DEVELOPMENT OF TRANSPORT MODELS TO PREDICT FLOW-PATTERN AND VOLUME OF TRAFFIC ON THE NATIONAL HIGHWAY NETWORK

BY

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

of

MASTER OF SCIENCE IN CIVIL ENGINEERING

September, 1993

DECLARATION

I hereby declare that the research work reported in this thesis was performed by me as a partial fulfilment 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 and to the best of my knowledge and belief, this thesis contains no material previously published or written by any other person, except when due reference is made in the text of the thesis.

September, 1993

(Tanweer Hasan)

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This thesis is dedicated to my father A.A.M. Abdush Shakur, to my mother F.A. Mahmuda Shakur and to my wife Momota. Their constant love, support and encouragement made it possible.

ACKNOWLEDGEMENT

The author is greatly indebted to his supervisor Dr. Alamgir Mojibul Hoque, Professor of Civil Engineering Department, BUET for his Constant guidance, continued encouragement, generous help and unfailing enthusiasm in the completion of this research work.

The author also wishes to express his thanks to Mr. Jobair-Bin-Alam, Asstt. Professor of Civil Engineering Department, BUET and to all his friends who provided assistance and suggestions in course of this study.

Mr. Malek and Mr. Shahid of Civil Engineering Department also deserve acknowledgement from the author for drafting this thesis.

ABSTRACT

A transport modelling system has been developed in this study to forecast traffic flow-pattern and traffic volume on the national highway network of Bangladesh. The model and the described procedure are intended to provide highway planners with a tool for simple, fast and inexpensive estimation of traffic projections.

This study attempts to combine the transport models of trip distribution and traffic assignment for forecasting traffic flow-pattern between old 20 districts and volume on the national highway network of Bangladesh. A doubly constrained gravity model of trip distribution and a capacity restraint traffic assignment model have been computerized for this purpose. It is assumed that, the shortest path will be selected on the basis of minimum travel time and minimum travel cost for passenger and freight movements respectively.

The gravity model is calibrated with the base year (1990) data and the results of calibration are used to formulate regression equation of power form between travel resistance and the resistance variables time and cost. The results of regression show that, the exponent for time is 2.05 with a correlation coefficient (r) of 0.98 and the exponent of cost is 1.76 with a correlation coefficient of 0.83. These high values of correlation coefficient indicate that, the gravity model developed in this study can be used for reliable forecasting of traffic flow-pattern between old 20 districts of Bangladesh.

The traffic assignment model has been applied for forecasting traffic volume on the national highway network of Bangladesh. Growth rate of traffic for passenger and freight movements have been calculated for all the 20 districts of Bangladesh assuming that, traffic growth rate is a function of some economic and demographic factors. Traffic volume on the road sections of the national highway network of Bangladesh has been projected for 20 years (1990-2010) at an interval of 5 years under existing condition of the network. The model has also been applied to forecast traffic volume over Jamuna bridge in 1997 which is assumed to be the opening year of the Jamuna bridge. To assess the validity of Forecasting, traffic volume over the Jamuna bridge in 1994 from this study and in the Jamuna bridge study have been compared. This comparison shows a variation of only 5.5% for total traffic (passenger and freight) between the predictions made in these two studies. The results also show that, due to the construction of the Jamuna bridge one of the heavily loaded Dhaka- Aricha highway will lose more than half of its traffic in 1997.

CONTENTS

LIST OF NOTATIONS

A_j	Attraction of traffic to zone j
b_j	Adjustment factor for zone j
c_{ij}	Travel cost from origin i to destination j
C_p	Capacity of particular route
C_i	Capacity of Link i
E	Income elasticity of transport demand
f	Generated traffic growth factor
GDP	Gross domestic product
GDPC	Per capita growth rate of GAP
l(i,j)	User cost on link (i,j)
L_p	Set of Links
N	Number of Lanes
PG	Population Growth
P_i	Generation of traffic at zone i
P(j)	the minimum user cost form a particular origin to a destination j
R_i	Separation factor between i and j
S_v	Service volume
T	Balanced travel time
T_o	Free flow travel time
TGR	Traffic Growth rate
T_L	Truck factor
t_p	Travel time from Origin to Destination
t_i	Travel time on link i
V	Assigned volume
v/c	Volume to capacity ratio
w	Side clearance Factor

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CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION

Transportation has profound and enduring effects on a nation and its people. The presence or lack of adequate transportation facilities shapes the boundaries of national, state, and local governments. The adequacy of the transporation system may determine a nation's foreign policy and extent of its political control over its people.

Transportation engineering involves a wide range of activities related to planning, design, operation, control, management, maintenance and rehabilitation of multimodal facilities and services. Transportation services are related to social and economic opportunities which are vital to the standard of living and the national economy.

Transporation planning, a part of transportation engineering, plays a significant role in the context of planning a city or a region. Because planning of cities or regions requires the planning of all land uses, employment, education and shopping of that city or region and all these fields are related to transport facilities. Transport planning is a relatively new science which has developed in an attempt to predict travel patterns in different areas with different transport systems. Since it tries to apply general mathematical relationships to the travel behaviour of individuals whose particular travel patterns obey no fixed mathematical rule, it cannot claim to be an exact science. Nevertheless, the accuracy of the techniques applied for synthesizing the travel behaviour can form a sound basis for the quantitative assessment of alternative courses of action and the evaluation of particular transport proposals.

There is a common basic approach which can be applied to all forms of transporation planning, whether planning for a specific new transport facility, such as a new airport, road or rail improvement scheme, or planning a national or local transport policy. In all cases the approach may be summarised by three distinct phases: a survey, analysis and model building phase; a forecasting phase; and an evaluation phase [Lane et al, 1971].

Model building is an important part of the transportation planning process. The accuracy of the traffic forecasting model -which relates the travel behaviour of individuals to some mathematical rule- determines the level of applicability of a transportation planning process. On the otherhand, the accuracy of data gathered within the study area reflect the accuracy that can be expected from the forecasting model.

