note: As both i=2 and 4 needs same time i=2 was taken because of least node traversed]

i = 2 j = 3 p(j) = 7

Label of node 3 is (2,7)

<u>For cut 4</u>

$$p(j) = \min_{i=2,3,4} \begin{bmatrix} p(2) + \min_{j=5}[l(2,5)] \\ p(3) + \min_{j=5}[l(3,5)] \\ p(4) + \min_{j=5}[l(4,5)] \end{bmatrix}$$

$$p(j) = \min \begin{bmatrix} 3 + 6^{l(2,5)} \\ 7 + 3^{l(3,5)} \\ 5 + 3^{l(4,5)} \end{bmatrix}$$

$$= 5 + 3^{l(4,5)} = 8$$

i = 4 j = 5 p(j) = 8

Label of node 5 is (4,8)

So the shortest path from node 1 to node 5 is 8 units in length and the links comprising it are determined by travelling back to the origin guided by the first element of the label. In this case 5 to 4 then 4 to 2 and finally 2 to 1.

One problem arises regarding direction of movement. No restriction has been placed on the direction in which any of the links may be traversed. However one way streets may be dealt with by replacing the oneway link with links, having an arbitrarily large length and travel time, which will never be used in calculation.

5.4.2 Traffic Assignment to Road Network

Traffic assignment is that part of the process of estimating traffic volumes on urban transportation networks. It deals with the steps which follow the trip distribution and modal split of the traffic. Thus the origin to destination trip table for trips via a particular mode in question is known at this stage. The main focus of the method is one on the alternative routes which travellers might choose within a mode between any particular origin-destination pair. There are various approaches to traffic assignment. Two widely used methods are explained here.

5.4.2.1 All-or-nothing Assignment

All-or-nothing assignment is basically an extension of the finding of minimum paths through a network. It is called all or nothing because every path from an origin to a destination has either all the traffic or none of the traffic. It is assumed that all travellers 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. Then the total flow is the sum of all the flows on each of the links or arcs.

The steps in the procedure are:

1. Find minimum path tree from each origin to all other nodes.

2. Assign the flow from each origin to each destination node, obtained from the trip table, to the path comprising the minimum path for that movement.

3. Sum up the volume on each path to obtain total volume.

5.4.2.2 Capacity-restrained Assignment

The principal shortcoming of the all or nothing assignment is that it completely ignores the effect of the volume of traffic on a link on user cost, time or level of service. Some user cost-volume relationships are shown in Figure 5.4 which are applicable to traffic assignment problem.

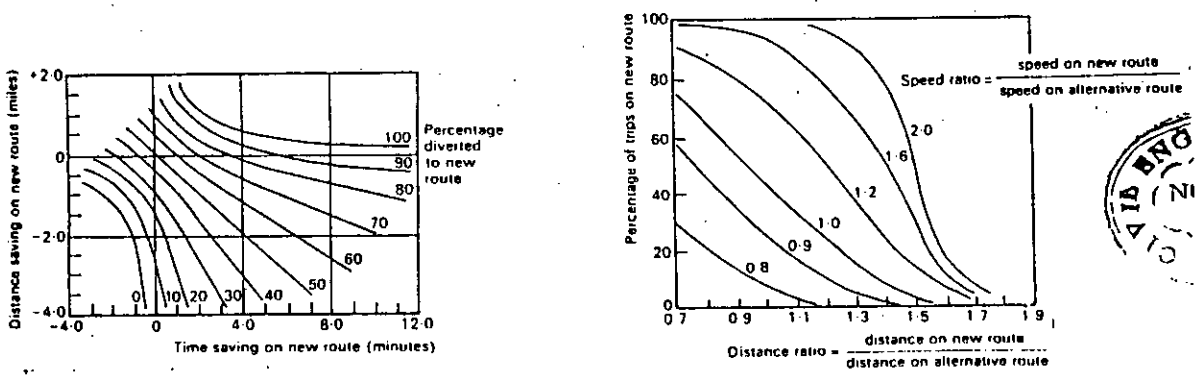

Figure 5.4 Diversion Curves [Source : Salter, 1983]

Somewhat similar functions are widely used in almost all assignment models. The relationship, developed by U.S. Federal Highway Administration [U.S. Department of Transportation, 1979] is used for this research and it is given in chapter 3 (section 3.3.3.)

The Wane State method incorporates a capacity restraint feature that attempts to simulate the manner in which equilibrium traffic flow are established in reality [Wohl et al, 1968]. Capacity restraint function used in this assignment method is extremely sensitive at volume away from capacity and travel time changes are very rapid. At volumes near capacity travel times change too slowly. These characteristics of restraint function result in the development of minimum path trees and assignments to these paths that would not carry any traffic at normal situation. By averaging these assignments for each iteration, these routes can be eliminated. But it requires many iterations. This technique is known as dynamic capacity restraint assignment.

The process of capacity restrained assignment as used in the model developed in this research is explained below:

Step 1: Using traffic-flow link time, calculate minimum path tree.

Step 2: Assign some percentage (Q%) of traffic to the minimum path. The lower this percentage is the higher the accuracy will be. The best procedure is to assign one vehicle each time. But the time required for this process will be too much. For the analysis done

in this thesis the percentage selected was ten.

Step 3: Calculate new travel time for links using capacity restraint function described in section 3.3.3.

Step 4: Find new minimum path tree.

Step 5: Repeat step 2 to step 4 for required number of times to assign all the traffic.

Number of repetition, N= 100/Q

For the analysis done in this research N= 10

5.5 CONCLUSIONS

Mathematical programming methods used in the thesis for quickest route finding and traffic assignment were explained in this chapter. These methods were described analytically for better under standing of the model developed in this thesis. Procedure to combine different steps were also provided.

CHAPTER 6

THE COMPUTER MODEL

6.1 INTRODUCTION

The preceding chapters of this thesis provide an introduction to the model developed in this research. This chapter introduces the model, its input and output phases and also checks the validity of the model.

The users can use the model perfectly to their need if they are familiar with its general structure, assumptions and limitations. But their main interaction with the model is through input and output procedures. Their willingness to use the model can ,therefore, be strongly influenced by the presentation and ease of interpretation of input and output. These procedures are of considerable importance if the model is to be accepted by traffic engineering professionals. This chapter describes the model together with its input and output phases. The model was designed in such a way that input data required are very few and easily obtainable. The output phase can present diverse types of information in tabular and graphical forms, such as equilibrium traffic volume, quickest paths, travel time etc. All of these outputs are presented independently so that users can get information and interpret them according to their requirements.

6.2 DESCRIPTION OF THE MODEL

In this section, different features of the model are described. The following framework is used for the discussion of the model:

a) Aim and capability of the model.

b) Features of the model.

c) Input procedure.

d) Output procedure.

e) Model validation.

f) Further application of the model.

6.2.1 Aim and Capability of the Model

The model was developed by computerizing traffic assignment for traffic optimization and road network evaluation. The model developed was named CATP (Computer Aided Traffic Planning Tools) which contains a number of useful features associated with micro-computers. These include `user friendliness', an immediacy of use through its installation on micro-computer system, an ability to run a `sketch planning' tool without large amount of data input. It permits a reasonable level of landuse/transport interaction modelling with only limited resources. It is based on traffic assignment model, and simulation of intersection delays. The model can handle traffic flow in different conditions of demand. The model permits interactive analysis of results.

The flexibility built into CATP makes it very useful in investigating problems in developing countries. Because the problems of large amount of slow moving vehicle and mixed modes of vehicles, motorized and non-motorized vehicles, are similar in these countries. Some more applications of the model is described in section 6.2.6.

6.2.2 Features of the Model

This model is a software system for transport planning based on the four step transport planning process (trip generation, trip distribution, modal split and trip assignment). It includes programs for highway and transit network simulation, capacity restraint assignment and selected link analysis. It is a menudriven software, which can be operated interactively or through pre-stored data files and can interface with data base management files. The package consists of three main modules: highway network analysis, matrix manipulation and graphical display.

Input/output for the model is primarily in a written form. Graphics facilities were introduced to enhance the acceptability of the model. The model can output information on network configuration, link volumes, speed, trip time, volume capacity ratio, trip tables and turn volumes.

It is essentially a dynamic capacity restraint traffic assignment

model which simulates travel demand, congestion level and network travel conditions over a given time period. For an engineer or planner the 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.

6.2.3 Input Procedure

Data input medium is a computer file or an interactive procedure. The interactive procedure uses interactive graphics to build and edit a network. The user selects the task to be carried out from a series of menus. Node and link numbering is to be assigned by the user. The major types of input to the model consist of

a) Network description

i) Node numbering
ii) Node coordinate
iii) Link length
iv) Link capacity
v) Average link speed

b) Trip demand data

i) Origin destination matrix
ii) Link volume input

c) Parameter values
i) Intersection delay

d) Output options.

Different input tables are shown in Appendix-C.

6.2.4 The Output Procedures

The output from traffic models can take many forms and levels of details. It is unlikely that an analyst can comprehend, much less use, all the data that a model can produce. It is therefore, necessary to be selective in the output requested and to carefully consider the means of presenting this output. Typically the output will be used to produce overall measures of traffic systems' performance and to answer specific queries about that performance.

It is an important point to remember when designing output displays is to present them in forms that the user is familiar with there are many ways to present output. In the model developed the output forms are:

i) storing output on computer file
ii) presenting output in printed form
iii) presenting output using graphics.

6.2.4.1. Storing Output on Computer Files

Presenting all the output as hardcopy is unlikely to be productive. The outputs are generally stored in disk files and then accessed by various analysts.

In the model developed the disk file outputs contains the ultimate

link volumes for equilibrium flow, the quickest routes for each iteration and travel time for the same. These gives the modelers and analysts the flexibility of post processing.

6.2.4.2. Presenting data in Printed Form

Summary reports containing text and diagrams of measures of performance can be presented in written form.

The output from the simulation program is presented in tabular form. Also the user has the flexibility to request for the data according to his own requirement.

Data summary in matrix and diagrammatic form makes it easier for people with little background in computing and traffic engineering to use it.

The report options available in the model includes :

a) Table of summary of link volumes

b) Table of summary of network performance parameters such as Total vehicle hours, Relative delay etc.

c) Road network map

d) Origin destination display

e) Minimum path trace

f) Detailed reports of road inventory and traffic condition.

6.2.4.3. Presenting Results Using Graphics

An important development in computer technology over the last decade is visual output forms - computer graphics, especially interactive graphics provide considerable scope for presenting the results of a model. The movement of vehicles along a route or around a network can be presented in easily understandable forms a graphical display.

Computer graphics is used in the model to show the quickest route for an individual on computer monitor. Outputs using graphics are shown in chapter 8 (section 8.4).

6.2.5 Validity of the Model

The validity of the model was checked using traffic data collected for Jamuna Bridge Construction study because the traffic data collected or generated for this purpose are recent and seemed reliable. Using the same origin-destination trip matrix and network description the traffic volume on different roads and on the proposed Jamuna bridge as predicted by the consulting agency and by the model is given in table 9.1. The data inputs and the detailed outputs are given in Appendix C.

6.2.6 Further Application of the Model

Though the model was developed for traffic optimization of road network and traffic effectiveness evaluation of road links it can also be used in solving some other traffic engineering problems. This model is useful as a tool for testing the impacts of one way streets, traffic control measures, constructions of new links and change in land use pattern, for example change in traffic generation and attraction pattern. These can be measured by finding out the equilibrium traffic volume under new traffic rules or changed conditions and comparing these results with traffic volume under existing situation.

It can also be used for modelling subareas within city wide road networks and for studying the effects introduction of different transportation engineering facilities such as flyover and route restructuring. Construction of a flyover eliminates problems at intersection. Change in traffic flow due to flyover construction can be predicted using the model. The model can also be applied in other modes of transportation where conception of nodes, links and traffic flow-travel time relationship can be adopted such as air and water transportation studies.