In this research work models have been developed to help in optimization of traffic flow through road networks and thus will provide a balanced traffic flow in the road network. A balanced network is one where tarffic is uniformly distributed over the network in such a way that transport cost or travel time becomes minimum.

Gravity Model of Trip Distribution has been developed to predict the flow-pattern exists among zones under the present situation of the road network as well as under some possible and proposed changes and improvements in future and a Capacity Restraint Traffic Assignment Model has been applied to estimate the volume of traffic on various links of the national highway network under the conditions mentioned earlier.

1.2 BACKGROUND OF THE STUDY PROJECT

Road transport has become the principal mode of transport for the movements of freight and passengers in Bangladesh. Railways and Inland waterways, the other main transport modes, together account for less than half the total motorized transport movements [Road Master Plan, 1991]. It is envisaged that roads, which provide highly flexible and relatively low-cost transport, will continue to meet an increasing share of freight and passenger transport demand in the future.

Government of Bangladesh has attached priority to the development of infrastructure. It has been substantially proved that, developed infrastructure of a country leaves a positive impact on a nations economy which determines its stand in the community of nations in the world. Since the country's independence, quite a number of roads and bridges were constructed and efforts are still underway to construct more roads and bridges in a bid to improve the nagging communication problem in the country.

Transport modelling though extensively practiced, is still in its early stages and undergoing changes day by day. Standard methodologies have not yet 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.

Forecasting of traffic volume using transport models have been extensively used in Australia, USA and the UK. 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 et al, 1985].

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 cannot 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 the origin-destination data, land use pattern or network structure can be accommodated using this method. As forecasting techniques can be mathematically defined, it is possible to computerize the procedure.

Traffic forecast or estimation of traffic on different road links is 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 network. To plan, manage and implement new projects this estimation is essential.

A number of projects have so far been undertaken in context of road improvement in this country. These are Intermodal Transport Study (1985), Road Rehabilitation and Maintenance Project RRMP-1 (1986), Road Improvement Project-No 1 (1987), Jamuna Bridge Project (1989), Second Road Improvement Project (1990), Feasibility Study of Dhaka-Khulna National Highway (1990), Road Master Plan Project (1991) and Second Road rehabilitation and Maintenance Project (1993). It is likely that, after implementation of the proposals made through these studies , road traffic will change to some considerable extent. Consultants associated with these projects used computer aided transport models to predict these changes setting model parameters in their own way.

In this research computer aided transport models have been developed to predict the flow-pattern and traffic volume on the national highway network of this country under the present situation as well as under some possible structural changes to the highway network in near future.

1.3 SIGNIFICANCE AND OBJECTIVE OF THE STUDY

Among the most important factors in public investment decisions is the projected demand for an existing or proposed facility. The pattern of traffic growth and projected traffic volumes have been recognized as prime factors in most analysis of highway projects. Growth of traffic has a significant effect on highway investment decisions pertaining to increase the capacity of existing highways and the construction of new facilities, when limited funds are available.

The purpose of this research is to develop computer aided transport models to predict flow-pattern and traffic flow volume on different road sections of the national highway network of Bangladesh. The main objectives of this study are:

- to develop a transport modelling system for traffic estimation on the national highway network of Bangladesh under present situation of the road network.

- to estimate projected traffic using zonal growth factors calculated assuming growth factors are function of some demographic and economic factors of those particular zones.

- to study the probable changes in the flow-pattern and volume of traffic due to some specific structural changes to the present national highway network.

1.4 ORGANIZATION OF THE THESIS

This thesis consists of eight chapters and five appendices. Chapter 1 discusses the objectives, background and significance of this present study.

Chapter 2 discusses the literature review in the light of transportation studies in Bangladesh and in other countries.

Chapter 3 addresses the problem of and the overall methodology used for developing the computer model. It also briefs about overall design 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. It provides the description of the model and also focuses on its problems and limitations.

Step wise procedure for implementation of the model is also provided in this chapter.

Chapter 6 describes the data variables and their uses. This chapter deals with explanation of variables used in the model and ways for collection of data for these variables.

Chapter 7 describes the outputs of the various application of the model in the study area. It also describes the validation of the model and the acceptability of the base year trip matrices.

Chapter 8 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.

Data files used by the model are presented in Appendix- A. Appendix- B contains the predicted traffic volume on some major links of the national highway network of Bangladesh. Appendix-C shows sample output of the model and also provides documents on the validity of the model. The revised trip matrices and networks for the inclusion of the Jamuna bridge in the network are given in Appendix-D. Appendix-E contains the flow chart and the corresponding computer program developed in this study.

CHAPTER-2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a general description of the national highway network of Bangladesh for which the traffic forecasting models have been developed. A review of the literature on transport studies with particular emphasis on transport modelling for forecasting rural traffic is also presented in this chapter. This review of literature reveals that limited research has been accomplished on the topic of transportation modelling to predict traffic flow-pattern and volume on rural highways. Some ideas from this review has been incorporated in the present study.

2.2 HIGHWAY NETWORK OF BANGLADESH

Bangladesh has a complex transportation system. The mechanized and nonmechanized traditional modes are involved in the road and water sectors. All three surface modes - road, rail and water play significant roles in the transportation of passengers and goods. Often one mode is competing with the other and expanding at the expense of the other. The modal share of various surface modes of transportation is given in Table 2.1.

Table 2.1 Modal Shares in passenger and Freight Transport
[Source: BTSS Project.]

	Passenger traffic (%)			Freight traffic (%)		
	Road	IWT	Rail	Road	IWT	Rail
Estimated 1985	64	16	20	48	35	17
Estimated 1989	68	15	17	59	30	11
Estimated 1991	69	15	16	59	30	11

For the last few years attempts are being made to develop and modernize the transportation system as a whole with road network in particular. The government has greatly increased its expenditure on construction, improvement, rehabilitation and maintenance of the road network. Priority has been given to the improvement of the national and regional networks to facilitate arterial movements and of feeder and rural roads to provide better access to decentralized administrative headquarters (Upazilla/Thana), growth centers and rural areas.