6.3 LIMITATIONS OF THE MODEL

The model attempts to represent average flow conditions on the network. Congestion has been encountered in the form of increased travel time requirement for each incremental traffic flow. All the

intersections has been assumed to be signalized. Drivers' route choice behavior is modelled on the basis of minimum path theory, that all the drivers passes through the minimum path for their origin and destination. The model does not consider vehicle movement disturbances, car following acceleration, deceleration or lane changing.

It is impossible to fully calibrate and validate a complex model as it contains a large number of parameters. Generally it is aimed at ensuring a good fit between simulation and practical data over the full range of conditions.

6.4 STEP WISE EXECUTION OF THE MODEL

This section describes execution of the model on micro-computer. The model is fully menu-driven and the menus are self-explanatory. While executing the program the first menu that will appear is like

```
MAIN MENU

1. Edit input data
2. Analysis of data
3. Output options
4. Exit
```

The first option provides the facility to input data into the program and edit them. Option 2 performs the mathematical calculation for the model. Option 3 provides outputs of the model in different forms.

For choice 1 of the 'Main menu' the next menu that will appear is like

```
INPUT MENU

1. Input Network Data
2. Input Traffic Data
3. Exit
```

In this menu, option 1 is for inputing data for road inventory such as link length, link width, node coordinates. Option 2 is for inputing data for traffic engineering aspects such as link capacity, existing traffic volume, delay at intersection.

For choice 2 of the 'Main menu' the next menu that will appear is like

```
FUNCTION MENU

1. Find quickest path
2. Find equilibrium traffic volume
3. Exit
```

This is the menu for performing the principal functions of the model. Option 1 of this menu finds the quickest path from one particular origin to another particular destination. Option 2 calculates equilibrium traffic volume for the network defined using option 1 of main menu.

For choice 3 of the 'Main menu' the next menu that will appear is like

```
OUTPUT MENU

1. Quickest route on display
2. Equilibrium traffic volume printing
3. Travel time printing
4. Exit
```

This is the menu to get required output from the model. Option 1 of this menu displays the quickest path on computer monitor. Option 2 prints equilibrium traffic volume and option 3 provides travel time on different links of the network.

6.5 CONCLUSIONS

In simulation process input to and output form the model are the aspects those are most visible to the user. As explained in this chapter, it is essential that the user understands the procedures easily. The effort in making the input and output more user friendly will provide grater acceptance and more use of the model.

As shown in this chapter the model is fully menudriven one. The menu is written in a form which is easy to interpret and execute. This chapter also demonstrates that the model has all the capabilities to be handy.

CHAPTER 7

DATA COLLECTION AND ANALYSIS

7.1 INTRODUCTION

In this chapter, a number of variables that have been identified as the traffic flow variables will be discussed along with the traffic data for which the model is developed. These data tables are the input for the analysis. The main objective of this chapter is to describe the variables and the evolution of data tables used in the analysis. The sources of the data and their conversion, where needed, are discussed in detail. Some of the data tables could be modified when new count stations and/or new traffic survey reports become available, in order to calibrate, modify and use the developed model to predict traffic volume on particular links.

7.2 DESCRIPTION OF VARIABLES

In this section the variables used in the model and in the analysis procedure are explained. It also includes the methods of collecting data for these variables.

7.2.1 Annual Average Daily Traffic (AADT)

AADT is the average 24-hour traffic volume for a given year, for both directions of travel, unless otherwise specified. This is the only response variable which needs to be predicted in the future years. This is measured by continuous traffic count stations on different functional classes of highway. For this study, 28 stations have been assigned at 25 locations. The position of the stations are shown in Fig. 7.1.

In our country, no census data of this kind was available. In the early stages of this study data tables were based on traffic data from Jamuna Bridge traffic study. The aim in these early stages was to use reliable data to validate the model. However, the literature [Saha, 1986] suggests the use of only recent practical data to develop models for estimating or forecasting traffic. This is why manual counting at the specified stations were made.

7.2.2 State Vehicle Registration or Zonal Vehicle Registration

The total number of vehicle registration in the zone where a count station is located and that for the whole area is a very useful data for traffic studies. These data are reliable in the sense that they are not estimates, but are counts made at motor vehicle registration offices throughout the state. This variable can estimate AADT on the assumption that AADT, in a particular year and

at a given place, is closely related to the number of vehicles registered then and there. The prediction of expected future traffic based on the projection of the trend of motor vehicle registration is a reasonably accurate indication of future highway traffic. In our country Bangladesh Road Transport Authority (BRTA) or other road transport authorities were unable to provide these data. Origin- destination survey were made to get the required data.

7.2.3 Peak Hourly Volume

Traffic volume during an interval of time shorter than a day more appropriately reflect the operating condition that should be used for design if traffic is to be properly served [AASHTO, 1984]. The brief but frequently repeated rush-hour periods are significant in this regard. In nearly all cases a practical and adequate time period is 1 hr for analysis and design.

The traffic pattern on any highway shows considerable variation in traffic volumes during the different hours of the day. It must be determined which of these hourly traffic volumes should be used in design. Though the design is made on the basis of peak-hour traffic of a year, the congestion at peak-hour of different days should be considered and the transport facilities available should be such that it can accommodate daily rush hours keeping congestion within a tolerable limit. For this research, two peak-hours has

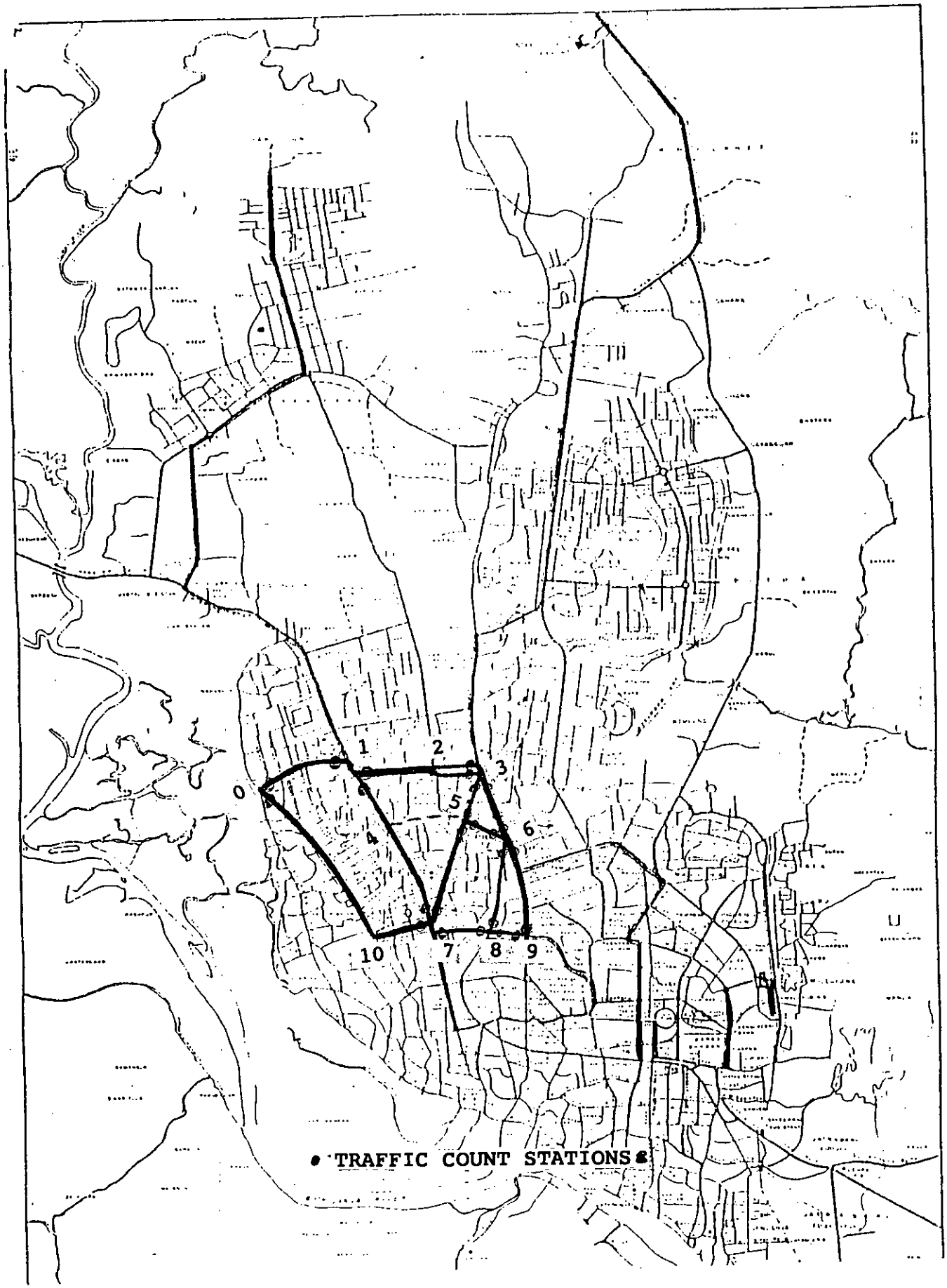

FIGURE 7.1 ROAD MAP OF STUDY AREA SHOWING TRAFFIC COUNT STATIONS.

been selected for analysis (7-30 to 9-30 am and 1-30 to 3-30 pm). The higher traffic volume of these two peak-hours was given in the program as input for analysis.

Traffic estimates used for the design of urban streets and highways are usually expressed as ADT volumes derived from the urban transportation planning process. Recently, however, considerations has been given to the development of DHVs by making peak hour traffic assignment in lieu of ADT assignments.

7.2.4 Highway Speed

One of the most important variable in traffic engineering is 'average highway speed' on different links. Speed is the rate of link length traversed in kilometer per hour. The studies on speed are mainly conducted for the following purpose -

a) Planning traffic control
b) Determination of speed trends
c) Study on accident
d) Highway capacity determination
e) Geometric design of Highways

There are three types of speed considered in traffic engineering - Spot speed, Running speed, and Journey speed.

Spot speed is the instantaneous speed of a vehicle at any specific

point. Running speed is the average speed over a particular course while the vehicle is moving and equals the length of the course divided by the time the vehicle is in motion. Journey speed is the effective speed of the vehicle on a journey between two points and is found by dividing the distance between the two points by the total time taken by the vehicle to complete the journey, including stoppage time due to traffic delays. The average speed considered in the model is basically running speed. Average running speed was collected from field survey for running speed of different vehicles.

7.2.5 Passenger Car Unit (PCU)

For converting different types of vehicles into same category for the purpose of analysis PCU is required. PCU has been explained in detain in chapter 4 (Section 4.2). Conversion of survey data into PCUs are shown in Appendix-A. In table 7.1, summary of survey data is presented.

Table 7.1 Traffic Volume in PCU on different roads of the study area

Name of the road	From node	To node	Volume in PCU in two peak hours
Farmgate	3	2	7151
Farmgate	2	3	6665
Mirpur Road	4	7	9755
Green Road	5	7	5963
Manik Mia Av.	1	2	14128
Sat-Masjid Road	0	10	5566
Airport Road	3	6	8135
Hatirpul Road	6	8	8045
Mirpur Road	1	4	8626
Asad Av.	0	1	8199

7.3 THE DATA TABLES

The twenty eight data tables, two at each station, are presented in Appendix-A as table A1 through A12. The data tables are of traffic volume count on urban arterials. Each row corresponds to ten minutes' sum of traffic. There are five columns each for bus and minibus, truck, car rickshaw and auto-rickshaw and scooter. The time in tables of Appendix A are labelled in rows to identify an observation that corresponds to Manual Traffic Record (MTR) count station.

The data tables were analyzed using PCU (Passenger Car Unit) method. The equivalency factors used were collected from - IRC

(Indian Road Congress) and RHD (Roads and Highways Department of Bangladesh). Stations or location specific models will be developed for highways having similar characteristics. In aggregate analysis, stations under a given category of highway to be analyzed as a group and a model applicable to any highway classifiable within a certain group is proposed. The value of the approach for each highway type was assessed through some trial estimates of traffic in chapter 8.