2.2.1 Classification of Road network of Bangladesh

The road network in Bangladesh is classified into six categories such as national highways, regional highways, Type A feeder roads, Type B feeder roads, Urban (Municipal) roads and Rural roads. National and regional roads may be considered as primary roads, Type A feeder roads as secondary roads and rural roads as tertiary roads. Definitions of these classes of highways are given below (Hoque,A.M., 1991):

National Highways: Highways connecting the national capital with divisional headquarters, old district headquarters, port cities and international highways.

Regional Highways: Highways connecting District headquarters of the region and with national highways.

Type A Feeder Roads: Roads connecting upazilla headquarters with Roads and Highways (R&D) Road network.

Type B Feeder Roads: Roads connecting major rural market / develop centers with Upazilla (Thana) headquarters, growth cenetrs with R&D network and one Upazilla with other Upazilla.

Urban Roads: Roads within the territorial boundaries of cities /towns and under municipal corporation or pourashavas.

Rural Roads: Roads connecting union headquarters and local markets with the upazilla headquarter or the road system, village and farms to local markets and union headquarter and roads within a village or between villages.

2.2.2 Characteristics of Road Network

Most of the paved roads under Roads and Highways Department (RHD) are one lane, 59% of the road network including 74.3% of the feeder road (Type A) have pavement less than 4m wide. Even 20.4% of the national highways and 54.2% of the regional highways are in this class. It is also noticeable that, 50.9% of National highways and 40.8% of regional highways are in the 4-6m class. Only 11.3% of the network have pavement wider than 6m most of which are national highways and a few portion of national highways have pavement width of 7.3m.

Available data relating to traffic counts as reported in RMP (1991) indicated that, on the paved road network (about 8000 km), around 1700 km bear motorized traffic more than 1000 vpd (vehicles per day). Only 500 km have traffic more than 2000 vpd. The RMP estimates that the road traffic is likely to double during the next 10 years. table 2.2 shows the road network of Bangladesh interms of surface type, traffic volume, length and carriageway width.

Vehicle fleet in Bangladesh is composed of two types of vehicles- Motorized and non-motorized. Motorized road vehicles include truck, bus, mini-bus, car, taxi, jeep, microbus, etc. and non-motorized vehicles include cycle-rickshaw, Bullock cart, etc. The size of vehicle fleet in Bangladesh is given in Table 2.3.

Table 2.2 Bangladesh Road Network in 1990: Surface type/ Traffic volume/carriageway width.
(Kilometers)

A. Total Road Network: Surface Type	Paved bitumen	-----Unpaved------ HBB	Gravel	Earth	Total
RHD Network					
National Roads	2828	28	--	7	2863
Regional Roads	1385	199	--	---	1584
Feeder Roads A[a]	4022	1888	147	3196 [b]	9253
Subtotal	8235	2115	147	3203	13700

Table 2.2 continued....

LGED Network	Paved	Unpaved	Total
Feeder roads B/ Rural roads	2900	15000	17900
Pourashava (Municipal) roads	2200	2100	4300
Subtotal	5100	17100	22200
Other Roads	--	130000	130000
Total	13335	152565	165900

B. RHD Network: (Traffic Volume)	Paved	Unpaved	Total
Primary or Core Network			
over 2000 vpd	504	---	504
1000-2000 vpd	1168	5	1173
subtotal	1672	5	1677
Secondary Network			
500-999 vpd	1378	---	1378
200-499 vpd	1666	141	1807
100-199 vpd	1533	484	2017
Subtotal	4577	625	5202
Tertiary Network			
Upto 100vpd	1750	3535	5285
Residual/traffic Unknown	236	1300	1536
Total	8253	5465	13700

C. Road Network: Carriageway Width	≤4m	4-6m	≥6m	Unknown	Total
National Roads	585	1458	820	---	2863
Regional Roads	858	647	79	---	1584
Feeder Roads A	5722	1509	476	1543	9253
Total	7168	3614	1375	1543	13700

Source: RHD, RMP, Bangladesh Transport Sector Review(1991).
Note: HBB = Herring Bone Brick.
a. Includes Upazilla connecting roads (about 6300 km)
b. Includes about 1550 km of Feeder Roads A.

Table 2.3 Size of Vehicle Fleet (motorized) in Bangladesh, 1988-1991 (Number of Vehicles)

Type of Vehicle	1988	1989	1990	1991
Motor car	35,443	38,278	41,340	43,960
Jeep/Station wagon/Microbus	23,049	24,893	26,884	28,673
Taxi	1,622	1,719	1,822	1,914
Bus	10,643	11,175	11,734	11,982
Mini-Bus	6,233	6,856	7,542	7,893
Truck	21,341	22,621	23,978	24,904
Auto-Rickshaw/Tempo	17,429	18,562	19,769	23,430
Motorcycle	97,639	108,379	120,301	130,292
Others	7,373	7,703	7,890	8,040
Total	220,772	240,186	261,260	281,088

Source: BRTA, Finance & Development (Sept, 1992).
Note : The above numbers are likely in excess of the actual number of vehicles on the road as there are no records of cancelled vehicles.

2.3 REVIEW OF PAST TRANSPORT STUDIES IN BANGLADESH

2.3.1 Meghna and Meghna-Gumti Bridge Study, March 1985

The feasibility study of the construction of Meghna and Meghna-Gumti Bridge forecasts traffic on the basis of expected changes in population and GDP. Although an analysis is made of socio-economic activities in the area of influence of the project, this apparently has not been used in forecasting road freight volumes. No modal split analysis was made, but induced traffic was estimated as a percentage of normal traffic with the opening of Meghna bridge alone and when both bridges were opened.

2.3.2 Intermodal Transport Study, December 1985

This study was undertaken with a need to study the transport sector as a whole before the formulation of the Third Five Year Plan (1985/86-1989/90) to facilitate apprepriate resource allocation to the transport sector. Technical assistance for the task of carrying out a preparatory study for the transport sector of the Third Five Year Plan was provided by the United Nations Development Programme (UNDP) with the Asian Development Bank (ADB) acting as the executing agency.

Major study items of the Intermodal Transport Study (ITS) were: analysis of past trends in the transport sector, assessment of existing situation including field surveys, modal split (distribution of traffic among different modes) analysis, transport demand projections based on macro-economic analysis, assembly and identification of investment project proposals, evaluation of projects and formulation of investment program, and analysis and formulation of recommendations for policy and institutional issues.

The ITS forecasts traffic on the basis of GDP elasticities of transport demand and analysis of intermodal competition and modal choice. GDP growth rates were established by districts and considerations given to self-sufficiency of food grains as well as the demand for transport of other commodities. The consultants used Fratar Method of Trip Distribution to prepare the trip matrices for the years 1985, 1990 and 2000.

On the basis of the trend analysis the road freight share of transport, expressed in tons and passengers, should increase from 68% in 1990 to 76% by 2000 with the corresponding figures for passengers being 41% and 43%. It should be mentioned that, ITS presented an alternative forecast where rail was assumed to take a higher share of freight both from road and inland water.

2.3.3 Road Improvement Project No.1, November 1987

This study forecasts traffic on the basis of expected changes in population and income and assumed transport demand income elasticity. Relationships were established through regression analysis of freight and passengers transport demand for different modes of transport in relation to GDP. Also considerations have been given to trend analyses of vehicle population, traffic counts, etc. Traffic growth rates presented in this study assumed the Meghna bridge to be opened by 1991 and both Meghna and Meghna-Gumti bridges by 1996.

2.3.4 Bangladesh Energy Planning Project, June 1987

This study forecasts traffic on the basis of a detailed analysis of modal split and projections of the demand for freight and passenger transprot. The modal share expressed in freight tons-km and in passenger-km was expected to increase between 1985 and 2000 from 44% to 59% and from 51% to 70% respectively.

2.3.5 Bangladesh Inland Water Transport Masterplan, May 1989

This study forecasts traffic in a way similar to the Intermodal Transport Study by regression analysis of the relationships between GDP and tons and passengers transported. The analysis, however, is more detailed in particular in relation to freight forecasts and the discussion of the demand for and consumption of individual commodities and modal choice. The modal share expressed in freight tons-km and passenger-km for roads is expected to increase between 1985 and 2005 from 47.3% to 66.4% and from 64.1% to 75% respectively.

2.3.6 Jamuna Bridge Project, August 1989

The Jamuna bridge is considered as a multipurpose project comprising an electricity interconnector, a road link, a rail link, environmental effects and potentially a gas pipeline interconnector in the future.

The primary objective of this study is to assess the technical and economic feasibility of improvements in accessibility to the Northwest. The feasibility report describes the surveys, studies, designs, cost estimating and economic evaluation carried out during the period 1987-1989 as part of the Phase-II study of the proposed bridge within the corridor and with the configuration (combined road/metre gauge rail bridge) and characteristics determined during the course of the work. This study was requested by the United Nations Development programme with the World Bank acting as Executing Agency.

This study forecasts traffic by the use of a complex transport modelling system of trip generation, distribution, modal split, assignment, etc. The complexity of forecasting was further increased by the inclusion in the analysis of rail on the bridge. The road passenger forecasts are the result of a transportation planning model which takes into consideration generalized transport costs, the elasticity of demand to changes in fares, and the growth in number and wealth of the population. The freight forecasts are based on assessments of regional development projects and the effect these may have on the range of commodities which move across the Jamuna. the effect of transport cost reductions on the demand for commodities is also considered.

2.3.7 Second Road Improvement Project, February 1991

This study deals with the analysis of traffic and economic evaluation methodology, highway engineering, investigations of soils and materials and pavements, etc. The study area consists of Dhaka-Aricha, Joydevpur-Tangail, Dhaka-Sylhet, Dhaka-Daudkandi and Comilla-Chittagong highway sections.

This study was financed by the Government of Switzerland with the Asian Development Bank acting as Executive Agency.

The study forecasts traffic through transport models such as trip distribution, traffic assignment etc. Traffic growth rates calculated in this project are function of population growth rate, growth rate in per capita GDP, the transport demand income elasticity and a supplement determined by a number of parameters representing assumed changes in inter-modal competition and transport corridor characteristics. This study provides growth rates by vehicle type and by road sections mentioned earlier.

The assessment of the annual average daily traffic (AADT) by road section has been based on traffic counts undertaken during the course of the study, by traffic count data collected from the Roads and Highways Department (RHD), from Bangladesh Inland Water Transport Corporation (BIWTC) and from previous study reports.

The traffic surveys carried out for this study include traffic counts, origin-destination surveys and axle load surveys. Measurements of road surface roughnesses were also carried out.

It should be mentioned here that the evaluation of road projects has been carried out for scenario's, with and without the Jamuna bridge.

2.3.8 Bangladesh Transport Sector Review, June 1991

This study was conducted by the Infrastructure Operations Division, Country Department 1, Asia Regional Office, World bank with a view to assess the relative roles of various transport modes, and the efficiency of current regulatory practices and to recommend a long-term development strategy for the transport sector of Bangladesh.

The study outlines that, the most appropriate strategy for transport development in support of national economic development objectives is not obvious in Bangladesh. A fairly standard and generally adequate doctrine for transport development is that transport networks should aid in the integration of national markets, and Government investment programmes in Bangladesh appear to be driven by such considerations. However, market integration could entail extensive and costly investments in transport infrastructure. Also important in a comprehensive transport strategy is the development of an effective regulatory and policy framework to enhance efficiency in the sector. This is particularly important for Bangladesh in view of the scarcity of resources. The study proposes development strategies with respect to future investments as well as various policy and institutional reforms necessary for improved efficiency in the sector.