7.4 TRAFFIC SURVEY

A comprehensive data set is required to form a basis for design and planning of streets and highways. The results of the data collected are used in i) traffic planning, ii) Traffic management iii) economic studies and iv) traffic and environmental control and monitoring.

The traffic studies can be classified into many categories of which the following three were done for this research work.

a) volume studies and characteristics
b) Origin destination survey
c) Road inventory studies

7.4.1 Volume Characteristics and Studies

Volume of traffic is a very important variable in traffic studies. It is the quantity of movement per unit of time at a specific location. The elements of movement are composed of pedestrian, cars, buses, trucks etc. Time period will depend on the purpose of study.

Traffic Volume data is required to study relative importance of any route, distribution of traffic flow, fluctuation in flow etc.

There are various methods of traffic volume studies. They may be manual counting or automatic counting. For this research manual counting was made. Trained people were posted at different sections and asked to count and record the number of vehicles in different categories in a prescribed form (given in Appendix-A).

7.4.2 Origin-Destination Survey

The purpose of this study is to collect travel information to provide the most efficient transportation system. The information gathered by origin-destination survey of transport vehicles are:

i) their origin-destination irrespective of the present routes
ii) Mode of travel
iii) Travel time and direction

The method followed for O-D survey is Drivers' interview, where they were stopped and interviewed at various points throughout the study area and the required information was gathered. Data of O-D survey was presented in table 8.3.

7.4.3 Road Inventory Study

The purpose of this study is to collect information about highway inventories. The data is collected to prepare a map and to provide data for the variables of the model. The data gathered include road width, pavement width, method of dividing traffic lanes, surface type and condition, and road length. These data were collected from Dhaka City Corporation (DCC). Data for road inventory was presented in table 8.2.

7.5 SUMMARY

The central idea of this chapter is to describe the variables used in model development. The variables identified in Chapter 5 have been discussed and the source of their numerical values are given. The methods by which certain data are estimated or converted to a form compatible with the proposed model are also presented. The reason of selection of the variables are discussed. This chapter is a guide to the data tables appearing in Appendix-A.

CHAPTER 8

MODEL APPLICATION AND RESULTS

8.1 INTRODUCTION

In this chapter the applications of the model are described. First the performance of the model is tested by trying to predict the passenger bus traffic volume over Jamuna bridge and comparing it with the passenger bus traffic over the bridge predicted by the consulting agencies. Then the model is applied in the study area which is explained later.

8.2 MODEL PERFORMANCE TEST

Model performance was tested using traffic data collected for Jamuna Bridge. All the data for this purpose was taken from "Jamuna Bridge Project, Phase II study, Feasibility report (1989)." These data were collected the consulting agencies Randel Palmer & Tritton and Bangladesh Consulting Ltd. The objective of this testing is to compare two bus passenger traffic volumes over Jamuna Bridge - one predicted by the consulting agencies and the other predicted by the model.

The road network of whole Bangladesh is shown in figure 8.1. Road network inventory data is given in Appendix C table C.1 and passenger bus traffic origin-destination matrix is provided in

Appendix C table C.2. Link 35-36 is the proposed Jamuna bridge. The detail output of the model is given in Appendix C table C.3.

8.2.1 Output of Model Performance Checking.

The output of the model is presented in Appendix C. From this it is found that passenger bus flow over Jamuna Bridge will be 3724 PCU/day. According to Jamuna bridge consulting agencies the predicted passenger bus flow is 3884 PCU/day.

The difference between these two predictions = (3884-3724)/3724
= 4.29%

8.2.2 An Overview on Model Testing

The performance of the model was tested using traffic data gathered or generated for Jamuna bridge analysis. The variation of the prediction made by the model and by the consulting agency is less than ten percent. This result provides the model with enough confidence to be valid for practical use.

The testing of the model with data within the study area was not possible because of lack of traffic data. But the model's validity checking demonstrates that the model will provide data reliable enough for design and planning purpose.

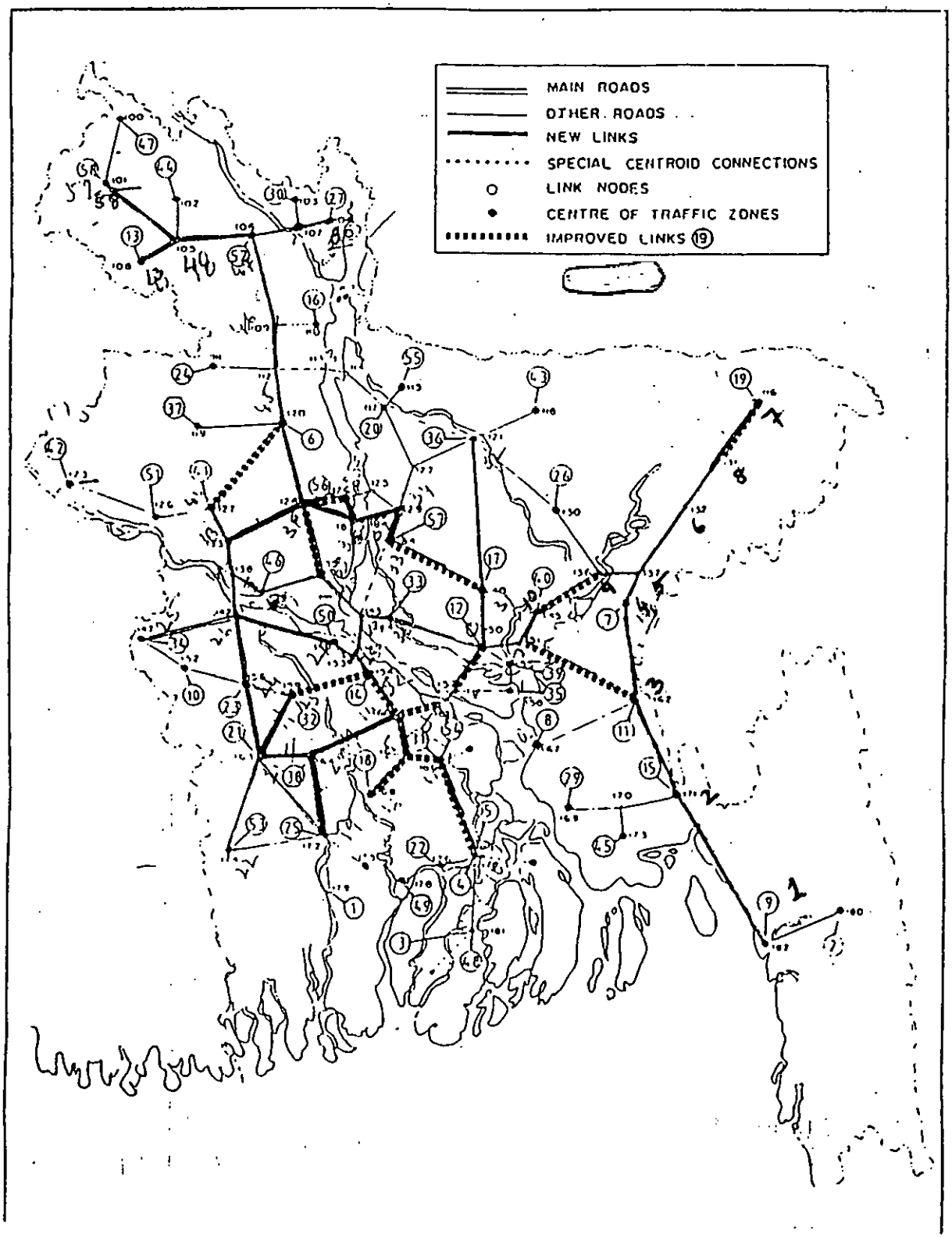

FIGURE 8.1 MAP OF BANGLADESH SHOWING ROAD NETWORK.

8.3 APPLICATION OF THE MODEL IN THE STUDY AREA

In this section the model is applied in the study area under this research project. Data for the study area is inserted into the model and the outputs are analyzed.

8.3.1 Study Area

The study area is located in new Dhaka bounded by the region Mohammadpur, Dhanmondi, New-market, Shahbag, New Eskaton and Farmgate area. The study area and its road network are shown in figure 8.2a and figure 8.2b. The corresponding view on computer is also given in section 8.3.3.

8.3.2 Input Data

In this section the input data required for the analysis are given. Two types of data are required - one for quickest route finding and the other for equilibrium traffic flow. Data required for quickest route finding for individual traffic are 'from node', 'to node', 'existing traffic volume' ,'link capacity', 'link length', 'average link speed'. These data are given in table 8.1. In traffic assignment for optimization of traffic volume for the purpose of finding equilibrium traffic volume the inputs required are 'from node', 'to node', 'link capacity','link length' and 'average link speed'. This data for the study are taken from the same table. The

origin destination matrix is given in table 8.2.

Existing traffic volume was obtained from traffic count, as explained in chapter 4. The raw data is provided in Appendix A. Existing Traffic volume was calculated in PCU/hr unit. The conversion factors used was given in chapter 4 (PCU by IRC, India).

Capacity of each link was calculated using equation given in chapter 4 (section 4.3).

In origin destination matrix the peak hour demand volume was obtained by origin destination survey. Some sample of drivers, at each station, was asked about their origin or point of entrance into the study area and destination or point of exit from the same. Vehicles which entered into or exited from the study area through a point in between two nodes were assigned to the nearest node.

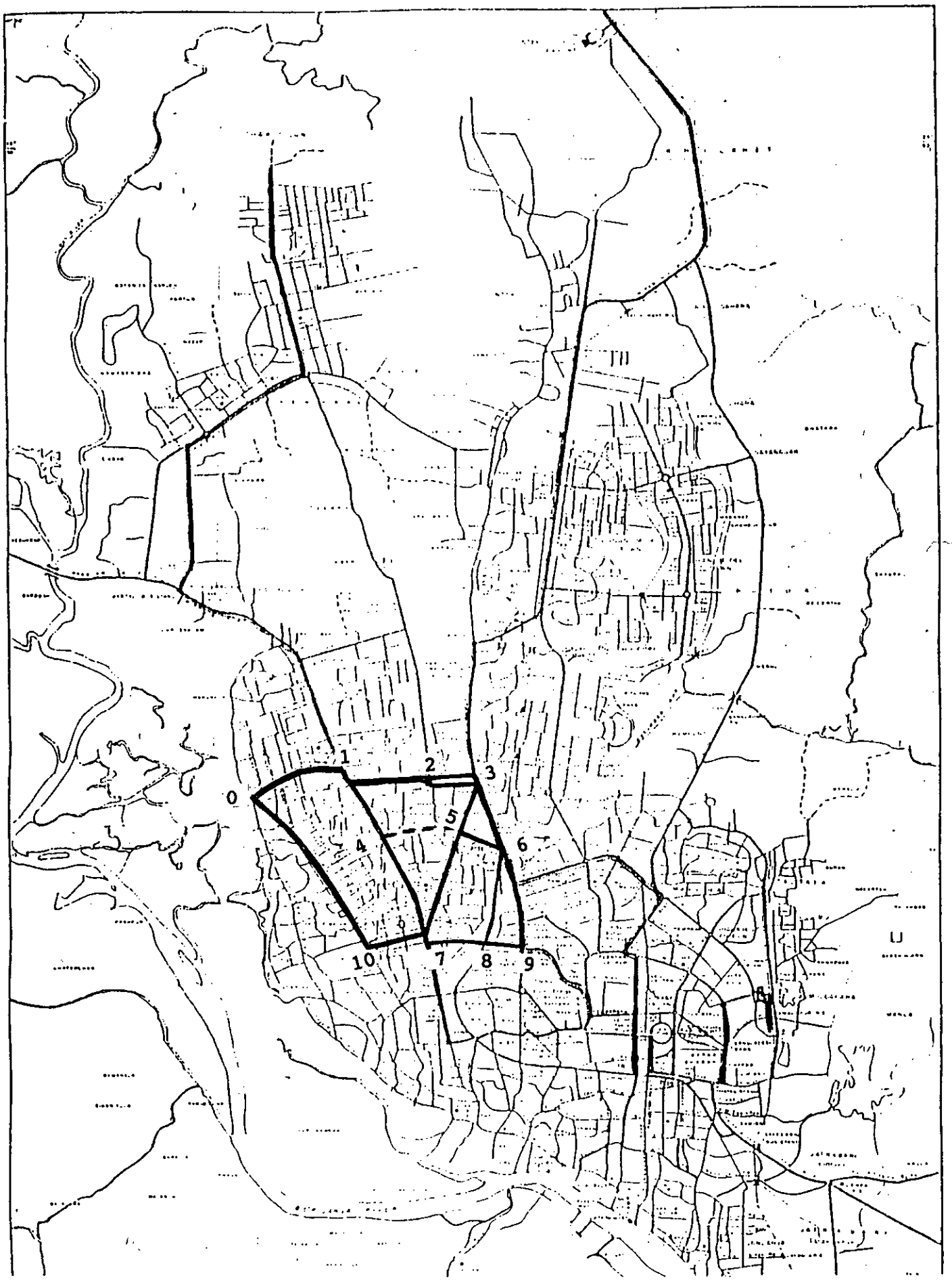

FIGURE 8.2 ROAD NETWORK OF STUDY AREA.