In comparison with overall economic growth rates, Bangladesh has witnessed rapid growth in transport demand with growth rates ranging between 5 and 6 percents p.a. for freight and 7 and 8 percent p.a. for passenger transport over the 1980s. Accommodating this high growth in transport demand will require substantial improvements in the transport system. Traffic densities on most of the network are still relatively low and therefore capacity exists for considerable expansion in transport services. However the system faces a number of critical bottlenecks: congestion at the major ferries; siltation of the rivers, in particular the river ports; and lack of storage capacity at key points causing the transport system to experience severe peaking in demand which exacerbates congestion at the ferries. Recognition of these as key constraints to development of the main transport network, and in view of the need to concentrate available resources, this study recommends concentrating development resources on an arterial corridor which links the ports of Chittagong in the east, and Mongla in the west to Dhaka. The arterial corridor would traverse each of the four main regions of the country - the southwest, northwest, central/northeast, and the southeast. Development of this arterial corridor would, among other benefits, lead to rationalization of traffic between the ports of Chittagong and Mongla, and for the overall main transport network, is estimated to result in a reduction in total system operating costs of the order of 10 percent.

To aid in the prioritization of investments in the sector, this study identifies core investment areas which include development of the "arterial corridor" linking the main seaports to Dhaka and the four main regions of the country, rehabilitation dredging of Mongla port, rehabilitation of road sections which would require extensive reconstruction if work is not undertaken immediately, a structured programme to complete selected rural roads, improvement of the numerous (about 80) ferry operation on the road network, etc.

To identify the critical constraints in the transport sector, this study analyzed the performance of the whole transport system. For the network development strategy, a transport network model - 'Bangladesh Transport Modeling System (BTMS)' - was developed for Bangladesh. The network model is designed to serve as initial screening device for examining alternative network improvement options for development of the main transport network taking into account the inter-modal interactions among the three surface transport modes. The model, however, is not specified at a level of detail adequate for assessing the feasibility of specific investments; that will require feasibility studies tailored to the specific circumstances of each investment. The transport model developed is a combination of trip distribution, modal split and traffic assignment sub models.

2.3.9 Road Master Plan Project, July 1991

The Government of Bangladesh has been provided by the United Nations Development Programme (UNDP) with technical assistance for the preparation of a Road Master Plan (RMP) for the country's main network with the Asian Development Bank (ADB) acting as the Executing Agency on behalf of UNDP. The main objectives are:

- the creation of a basic document for the formation of a long term, optimized, road development and maintenance policy in Bangladesh.

- The determination of the appropriate level of expenditure on investment and maintenance given local resource and absorptive capacity constraints.

- the introduction of modern planning techniques, in the Roads and Highways Department (RHD) in charge of the administration of roads, using the Highway Design and Maintenance Model (HDM), based on a road information system, with appropriate training of RHD stuff in these techniques.

Traffic surveys of this project included Axle-load surveys, OD surveys, and additional surveys such as general-speed surveys, Traffic free speed surveys, single-lane bridge surveys and Ferry delay studies. The consultants have estimated Average Annual Daily Traffic (AADT) 1990 on almost all links of the country's network, and where possible, for the various categories of non-motorized traffic as well as for motorized traffic. The main sources were the Annual Traffic Survey Reports RHD and the Study's traffic counts at 105 stations.

While projecting traffic, the consultants analysed past traffic data from 1982 to 1990 to investigate the pattern of growth rate over time. For better results, they analysed trucks, buses and light vehicles separately. The results of the analysis are presented in the form of regression equation. Both linear and exponential regression equations were derived of which linear equation appeared more appropriate.

Growth rates for different categories of motorized vehicles as forecasted by the consultants are 7%, 6.5% and 9% for truck, bus and light vehicles respectively for the year 1990 to 2000. The values are 0.5% less for the post 2000 years.

The consultants also carried out a preliminary examination of the eixisting network from the aspect of route discontinuity, detours or possible new roads needed relating to main projects. The results of the examination gave a list of "missing links" or of "new links" which, if built, would possibly save significant distances for existing traffic or greatly improve the physical ties between neighbouring areas. According to the judgement of the consultants, three new or missing links seemed to be viable: the Dhaka-Khulna road, the

Hatikamrul-Bonpara-Natore road in relation to the Jamuna bridge construction and the direct road between Chandpur and Daudkandi.

2.4 OVERSEAS RESEARCH ON TRANSPORT PLANNING

Extensive research has been done in the USA, UK, Australia & Japan on different transport modes to optimize their performance. Some relevant researches are discussed below.

Morf and Houska (1958), in their study of the Illinois rural highway network, came to the conclusion that the four factors responsible for traffic growth patterns were (1) geographic location, (2) type and width of pavement, (3) proximity to an urban area and (4) type of service the roadway provides. They observed that growth was assumed to take the form of an s-shaped curve with 3 stages of development - (1) increasing growth rate (1st stage), (2) constant growth rate (2nd stage), and (3) decreasing growth rate (3rd stage). They observed that truck traffic on rural primary highways was increasing at a faster rate than passenger car traffic. Their study also indicated that population is the principal component that affects the trend, followed by persons per vehicle and gallons of gasoline or vehicle miles per vehicle for rural roads of Illinois.

Covault (1958) considered the impact of growth trends in population, motor vehicle registration, motor vehicle use, and motor fuel consumption on traffic growth.

Magridge (1977) used forecasting car ownership as a technique to forecast traffic. The conversion of a car ownership forecast to a traffic forecast was treated as the main problem. He used two important techniques, time series analysis and cross-section analysis, to forecast car ownership. The basic assumption in a cross-section analysis, as compared with a time series analysis, is that there is a stable relationship between car ownership and income.

Hartgen (1980) introduced the concept of adjustment factors to base line forecasts of traffic to account for various additional concerns that had not previously been considered, or for which the previous assumptions were no longer valid. He recommended dealing with the urban and rural context separately. Among the aspects considered were changes in energy supply and price, auto ownerhsip and use, households, employment, etc. He also discussed probable range of forecast errors.

Chen (1981) proposed an improved method for statewide vehicle counting programme for Indiana with the help of statistical theory. The method is applicable to rural and suburban roads carrying 500 or more vehicles per day. Ritche (1986) also used a statistical approach for a better statewide traffic counting programme for California. Both of these studies provide estimates of AADT that are the basis for computing percent year traffic in forecasting techniques.