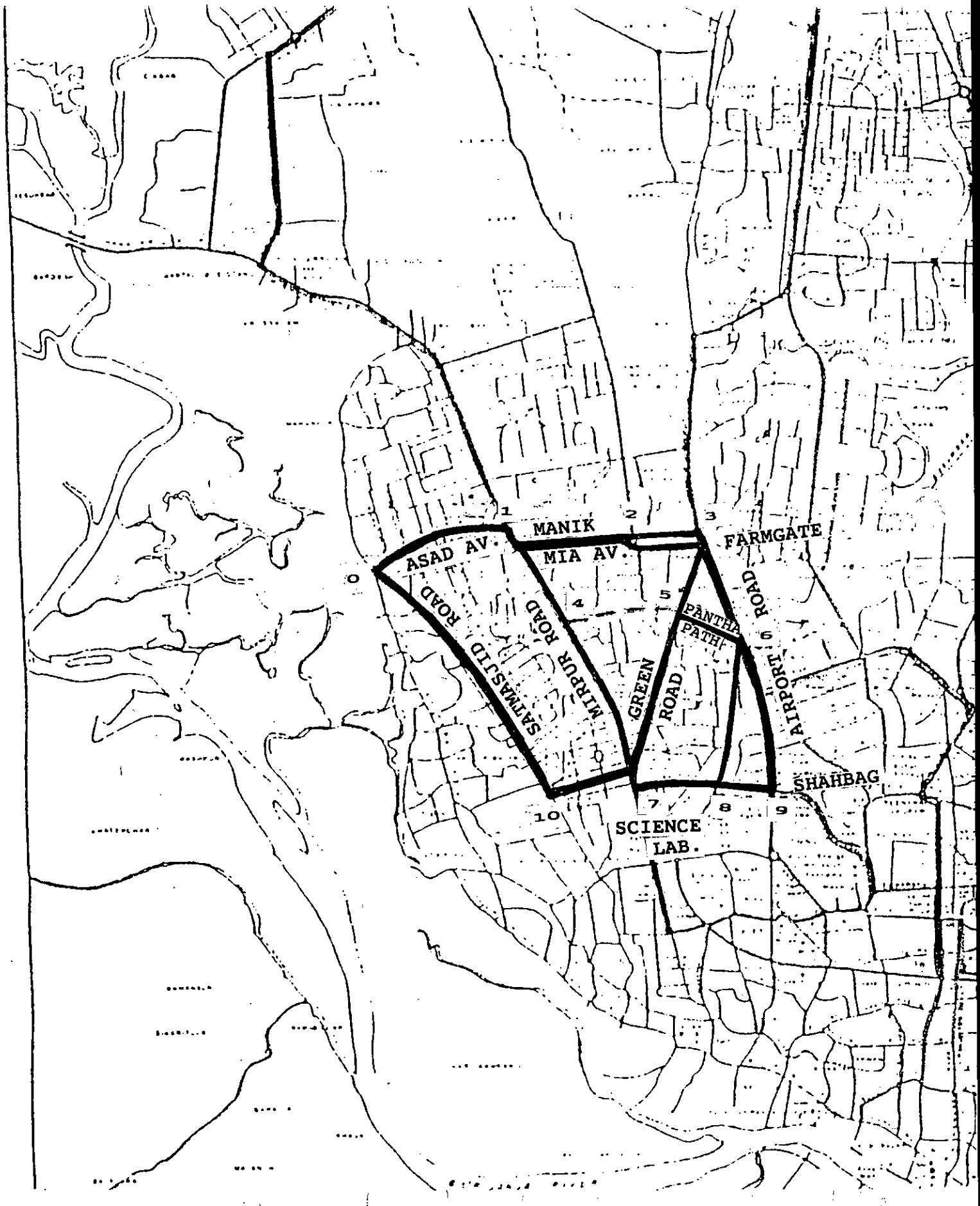

FIGURE 8.3 ROAD NETWORK OF STUDY AREA (ENLARGED)

Table 8.1 Input data for network optimization

From node	To node	Existing volume, PCU	Capacity PCU/hr	Link length,ft	Operating speed,mph
0	1	1404	1250	3000	10
0	10	1809	2400	5500	20
1	2	4023	4300	2188	10
1	4	3170	2400	1850	10
2	3	5823	3000	1850	10
3	5	1788	1200	1850	10
3	6	3273	2400	3250	15
4	7	3170	2400	3250	10
5	6	1420	2400	3250	10
5	7	1820	1200	2875	10
6	8	2413	1250	2750	10
6	9	2441	2400	3000	10
7	8	2229	1800	1600	10
8	9	2922	1800	1100	10
10	7	2682	1750	1700	10
1	0	1404	1250	3000	10
10	0	1809	2400	5500	10
2	1	4023	4300	2188	20
4	1	3170	2400	1850	10
3	2	5823	3000	1850	10
5	3	1788	1200	1850	10
6	3	3273	2400	2250	10
7	4	3170	2400	3250	10
6	5	1420	2400	1250	10
7	5	1820	1200	2875	10
8	6	2413	1250	2750	10
9	6	2441	2400	3000	10
9	8	2922	1800	1100	10
7	10	2682	1750	1700	10
4	5	1420	2400	1850	10
5	4	1420	2400	1850	10

Table 8.3 Origin-destination matrix

From node	To node	Observed Peak hour Volume in PCU/hr
0	9	804
0	6	642
10	6	1520
10	9	1226
3	9	1520
1	9	1532
4	6	720
2	9	630
7	6	1358
7	9	805
5	9	678
6	9	756

8.3.3 Output Data

There are two different types of outputs which can be obtained from the model - one is quickest path from particular origin to particular destination and the other is equilibrium traffic volume.

8.3.3.1 Quickest Paths

Within the study area some routes of minimum time consumption are shown. This section shows the quickest paths for some particular origins and destinations before and after construction of the link road between Mirpur road and Green road. On computer monitor the network is shown in white colour over black background and the

quickest path is shown in green colour.

8.3.3.1 I) <u>Before the construction of the link road</u>

a) From node 0 to node 6
The quickest path is 0-1-2-3-6
Required time=16.08 mins
Computer output on monitor-

⇒ Asadgate-Farmgate- Banglamotor.

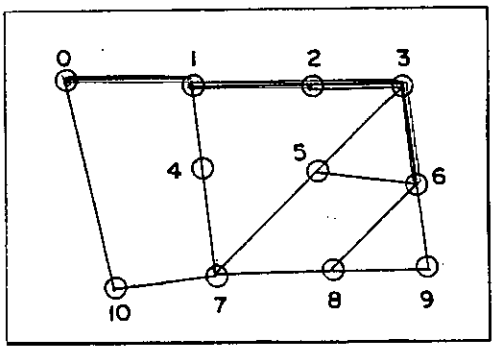

Figure 8.3.1

b) From node 0 to node 9

The quickest path is 0-10-7-8-9
Required time= 17.94 mins
Computer output on monitor-

⇒ Asadgate- Science lab.- Shahbag

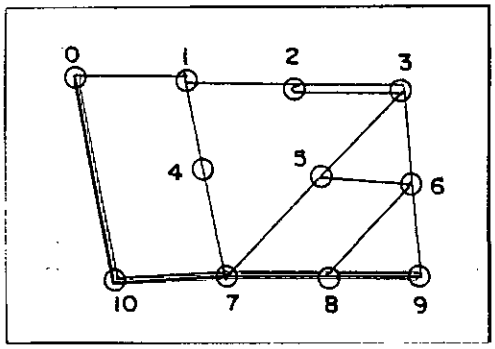

Figure 8.3.2

c) From node 0 to node 7

The quickest path is 0-10-7
Required time=9.87 mins
Computer output on monitor-

⇒ Asadgate- Satmasjid Road- Science lab.

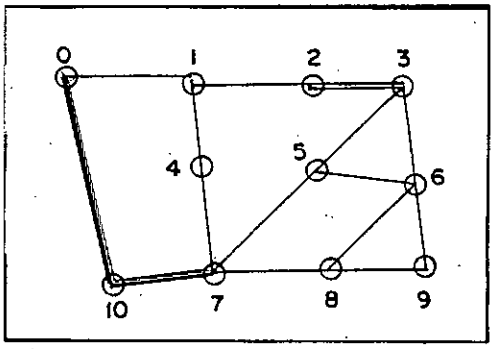

Figure 8.3.3

d) From node 10 to node 3

The quickest path is 10-7-5-3
Required time=12.30 mins
Computer output on monitor-

- Science lab.- Green road- Farmgate

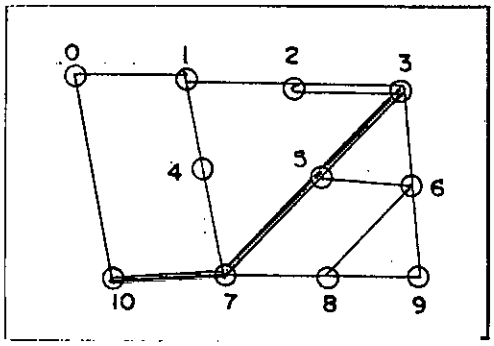

Figure 8.3.4

8.3.3.1 II) <u>After the construction of the link road</u>

a) From node 0 to node 6

The quickest path is 0-1-4-5-6
Required time=15.07 mins
Computer output on monitor -

- Asadgate-Panth path- Banglamotor.

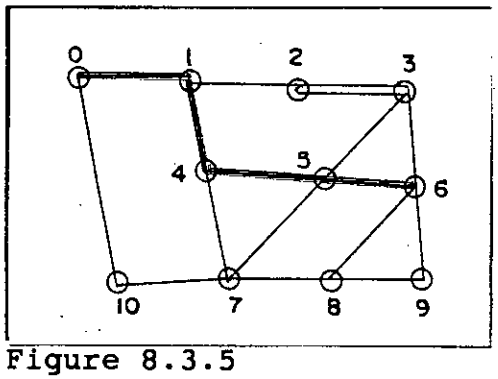

Figure 8.3.5

b) From node 0 to node 9

The quickest path is 0-10-7-8-9
Required time=17.94 mins
Computer output on monitor-

- Asadgate- Science lab.- Shahbag

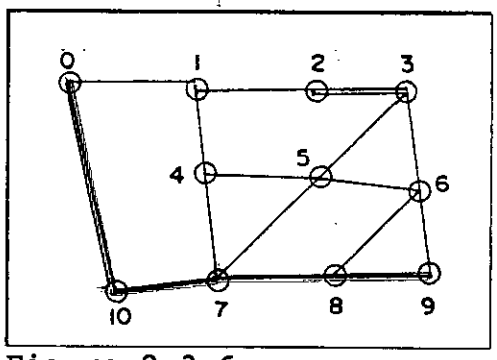

Figure 8.3.6

c) From node 0 to node 7

The quickest path is 0-10-7
Required time=9.87 mins
Computer output on monitor-

Asadgate- Satmasjid road- Science lab.

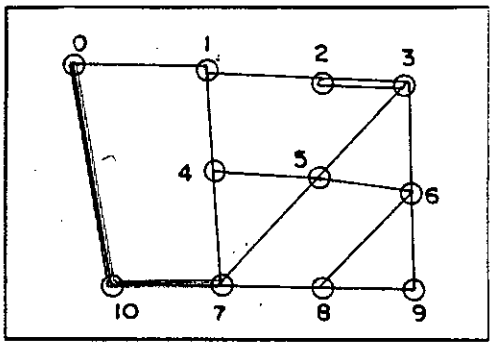

Figure 8.3.7

d) From node 10 to node 3

The quickest path is 10-7-5-3
Required time=12.30 mins
Computer output on monitor-

Science lab.- Green road- Farmgate

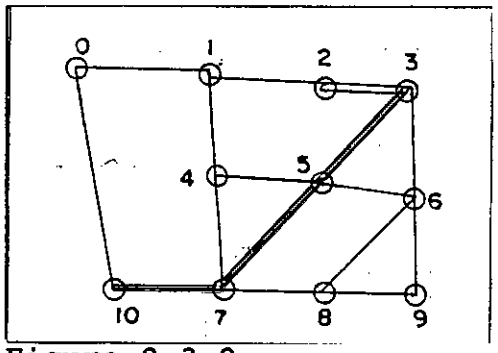

Figure 8.3.8

8.3.3.2 Equilibrium Traffic Volume

Equilibrium traffic volume is the traffic volume on each link when all the vehicles flow along routes of minimum travel time. In a balanced network, Each of the vehicles reaches its destination consuming minimum time [Morlok,1978]. So the over all time requirement or total travel impedance for a balanced network is the minimum. The traffic flow on each link for balanced network is the equilibrium traffic volume. Infact it is the output of traffic

assignment procedure. The equilibrium traffic volume before and after construction of the link 4-5 are given in the following tables.

Table 8.4 a) Before construction of the link

Origin	Destination	Equilibrium Traffic volume PCU/hr	Travel time mins
0	1	800	2.966
0	10	640	5.438
1	2	1178	2.163
1	4	1224	1.829
2	3	1808	1.829
3	6	3328	2.558
4	1	72	1.829
4	7	1872	3.213
5	6	3183	1.421
6	9	4036	3.411
7	5	2513	9.664
7	8	4889	5.378
8	6	1005	2.719
8	9	3884	3.698
10	7	3380	1.932

Table 8.4 b) After construction of link 4-5

Origin	Destination	Equilibrium Traffic volume PCU/hr	Travel time mins
0	1	800	2.966
0	10	640	5.438
1	4	2330	1.829
2	3	630	1.829
3	6	2150	2.225
4	5	2132	1.829
4	7	918	3.213
5	6	4811	4.202
6	9	4342	3.411
7	5	2009	3.269
7	8	4439	5.378
8	6	861	2.719
8	9	3578	1.251
10	7	3380	1.933

8.3.3.3 Comparison Between Existing Travel Time and Optimized Travel time

In this section travel time required for existing traffic flow condition and travel time required for balanced or optimized condition are compared.

8.4 c) Comparison Between Optimized Travel Time and Existing Travel Time

Origin node	Destination node	Travel time, mins	
		Existing traffic flow	Optimized traffic flow
0	6	16.08	15.68
0	9	17.94	17.28
0	7	9.87	9.36
10	3	12.30	10.76

8.3.3.4 An Overview

The effects on traffic flow of the construction of link 4-5 are explained here.

a) Change in travel time of different links

Table 8.4(a) and 8.4(b) shows that travel time on links 3-6, 7-5 and 8-9 reduces and travel time on link 5-6 increases which are shown in table 8.5 (a).

Table 8.5 a) Change in travel time due to construction of the link

Link Number	Travel time required before construction of new link, mins	Travel time required after construction of new link, mins	Percentage change with respect to new travel time
3-6	2.558	2.225	15 (Decrease)
7-5	9.664	3.269	196 (Decrease)
8-9	3.698	1.251	196 (Decrease)
5-6	1.421	4.202	66 (Increase)

b) Change in travel demand on different links

Table 8.4(a) and 8.4(b) shows that traffic volume on links 1-2, 3-6, 7-5 and 8-9 reduces . On the other hand traffic volume on link 5-6 increases. These are shown in tabular form in table 8.5 (b)

Table 8.5 b) Change in travel demand due to construction of the link

Link Number	Traffic volume before construction of new link, PCU/hr	Traffic volume after construction of new link, PCU/hr	Percentage change with respect to new travel demand
3-6	3328	2150	55(Decrease)
7-5	2513	2009	25 (Decrease)
8-9	3884	3578	9 (Decrease)
5-6	3183	4811	34 (Increase)

c) Overall saving in travel time due to construction of link 4-5

Total Travel impedance (travel time unit,minutes), as explained in section 5.3, is calculated in the unit of PCU-mins and presented in tabular form in table 8.5 (c).

Table 8.5 c) Change in travel impedance due to construction of the link

Link Condition	Total Travel Impedance, PCU-MINS	Reduction in Travel Impedance*, %
Before construction of Link 4-5	121105.27	19
After construction of Link 4-5	101714.25	

* Saving in time = (121105.27-101714.25)/101714.25*100=19.06%

8.4 SUMMARY

This chapter provides the outputs of the model and analysis procedure. From the outputs it was found that due to the construction of the link overall travel impedance reduces by about 20%, which is quite a large saving. Also travel demand on less capacity roads, such as link 7-5 (capacity 1200 PCU/hr) and link 8-9 (capacity 1800 PCU/hr) reduces which in turn reduces congestion on these links.

CHAPTER 9

SUMMARY AND CONCLUSIONS

9.1 INTRODUCTION

Increasing urbanization and concentration of people in urban cities have given rise in urban travel demand. This thesis was set out to study and develop an usable and effective method for optimizing traffic within limited resources. The model and the procedure described in the thesis are intended to provide highway planners with a tool for simple, fast and inexpensive estimation of traffic projections. This chapter summarizes the results of the research project. Some problems and limitations of the model and suggestions to overcome them have been discussed in this chapter. This chapter also includes recommendations for further study in this field.

9.2 SUMMARY OF THE RESULTS

This section summarizes the results, of analysis done in chapter 8, in the following sections. First comments on model validity testing are presented. Then summary of the results of model application in the study area are given.

9.2.1 Summary on Validity of the Model

The model was assigned to national road network for estimation of passenger bus traffic flow over Jamuna Bridge. Minimum traffic impedance trees were prepared and iterative capacity restrained assignment was done by the model. The detailed link flows are presented in Appendix C Table C.3.

The output is summarized in Table 9.1 which shows that the variation between predictions made by Jamuna Bridge consulting agencies and by the model developed in this research is less than 5%. Such an imbalance is well within the order of accuracy of a transport model [Jamuna Bridge Feasibility Study, Phase II, 1989].

Table 9.1 Summary of Validity Check of the model developed

Predicted Passenger Bus Traffic volume over Jamuna Bridge	Consulting Agencies PCU/day	Model PCU/day	Ratio of predictions Col.2 / Col.1
	3884	3724	1.04

As the predictions are very close, it is demonstrated that the model is well designed for its role as traffic volume estimation tools.

9.2.2 Summary of the Results of Model's Application in the Study Area

Using the model traffic effectiveness of Pantha path-Mirpur Road link road was studied. Study reveals that this road has considerable effect on the overall traffic pattern and travel time of flow. In fact its local effect for the present traffic is not as pronounced as its overall effect on the network. In quickest route analysis in chapter 8, it was found that only for origin of node 0 and destination of node 6 link 4-5 is used and corresponding saving in travel time is about 6%. But for the whole network under study the saving in user-cost (Travel impedance), due to the construction of the link road, is about 19%.

Change in travel time and travel demand, due to construction of the link, on other roads were calculated. It was found that travel time on links 3-6, 7-5 and 8-9 reduced by 15%, 196% and 196% respectively. On the other hand, travel time on link 5-6 increased by 66%.

9.3 GUIDELINE FOR APPLICABILITY OF THE MODEL

The model has been developed for optimization of traffic through a system of road network. One of the specific purposes of this research work was to analyze the effectiveness and requirement of the under construction link road between Mirpur road and Green

Road. Besides these the model has a wide area of application.

One use may be guiding a specific bunch of traffic through a particular route so that the overall traffic cost reduces. Another field of use is estimating traffic over a proposed bridge or ferry-connection and check relative saving in travel time.

The most important field of use is analyzing effectiveness of traffic control measures. For example, if a route is made one way from a zone of residential area to a central business district (CBD), how much traffic it will attract and what the saving in time will result in. These questions can be answered using the model. The impact of exclusion of rickshaw or other slow moving vehicle from a particular link can also be assessed using this model. In this case, the average running speed for this particular link increases and it must be determined from field survey.

The model can be applied to any network - urban, rural or a national level network. It can also be applied to any city, only with the input data for the specific one.

9.4 SUGGESTIONS FOR THE APPLICATION OF THE MODEL

A few problems may appear as soon as users begin to use the model to predict link volume. The most serious problem in the application of this procedure is one that is common to all traffic forecasting

or estimating processes, the accuracy of this model is determined to a large extent by the accuracy of the input, especially the origin-destination trip matrix and road inventory data.

The road inventory data can be obtained from Roads and Highways department or from city development corporations. The main problem is estimation of average speed. It can be obtained by either moving with a vehicle through the network or multiplying design highway speed by a speed reduction factor for a particular level of service. The easiest way to calculate the average annual growth rate from historical data and assume an increasing, decreasing or constant rate for the future. It can also be calculated from the equation given below

$$TGR = \frac{(100+PG)*(100+GDPC+E)}{100} - 100$$

where TGR - Traffic Growth Rate (% pa)

PG - Population Growth Rate (% pa)

GDPC - Per Capita Growth in GDP (% pa)

E - Income Elasticity of Transport Demand (%)

The applicability of the model in various areas may also cause problem. The problem arises from the fact of determination of the statistics of the area whether it is urban or rural. Judgement is required in making this determination. In very approximate terms, highways with more than 10 uncontrolled access points per mile (on

one side can be classified as `urban' or `suburban'. Also, any highway on which left or right turns cause appreciable delay to through vehicles would also be classified as `suburban' or `urban'. Multilane urban or suburban highways and urban arterials differ from rural roads in the following features - (1) their road side development (2) the density of traffic access (3) signalized intersection spacing [Saha, 1986].

In model formulation and data preparation, it was assumed that income elasticities are constant over time. Historically, travel has been growing at a fairly constant rate for many years. Therefore, assumption of constant elasticity would not introduce any substantial error. On the other hand, variable elasticity is not common in traffic forecasting which involve more sophisticated and expensive analysis [Salter, 1983].

Users are expected to weigh the results of traffic estimation models in terms of local situation and adjust them according to their professional judgement of the specific area.

9.5 CONCLUSIONS

The principal objective of this thesis was to develop a simple, fast and inexpensive computer based traffic estimation model for road networks. The study first identified suitable methodologies

and then implemented them on computer software with graphical interface. The analysis was done to evaluate traffic engineering effectiveness of a link road (Mirpur road to Green road link).

Ford Fulkerson's shortest route algorithm for trip assignment has been used in conjunction with capacity restraint traffic assignment process to develop a methodology for simulation of travel pattern of road networks in urban area. Within the framework of the mathematical concept used and available data it is concluded that the method can be gainfully used for synthesizing travel pattern in Bangladesh. The model when used for metropolitan areas should be calibrated on the basis of field data.

The step by step instructions in section 6.4 are provided to give a structured approach in implementing the model. The developed model is expected to provide highway planners with a means to estimate link traffic, change in travel time or effect traffic control measures if any structural or planning parameter changes.