Neveu (1982) developed a set of elasticity based models to forecast rural traffic. The models forecasted future year AADT as a function of base year AADT, modified by various demographic factors. He claimed that the type of service the roadway provides is the only factor that had an appreciable effect on traffic growth rates. Multiple linear regressions was used to identify factors that best estimated AADT and their respective elasticities.

Memmott (1983) showed the impact of different traffic growth rates on the estimate of future benefits from a proposed project, as well as the factors affect traffic progjection errors. These factors included the year the projection was made, the percentage of commercial and industrial land development, and change in highway capacity. He also presented a simple model for projecting future traffic volume that is based on a multiple regression analysis of historical traffic volume data and adjustments for capacity changes and land development.

Taliadoros (1983) used a logistic growth model to estimate parameters to forecast traffic at ten continuous traffic count stations in Indiana. He adopted the S-shaped concept of Morf & Houska (1958). This study asserted that traffic data alone can provide reasonable predictions. It did not take into account any socio-economic variables and thus avoided the impact of inaccurate projections of these variables. The study does not predict temporary fluctuations in traffic growth, but only intends to project the overall growth pattern at each station.

Benjamin (1984) used time series analysis to forecast future traffic. Time series analysis uses a logistic function in which model parameters are estimated by ordinary least squares. The logistic function cannot account for sudden shifts in behaviour or changes in transportation network, but it can provide estimates of future trends when network changes are small.

Armstrong (1984) in his studies of forecasting, concluded that sophisticated extrapolation techniques have had a negligible payoff for accuracy in forecasting. He recommended simple methods and the combination of forecast technique. The combination may produce significant improvements in forecast reliability. He suggested starting with the least expensive method(s) and/or the most understandable method(s), and then investigating in successively more expensive methods. Armstrong suggested use of methods that are as different as possible, and simply weight each forecast equally. He proposed that complexities should be avoided unless absolutely necessary. So, simple methods, which are easily understood, have been undertaken to develop traffic growth factor models in his study.

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.

The Minnesota Department of Transportation (1985) computes a route specific growth factor from a trend analysis of the specific route. By linear regression, a line is fitted to the data and that line is extended to the design year. The overall growth is then the difference between design year AADT and base year AADT.

Albright (1985) of New Mexico State Highway Department has designed a procedure for forecasting Heavy commercial and Average Daily Traffic (ADT) on the New Mexico interstate system and the calculating the percent Heavy commercial traffic. This process, and the computer program developed from it, is called Trendline. Trend-line indentifies fourteen distinct heavy commercial truck sectors on the New Mexico interstate systems. Separate forecasting models were developed for each sector.

Saha (1986), in his study, developed two different kinds of models - aggregate and disaggregate - to forecast traffic volumes at rural locations in Indiana's state highway network. These models are developed using traffic data from continuous count stations in rural locations, and data for various country, state and national level demographic and economic predictor variables. Aggregate models are based on the functional classification of a highway, whereas the disaggregate models are location-specific. These models forecast future year AADT as a function of base year AADT, modified by the various predictor variables.

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 techniques offer traffic planners new and perhaps more approximate means for using computers in their work.

Ashtakala and Murthy (1988) of Concordia University, Canada developed gravity models for commodity flows between cities, towns, etc., in the province of Alberta, Canada. The data base for this study is obtained from the commodity flow survey done in 1977 for the Alberta Transporation

Department. They developed a set of gravity models, one for each category, to represent the commodity flows on a province-wide basis. The gravity models developed are calibrated by an optimization technique that uses a power function for the spatial separation factor and regression analysis.

2.5 TRANSPORT 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. Transport 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, land-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 arguement.

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.

2.5.1 Comments on Transportation Modelling Systems

This is a relatively new field of study and only a little work on models 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 them are remain to be tested extensively under user environment.

CATP is a capacity restraint traffic assignment model based on optimization technique. It was developed by Alam, J.B. in the Department of Civil Engineering at Bangladesh University of Engineering and Technology (BUET). The model was applied to assess the effectiveness of the Panthapath-Mirpur road link in Dhaka City, Bangladesh [Alam, J.B., 1992]

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 [Ritche et al, 1987].

TRANSTEP is 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 land-use/transport planning issues at either the strategic or detailed planning level [Young et al, 1988].

SATURN is a tool for testing the impacts of one way streets, traffic control measures and bus-only streets. It is the 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, is 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 devices and measures such as street closures, 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 model developed by UK Department of Transport intended for relatively small road networks, but which may contain complex traffic and pedestrian control techniques [Young et al, 1988].

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

CHAPTER-3

STUDY DESIGN AND METHODOLOGY

3.1 INTRODUCTION

The forecasting of traffic on rural highways has not been a major focus of transportation research. Some of the current researches in this area has been overviewed in Chapter 2. In this research, an effort is made to develop models to predict future traffic pattern and volume on the national bighway network of Bangladesh.

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 transport models developed in this research, 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

The following sections explain the principles which were followed while developing the distribution and assignment model, study area where the models were applied and traffic survey for input data collection for the models.

3.2.1 Selection of Model Parameter

Choice of mode as well as, choice of a particular route for a trip between two places (origin and destination) depends on various factors such as journey time/length, journey purpose, income of the trip maker and relative travel time or cost. Transport models are usually formulated using optimization techniques. For optimization of traffic flow one of the variables (factors) mentioned above is generally chosen as independent parameter and the others are related to it by empirical relationships or equations. In this study, the travel time and the travel cost have been chosen as the independent variable for modelling of passenger and freight movements respectively. Thus it is postulated that, passenger movements will follow 'minimum time' routes while the freight movements will follow 'minimum cost' route. Hence, in the optimized condition, for passenger movements the flow of traffic 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. Similarly for freight movements, travel cost will be minimum. Other variables such as flow volume, capacity, free flow travel time are incorporated in the model using relationships which are explained in section 3.3.

3.2.2 Selection of Study Area

This study deals with the prediction of traffic volume and traffic flow patterns on the national highway network of Bangladesh. Determination of traffic flow pattern among old twenty districts is one of the main objectives of this study. To meet this need, a number of regional highways have been included. Fig 3.1 shows the relevant highway network and the study area and Table 3.1 gives description of the links of the highway network.