9.6 RECOMMENDATION FOR FUTURE STUDY

The methodology presented in this thesis was based on some selected count stations. In our country no continuous counting stations is there. Data from continuous count stations are required to implement such models for practical purpose. Further studies on

traffic estimation will be helped by installation of a lot of continuous count stations at locations representing a variety of highway categories and traffic characteristics. It is expected that, with an increased number of counting stations. The present methodology will provide better statistical results and model performance. Moreover, with an increased number of count stations, it may become possible to divide the whole network into zones of concentrations or otherwise separate the areas and study the effect of concentrations on road system. The development of models for each sector would be similar to the model developed in this theories.

A detailed study on traffic volume, capacity and travel time should be made. A discrete relationship constant for every link and all the volume ranges was used. This should be modified after further detail study on this issue.

Time series analysis could be used to forecast future traffic. The time series analysis combined with this model will provide reliable traffic estimates. The time series provides exact traffic volume at different times and so, the perfect quickest routes at that particular time can be made available.

One of the major problem encountered in the analysis is intersection variables. Intersections encountering, delay at intersections, movement at intersections are yet to be studied.

Combining intersection lag time with the model with some regression analysis or probability method will provide better result.

The model dealt with traffic assignment part of four step traffic planning process. The combination of traffic generation, traffic distribution and modal split will enhance the field and effectiveness of the model.

For traffic generation studies growth rate, population increase rate, accessibility of different points should be investigated. For modal split, information about modes to be available their relative cost and travel time data are required. So more studies on these issues and their implementation on the model will increases the applicability of the model.

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APPENDIX A

TABLE A1 LOCATION : AIRPORT ROAD

TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	56	1	165	0	17	8135
10-20	78	1	218	0	27	
20-30	102	5	351	0	39	
30-40	95	1	406	0	41	
40-50	101	4	420	0	59	
50-1 hr	102	7	377	0	62	
0-10	108	10	452	0	45	
10-20	105	6	427	0	61	
20-30	109	8	432	0	79	
30-40	93	4	397	0	62	
40-50	84	9	310	0	60	
50-2 hr	84	3	348	0	56	
SUM	1117	59	4303	0	608	
SUM IN PCU	3351	177	4303	0	304	

TABLE A2 LOCATION : HATIRPUL ROAD

TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	1	2	55	329	23	8045
10-20	1	8	83	310	30	
20-30	3	6	67	282	56	
30-40	6	5	53	424	49	
40-50	1	9	70	375	36	
50-1 hr	0	7	50	360	33	
0-10	4	16	70	368	25	
10-20	4	7	71	382	29	
20-30	6	5	86	342	41	
30-40	0	19	70	480	41	
40-50	2	5	44	288	45	
50-2 hr	0	3	81	500	42	
SUM	28	92	800	4440	450	
SUM IN PCU	84	276	800	6660	225	

TABLE A3

LOCATION : MIRPUR ROAD AT SCIENCE LAB

TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	25	1	131	146	35	9755
10-20	26	2	191	263	56	
20-30	35	0	283	285	43	
30-40	20	4	279	323	31	
40-50	35	3	310	363	26	
50-1 hr	29	4	208	311	42	
0-10	31	1	190	290	30	
10-20	24	1	178	408	42	
20-30	28	0	176	399	40	
30-40	17	6	153	350	31	
40-50	26	2	163	440	29	
50-2 hr	19	5	157	480	29	
SUM	315	29	2419	4058	434	
SUM IN PCU	945	87	2419	6087	217	

TABLE A4

LOCATION : GREEN ROAD

TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	1	0	30	276	24	5963
10-20	2	1	31	272	20	
20-30	3	3	37	340	25	
30-40	0	0	29	279	28	
40-50	4	0	34	290	26	
50-1 hr	6	1	35	285	31	
0-10	5	1	48	285	22	
10-20	4	2	52	276	20	
20-30	9	0	49	336	25	
30-40	2	0	41	251	20	
40-50	1	3	41	279	18	
50-2 hr	5	2	30	297	25	
SUM	42	13	457	3466	284	
SUM IN PCU	126	39	457	5199	142	

TABLE A5 LOCATION : NEW ELEPHANT ROAD

TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	6	0	214	233	36	7425
10-20	2	0	198	278	46	
20-30	0	0	196	290	31	
30-40	5	2	164	261	35	
40-50	4	0	161	281	49	
50-1 hr	3	0	192	267	40	
0-10	8	2	167	270	49	
10-20	13	1	199	272	47	
20-30	7	5	198	267	33	
30-40	3	5	179	263	35	
40-50	6	4	175	274	31	
50-2 hr	4	3	132	224	30	
SUM	61	22	2175	3180	462	
SUM IN PCU	183	66	2175	4770	231	

TABLE A6 LOCATION : PANTHA-PATH

TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	0	3	88	196	21	4734
10-20	0	4	70	215	28	
20-30	1	4	69	168	40	
30-40	5	3	71	163	22	
40-50	0	2	69	201	27	
50-1 hr	0	5	68	166	32	
0-10	8	1	58	206	20	
10-20	6	3	88	195	20	
20-30	4	0	86	198	31	
30-40	1	5	69	219	22	
40-50	1	1	66	209	28	
50-2 hr	2	8	68	202	21	
SUM	28	39	870	2338	312	
SUM IN PCU	84	117	870	3507	156	

TABLE A7 LOCATION : MANIK-MIA AV.

TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	75	35	361	401	65	14128
10-20	51	32	354	371	61	
20-30	37	35	331	381	75	
30-40	34	32	441	403	86	
40-50	39	29	460	451	101	
50-1 hr	37	27	398	408	114	
0-10	36	27	331	407	112	
10-20	27	28	330	401	101	
20-30	28	30	303	402	96	
30-40	24	26	238	421	81	
40-50	23	30	245	380	75	
50-2 hr	27	27	240	370	61	
SUM	438	358	4032	4796	1028	
SUM IN PCU	1314	1074	4032	7194	514	

TABLE A8 LOCATION : SAT-MASJID ROAD

TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	18	1	130	190	21	5566
10-20	7	2	133	170	20	
20-30	10	0	160	172	22	
30-40	9	1	140	159	25	
40-50	14	1	157	211	30	
50-1 hr	14	3	115	205	31	
0-10	9	3	81	231	28	
10-20	12	1	80	241	32	
20-30	15	3	80	243	35	
30-40	11	2	69	238	27	
40-50	11	8	68	182	28	
50-2 hr	11	2	67	170	29	
SUM	141	27	1280	2412	328	
SUM IN PCU	423	81	1280	3618	164	

TABLE A9

LOCATION : MIRPUR ROAD AT ASAD GATE						
TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	25	1	195	176	40	8626
10-20	15	1	216	219	30	
20-30	17	1	296	240	43	
30-40	22	6	252	275	45	
40-50	17	2	251	290	50	
50-1 hr	22	3	186	305	55	
0-10	23	3	155	350	62	
10-20	22	1	145	372	67	
20-30	16	2	139	377	64	
30-40	12	4	131	370	57	
40-50	15	8	150	285	46	
50-2 hr	15	2	130	283	45	
SUM	221	34	2246	3542	604	
SUM IN PCU	663	102	2246	5313	302	

TABLE A10

LOCATION : ASAD AV.						
TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	5	3	57	176	41	8199
10-20	4	8	51	190	30	
20-30	9	7	25	210	35	
30-40	4	5	50	206	34	
40-50	6	3	38	180	24	
50-1 hr	9	0	31	210	31	
0-10	4	4	35	201	30	
10-20	12	4	61	160	28	
20-30	22	1	52	210	22	
30-40	12	1	43	194	29	
40-50	12	1	45	210	38	
50-2 hr	6	3	44	201	34	
SUM	105	40	532	2348	376	
SUM IN PCU	315	120	532	7044	188	

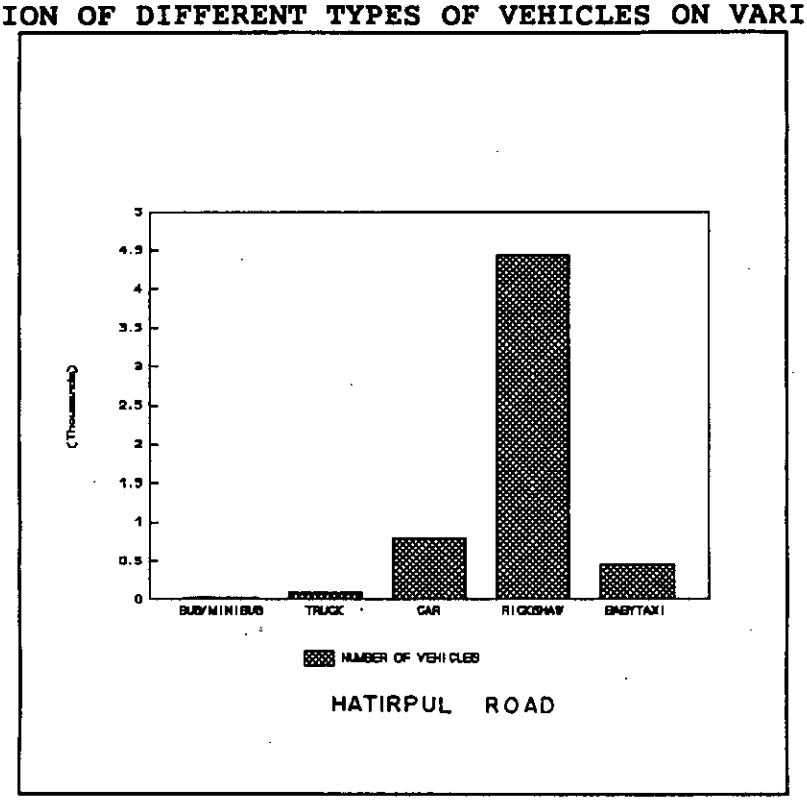
TABLE A11 LOCATION : FARMGATE (LINK 3-2)

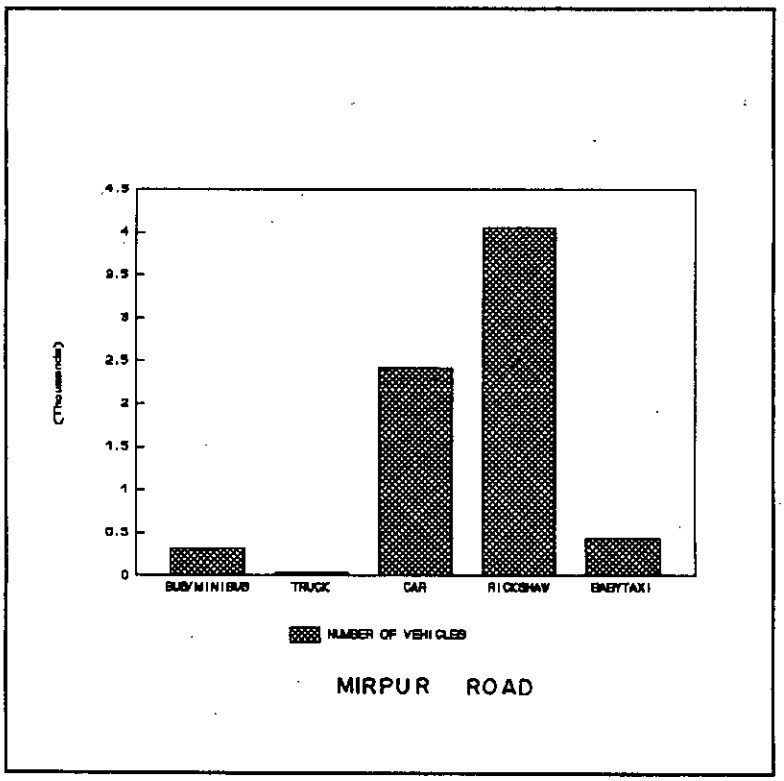
TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	16	11	76	160	22	7151
10-20	28	22	94	190	23	
20-30	24	12	67	193	21	
30-40	25	14	70	285	16	
40-50	27	12	74	265	35	
50-1 hr	16	20	65	320	20	
0-10	20	14	59	280	20	
10-20	16	18	50	338	24	
20-30	18	23	70	340	25	
30-40	22	20	65	300	40	
40-50	22	21	95	235	35	
50-2 hr	28	10	75	266	31	
SUM	262	197	860	3172	312	
SUM IN PCU	786	591	860	4758	156	