Table 3.1 Description of the highway network

Link	Description	Type
0-1	Chittagong - Chittagong Hill Tracts	Regional
0-20	Chittagong - Feni	National
20-3	Feni - Noakhali	National
20-2	Feni - Comilla	National
2-23	Comilla - Sarail	National
23-4	Sarail - Sylhet	National
2-21	Comilla - Daudkandi	National

Table 3.1 continued...

21-5	Daudkandi - Dhaka	National
22-23	Bhairab - Sarail	National
22-24	Bhairab - Kisoregonj	Regional
24-8	Kisoregonj - Mymensingh	Regional
5-25	Dhaka - Joydevpur	National
25-8	Joydevpur - Mymensingh	National
5-28	Dhaka - Aricha	National
25-9	Joydevpur - Tangail	National
9-26	Tangail - Elenga	National
26-7	Elenga - Jamalpur	National
7-8	Jamalpur - Mymensingh	National
26-27	Elenga - Bhuapur	Regional
27-30	Buapur - Sirajgonj	BIWTC ferry
30-34	Sirajgonj - Hatikamrul	Regional
5-29	Dhaka - Mawa	National
29-33	Mawa(east) - Mawa (West)	RHD ferry
33-6	Mawa - Faridpur	National
28-31	Aricha - Nagarbari	BIWTC ferry
28-32	Aricha - Daulatdia	BIWTC ferry
32-38	Daulatdia - Ahladipur	National
38-6	Ahladipur - Faridpur	National
6-10	Faridpur - Barisal	National
10-11	Barisal - Patuakhali	National
6-39	Faridpur - Jhenaidah	National
39-11	Jhenaidah - Jessore	National
11-12	Jessore - Khulna	National
39-13	Jhenaidah - Kushtia	National
13-36	Kushtia - Dasuria	National
36-42	Dasuria - Bonpara	National
42-35	Bonpara - Natore	National
35-18	Natore - Rajshahi	National
31-37	Nagarbari - Kashinathpur	National
37-17	Kashinathpur - Pabna	National
17-36	Pabna - Dasuria	National
37-34	Kashinathpur - Hatikamrul	National
34-15	Hatikamrul - Bogra	National
15-35	Bogra - Natore	National
15-19	Natore - Rangpur	National
19-16	Rangpur - Dinajpur	National

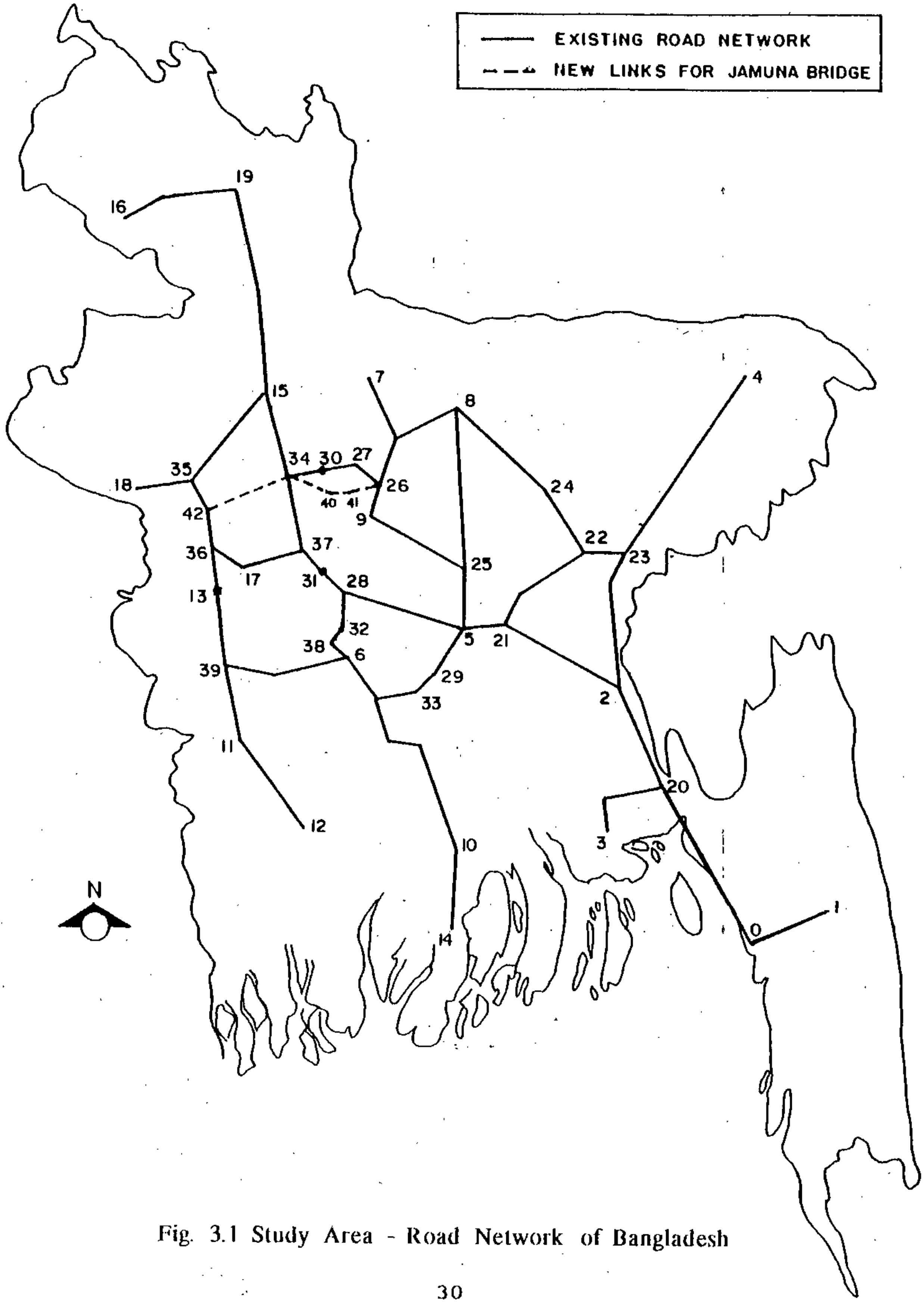

Fig. 3.1 Study Area - Road Network of Bangladesh

3.2.3 Traffic Surveys

The collection, analysis and interpretation of traffic data are vital elements in developing transport models. This section deals with traffic survey procedures used in this research.