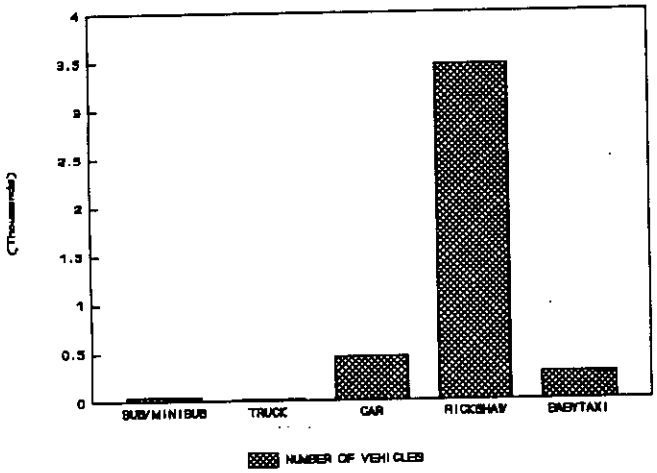
TABLE A12 LOCATION :FARMGATE (LINK 2-3)

TIME, MINS	BUS/ MINI BUS	TRUCK	CAR	RICK SHAW /VAN	BABYTAXI /MOTOR CYCLE	TOTAL PCU IN PEAK TWO HOURS
0-10	19	15	133	107	40	6665
10-20	13	10	123	101	30	
20-30	18	18	153	203	45	
30-40	11	16	189	100	55	
40-50	19	7	140	210	67	
50-1 hr	17	21	163	214	70	
0-10	17	11	108	124	67	
10-20	20	16	186	270	45	
20-30	14	12	138	201	68	
30-40	21	15	167	258	55	
40-50	21	16	195	227	72	
50-2 hr	20	17	155	201	64	
SUM	210	174	1850	2216	678	
SUM IN PCU	630	522	1850	3324	339	

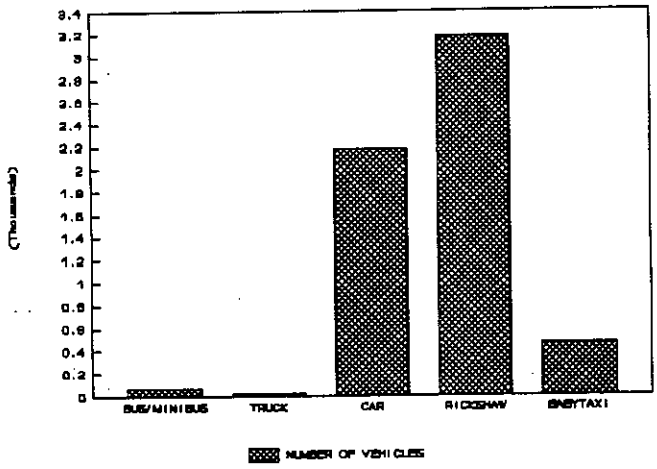
DISTRIBUTION OF DIFFERENT TYPES OF VEHICLES ON VARIOUS ROADS



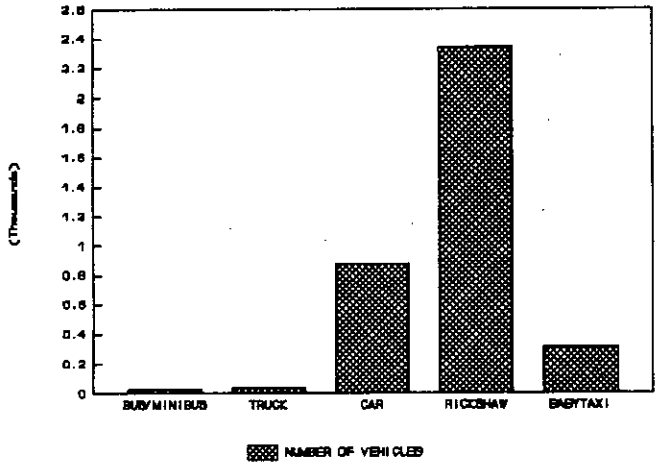




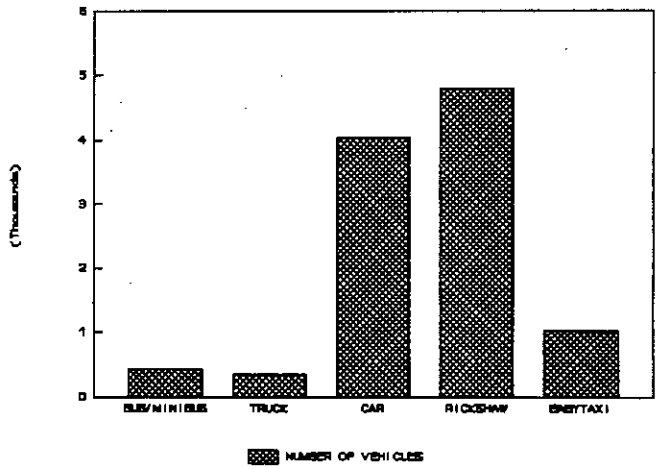
GREEN ROAD



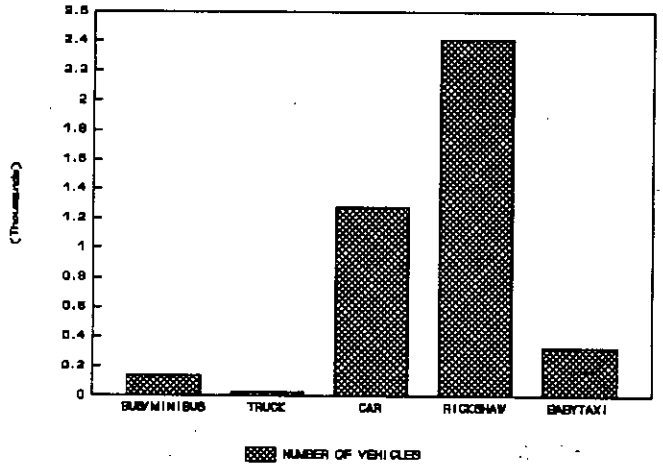
NEW ELEPHANT ROAD



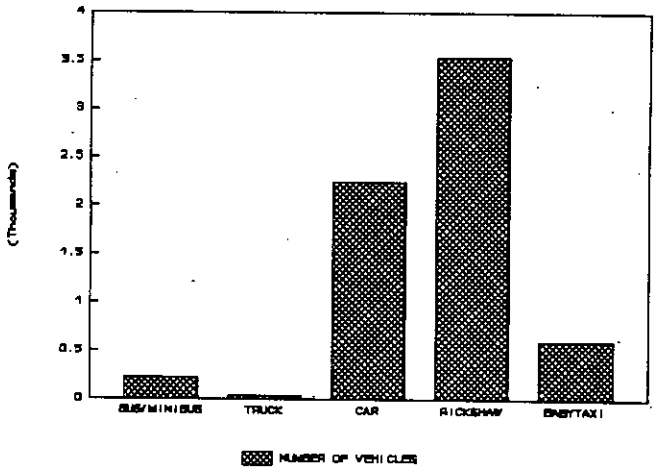
PANTHAPATH ROAD



MANIKMIA AVENUE



SAT MASJID ROAD



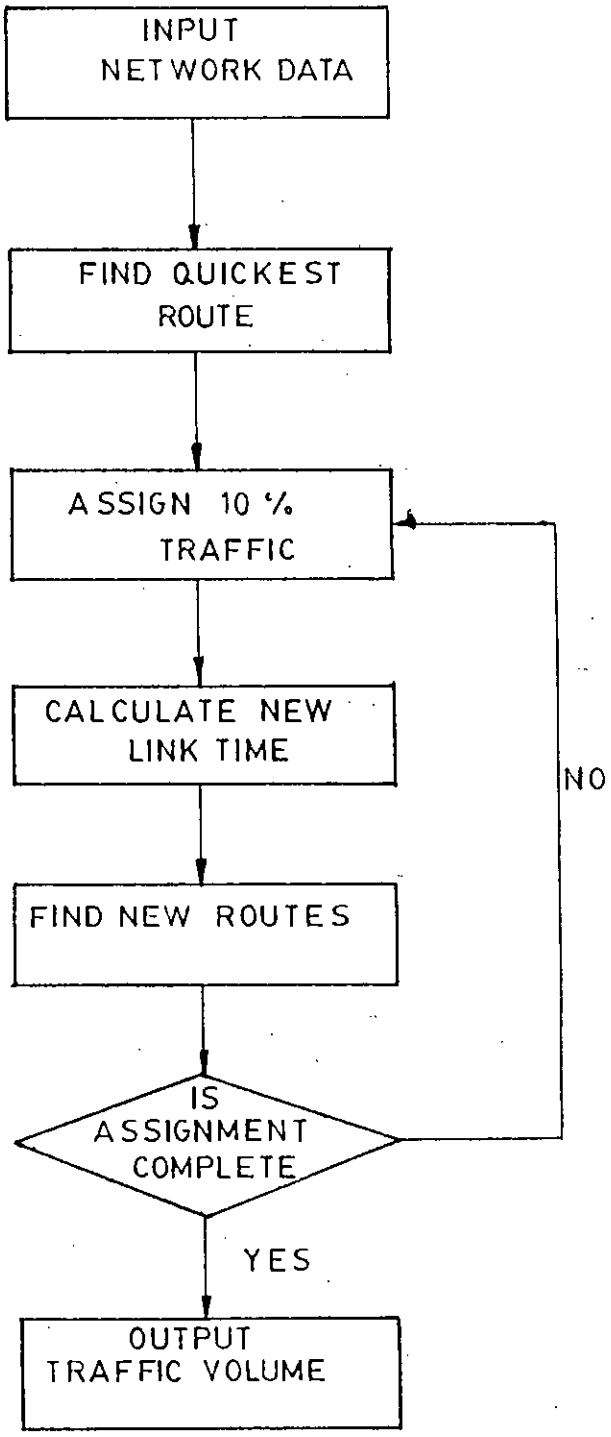
MIRPUR ROAD AT ASAD GATE

APPENDIX B

FLOW CHART And PROGRAM

APPENDIX B

FLOW CHART



```
/*PROGRAM FOR TRAFFIC OPTIMIZATION OF ROAD NETWORK AND */
   /* TRAFFIC EFFECTIVENESS EVALUATION OF ROAD LINKS*/
   /*                BY MD. JOBAIR BIN ALAM        */
 /*********************************************************/
        /* FOR M.Sc. THESIS UNDER SUPERVISION OF*/
                 /*DR. MD. MAZHARUL HOQUE*/
     /* THE PROGRAM WAS WRITTEN IN TURBO-C LANGUAGE*/

#include <stdio.h>
#include <dec.h>
#include <stdlib.h>
#include <graphics.h>
#include <alloc.h>
  int  n;
  int i,j,k,nn;
  float qrt;
  FILE *fpo2;
void ROUTE();
void Q_ROUTE();
void N_EQU();
void OUT_P();
void L_TIME();
void INPUT1();
void INPUT2();
void QR_FIND();
void NET_EQ();
void DRAW();
void pnode(short x,short y,char *bit);
/*main program begins*/

void  main ()
{
int  true;
char  ch;
FILE *fp;

fpo2=fopen("OUTP2.DAT","w");
fp=fopen("INP.DAT","r");
fscanf(fp,"%d\n",&n);
true=1;
while(true){
     clrscr();
     printf("MAIN MENU\n\n\n");
     printf("1. FIND QUICKEST ROUTE\n");
     printf("2. FIND EQUILIBRIUM TRAFFIC VOLUME\n");
     printf("3. EXIT\n");
     ch=getch();
     switch(ch)
     {
          case '1':
             QR_FIND();
             DRAW();
              break;
```

```
        case '2':
                NET_EQ();
                break;
            case '3':
                true=0;
                break;
            default:
                printf("Illegal entry\n");
                break;

        }
    }
}

void  QR_FIND()
 {
printf("origin node-\n");
scanf("%d",&i);
printf("destination node-\n");
scanf("%d",&k);
INPUT1();
ROUTE();
printf ("PROGRAM FOR QUICKEST ROUTE FIND ENDS\n\n");
return;
}
/*subroutine quick route find */
void ROUTE()
{int i1,j1;
float time,ctime,stime;
stime=n*10000.0;
pnn[i]=0;
pnnt[i]=0.0;
label1:
     ctime=0.0;
     for(i1=0;i1<n;i1++){
          if(pnnt[i1]>9999.9)continue;
          for(j1=0;j1<n;j1++){
               if(1c[i1][j1]!=0){time=pnnt[i1]+1t[i1][j1];
                            if(time<pnnt[j1]){pnn[j1]=i1;
                                        pnnt[j1]=time;}

               }
           }
      }
      for(j1=0;j1<n;j1++) ctime=ctime+pnnt[j1];
      if(abs(ctime-stime)>1.0){stime=ctime;
                  goto label1;}

Q_ROUTE();
return;
}
```

```
/*outputs from Q_ROUTE() are qr[] and qrt */

void Q_ROUTE(){
int j1,i1,d;


j1=0;
qr[j1]=k;
for(j1=1;j1<n;j1++){
     i1=qr[j1-1];
     if(pnn[i1]==i){qr[j1]=i;
                    break;}
     else
          {qr[j1]=pnn[i1];}
}
nn=j1;
qrt=pnnt[k]+2.5*(nn-1);
printf("\nQuickest route-");
for(j=nn;j>=0;j--){
    printf("%d-",qr[j]);
    }
printf("\n");
printf("Total time=%f\n",qrt);
fprintf(fpo2,"\nQuickest route-");
for(j=nn;j>=0;j--){
     fprintf(fpo2,"%d-",qr[j]);
    }
fprintf(fpo2,"\n");
fprintf(fpo2,"Total time=%f\n",qrt);

return;
}

/*Network Equilibrium*/
void NET_EQ()
{
INPUT2();
N_EQU();
OUT_P();
return;
}

/*Network Equilibrium*/
void N_EQU()
{int i3,i4,o,d;

for(i3=0;i3<4;i3++){
     for(i=0;i<n;i++){
     for(k=0;k<n;k++){
                    for(d=0;d<n;d++){
                    pnnt[d]=10000.0;
                    pnn[d]=0;
                    qr[d]=0;
```

```
                    }
            if(od[i][k] !=0){

                ROUTE();
                for(i4=nn;i4>0;i4--){
                        o=qr[i4];
                        d=qr[i4-1];
                         lv[o][d]=lv[o][d]+od[i][k]*0.25;
                        }
            }
     }
    }
    L_TIME();
}
return;
}

void L_TIME()
{float x;
int o,d;
for(o=0;o<n;o++){
     for(d=0;d<n;d++){
         if(ll[o][d]>0.1){
              x=lv[o][d]/lc[o][d];
              x=x*x;
              x=x*x;
              lt[o][d]=lt0[o][d]*(1+0.15*x);
               }
     }
}
return;
}


void OUT_P()
{
int o,d;
FILE *fpo1;
fpo1=fopen("OUTP1.DAT","w");
fprintf(fpo1,"                          Link Volume & Link Travel
Time\n");
fprintf (fpo1,"Origin--Destination-----Traffic volume------Travel
Time\n");
for(o=0;o<n;o++){
     for(d=0;d<n;d++){
        if(lv[o][d]>0){

fprintf(fpo1,"%3d-----%4d---------%10d-----------%f\n",o,d,lv[o][
d],lt[o][d]);}
      }
  }
```

```
fclose(fpo1);
return;
}

void INPUT1()
{
int o,d,nd;
FILE *fp1;
fp1=fopen("INP1.DAT","r");
for(o=0;o<n;o++){
     for(d=0;d<n;d++){
          lv[o][d]=0;
          lc[o][d]=0;
          ll[o][d]=0.0;
          ls[o][d]=0.0;
          }
   }
fscanf(fp1,"%d\n",&nd);
for(j=0;j<nd;j++){
    fscanf(fp1,"%d%d",&o,&d);
fscanf(fp1,"%d%d%f%f\n",&lv[o][d],&lc[o][d],&ll[o][d],&ls[o][d]);
     }

for(o=0;o<n;o++){
     for(d=0;d<n;d++){
        if(ll[o][d]>0.1)
           lt0[o][d]=ll[o][d]/ls[o][d]*0.87*60.0;}
}
for(d=0;d<n;d++){
          pnnt[d]=10000.0;
          pnn[d]=0;
          }


L_TIME();
fclose(fp1);
return;
}



void INPUT2()
{
int o,d,nd;
FILE *fp2;
fp2=fopen("INP2.DAT","r");
for(o=0;o<n;o++){
     for(d=0;d<n;d++){
          ll[o][d]=0.0;
          od[o][d]=0;
          lc[o][d]=0;
          ls[o][d]=0.0;
          lv[o][d]=0;
     }
```

```
   }
fscanf(fp2,"%d\n",&nd);
for(o=0;o<nd;o++){
    fscanf(fp2,"%d%d",&i,&j);
     fscanf(fp2,"%d%f%f\n",&lc[i][j],&ll[i][j],&ls[i][j]);

     }
fscanf(fp2,"%d\n",&nd);
for(o=0;o<nd;o++){
     fscanf(fp2,"%d%d",&i,&j);
     fscanf(fp2,"%d\n",&od[i][j]);
     }

for(i=0;i<n;i++){
     for(j=0;j<n;j++){
        if(ll[i][j]>0.1)
 lt0[i][j]=ll[i][j]/ls[i][j]*0.87*60.0;

       }
}
L_TIME();
fclose(fp2);
return;
}


void DRAW()

 {      int driver,mode;
     float  sh,sv;
     char   *bit;
     int    image_size;
     int    mlink,mnode;
     short  x1,x2,y1,y2;
     short  node[50][3],con[50][4];
     FILE   *f1 ;
        FILE   *f2 ;
        FILE   *f3 ;
     f1=fopen("inf.dat","r");
     f2=fopen("link.dat","r");
     f3=fopen("node.dat","r");
     fscanf(f1,"%f%f\n",&sh,&sv);

     driver=0;
     mode=0;
     initgraph(&driver,&mode," ");

     setcolor(BLUE);
     fscanf(f1,"%d\n%d",&mlink,&mnode);
     rectangle(200,10,205,15);
     bit=malloc(imagesize(200,10,205,15));
     getimage(200,10,205,15,bit);
     cleardevice();
```

```
/*node data input*/
      for(i=0;i<mnode;i++)
      {     for( j=0;j<2;j++){
                fscanf(f3,"%d",&node[i][j]);}
                x1=sh*node[i][0];
                y1=sv*node[i][1];
                pnode(x1,y1,bit);
      }

/*link data input*/

     for(i=0;i<mlink;i++)
     { fscanf(f2,"%d%d\n",&con[i][0],&con[i][1]);
       x1 = node[con[i][0]][0]*sh;
       y1 = node[con[i][0]][1]*sv;
       x2 = node[con[i][1]][0]*sh;
       y2 = node[con[i][1]][1]*sv;
       moveto(x1,y1);
       lineto(x2,y2);
        }
        setcolor(GREEN);

      for (i=nn;i>0;i--)
        {    x1=(node[qr[i]][0]+2)*sh;
          y1=(node[qr[i]][1]-2)*sv;
          moveto(x1,y1);
          x2=(node[qr[i-1]][0]+2)*sh;
          y2=(node[qr[i-1]][1]-2)*sv;
          lineto(x2,y2);
       }
       getch();
       closegraph();
       printf("Retuning to default mode.Press any key.\n\n");
       getch();
       fclose(f1);
          fclose(f2);
       fclose(f3);
       return;
}

void pnode(short x,short y,char *bit)

{
     x=x-2;
     y=y-2;
     putimage(x,y,bit,1);
          return;
}
```

APPENDIX C

INPUT DATA

TABLE C1

NUMBER OF LINKS=59

NODE A	NODEB	CAPACITY PCU/DAY	LENGTH IN km	SPEED km/hr
1	2	3600	107	41.96
2	3	3600	54	40.5
3	4	3600	80	41.38
3	9	4800	83	30.18
4	5	3600	6	21.18
5	6	3600	57	46.85
6	8	3600	50	42.86
8	7	4800	64	34.29
5	11	3600	14	14.74
11	10	4800	41	33.24
9	10	3600	38	44.71
9	0	3600	14	17.87
0	31	3600	34	36.84
0	12	4800	40	16
12	13	3600	1	0.2
0	30	3600	64	34.29
31	32	3600	88	43.64
31	33	4000	64	30.97
33	34	4000	15	30
34	35	4000	10	40.25
35	36	4000	4.5	30
36	37	3600	12	40.25
36	38	3600	20	40.25
37	38	3600	20	21.82
38	39	4800	55	50
39	40	3600	6	51.43
39	41	3600	47	42.73
41	42	3600	26	33.91
40	29	2000	1	0.31
29	30	3600	24	42.35
29	28	2000	1.2	0.37
28	27	3600	39	34.41
28	52	3600	20	41.38
27	26	3600	7	43
36	24	3600	52	43.33
24	21	3600	45	39.13
21	22	3600	69	35.08

21	20	3600	34	30.91
20	14	3600	67	43.25
52	23	3600	56	36.52
23	24	3600	27	38.57
52	14	3600	32	30
14	13	3600	20	21.82
14	15	3600	28	29.47
15	16	3600	27	32.4
15	17	3600	16	33.1
17	18	3600	68	23.05
42	26	3600	32	21.82
42	43	3600	17	40.8
43	44	3600	17	40.8
44	45	4800	72	38.92
38	45	3600	60	46.75
38	43	3600	60	45.25
45	46	3600	58	45.26
46	47	3600	56	43.64
47	48	3600	40	35.29
48	49	3600	41	35.65
48	53	3600	83	35.75
47	50	3600	58	34.28

TABLE C2 ORIGIN-DESTINATION MATRIX (PASSENGER BUS)

FROM NODE	TO NODE	VOLUME PCU
45	0	538
45	34	84
0	49	111
46	0	489
46	30	23
46	34	42
38	0	679
38	32	17
38	34	679
44	1	15
44	3	13
44	0	519
44	34	45
50	34	18
50	0	29
1	52	17
3	52	17
0	18	159

0	21	314
0	26	160
0	52	780
30	21	21
30	60	60

TABLE C3

MODEL PERFORMANCE TEST RESULT

Link Volume & Link Travel Time

Origin	Destination	Traffic volume, PCU	Travel Time, mins
0	9	84	40.895355
0	30	1128	97.427818
0	31	420	48.175896
5	6	60	63.509075
9	10	60	44.365913
10	11	60	64.386276
11	5	60	49.579376
14	15	156	49.596199
15	17	156	25.232630
17	18	156	153.995667
24	21	332	60.030666
27	26	160	8.497674
28	27	160	59.163033
28	52	988	25.229578
29	28	1148	169.297302
30	29	1148	29.582056
31	0	2328	48.175896
31	33	420	107.872139
33	31	2284	107.872139
33	34	420	26.100000
34	33	2284	26.100000
34	35	420	12.968945
35	34	3144	12.968945
35	36	420	7.830000
36	24	312	62.644817
36	35	3144	7.830000
36	38	108	25.937889
38	36	3144	25.937889
38	45	108	66.994652
43	38	584	69.215469
44	43	584	21.750000
45	38	1212	66.994652
45	46	108	66.893509
46	45	592	66.893509
46	47	108	66.984421
47	46	44	66.984421
47	48	108	59.166901
48	49	108	60.033657
50	47	44	88.319725
52	14	156	55.680000