3.2.3.1 Need for Traffic Data

Traffic engineers and planers need information about traffic for a variety of purposes such as managing road and traffic system and designing implementing changes to it. The purposes 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 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

In this research, the data represented in the reports of the past transport studies (discussed in Chapter 2) have been used. Primarily, information on road inventory and traffic were required. The road inventory includes road length, width, number of lanes and roadway condition. Traffic volume and origin-destination (O-D) surveys provide the traffic data. The details of these data have been discussed in Chapter 6.

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. The long range plans as well as the immediate action programs should be modified continuously to meet changing needs. As a result of these requirements, the transportation planning process has become -what is 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. These data provide the basis for identifying the prohlems. They also provide the basis for the development of the various models used to forecast future land-use, determine travel patterns, and assess the effect of probable changes in the transportation system.

3.3.2 Methodology Developed for the Study

The current practice at the Roads and Highways Department (RHD) to estimate traffic volume and flow pattern is based on the yearly traffic count survey conducted by the department. Knowing the traffic volume for the prevailing condition, they forecast traffic based on traffic growth factors determined by analyzing the past trend. Consultants associated with various transport studies handled the problem of forecasting of traffic using transport models. But the methods they used vary from project to project. Most of the past transport studies were not undertaken to formulate transport models for the prediction of traffic on transportation network of Bangladesh - the models were formulated to assess traffic movements as a partial requirement of the feasibility of a particular project.

The only transport model 'Bangladesh Transport Modelling System (BTMS)' [Transport Sector Review, 1991] was developed for assessing the performance of total transport system of this country. It requires vast amount of data which may not be easily obtainable considering the fact that, there is no systematic and organized program for recording and processing traffic data in this country. Recognizing the above mentioned facts, the need for the development of transport models for forecasting traffic flow-patterns and volume is strongly felt.

A clear distinction should be made about the nature of the traffic planning methodologies. They are divided into two separate groups: (1) those that address the planning problem as a network analysis based on traditional four-step process (traffic generation, distribution, model split and assignment) which require enormous data and sophisticated computer resources and (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 present study intends to find a suitable middle ground between the above two types of processes using network analysis and traffic distribution and assignment techniques. Though sophisticated mathematical and computational analysis are included using computer, the complications have been substantially reduced using some assumptions and thus reducing the amount of data and computer resources requirement.

Trip distribution is that part of the transportation planning process which relates to a given number of travel origins for every zone of area under study, to a given number of travel destinations located within the other zones of the area. It is not necessarily concerned with the mode of travel used for a given trip, nor the routes which could be taken to complete this trip. Rather it is concerned with establishing the links between a number of zones for which trip generation calculations have previously been made.

The underlying principle of trip distribution modelling is that, travel between any two points will increase with increase of attraction of such travel, but decrease as the resistance to travel increases. During the past thirty years various mathematical procedures based on this principle have been developed and used for predicting interzonal travel patterns, and they tend to fall into two main groups:

a) **Growth Factor Methods**: In these methods, the growth factors are applied to present day interzonal movements such as uniform factor method, average factor method and Fratar method; and

b) **Synthetic Methods**: In these methods, an attempt is made to understand the causal relationship behind patterns of movement, by assuming them to be similar to certain laws of physical behaviour. Once understood, these causal relationships are projected into the future and the appropriate travel pattern is synthesized some of the synthetic models are gravity model, opportunity model, electrostatic model, etc.

The gravity model is selected in the present study for trip distribution, because it is simple to understand and apply, and is well documented. It adapts the concept of gravity as advanced by Newton in 1686 and is based on the assumption that trip interchanges between zones is directly proportional to the relative attraction of each zone and inversely proportional to some function of the spatial separation between zones. In mathematical terms it can be expressed as:

$$T_{ij} = KP_iA_j(R_{ij})^{-n}$$

where, T_{ij} = Number of trips produced in zone i with a destination in zone j

P_i = Total number of trips produced in zone i

A_j = total number of trips attracted in zone j

R_{ij} = Measure of the resistance of travelling between zones i and for example, distance, journey time, cost (fare, etc.

n,k = Constants

The gravity model used in this study- considering it to be doubly constrained and expressing R_{ij} interms of time (t_{ij}) and cost (C_{ij})- is of the form as follows:

$$T_{ij} = P_i \frac{A_j R_{ij}}{\sum_{j=1}^{n} A_j R_{ij}}$$

where, for passenger movements

$R_{ij} = (t_{ij})^{-n}$

and for freight movements

$R_{ij} = (C_{ij})^{-n}$

The generalized cost C_{ij} for travelling between a particular pair of zones has been defined as follows:

C_{ij} = (unit cost of travel time)* (total travel time between i and j) + (unit cost of distance)*(total travel distance between i and j).

For prediction of travel patterns, the model proposed is calibrated with the base year data considering the model to be doubly constrained i.e. the number of trips leaving each zone is equal to the number of trips generated by that zone and the number of trips entering any zone is equal to the number of trips attracted by that zone.

Traffic growth factors for prediction of future traffic flow-pattern and volume are calculated assuming growth of traffic to be a function of population of the region, gross domestic product (GDP) and income elasticity of transport demand. The equation used for this purpose is as follows (SRIP, 1991):

TGR = {(100+PG)(100+GDPC*E)/100}-100

Where,

TGR = traffic growth rate (% p.a.)

PG = population growth rate (% p.a.)

GDPC= per capita growth rate in GDP (% p.a.)

E = income elasticity of transport demand.

In this study, traffic prediction has been made both for the existing and future changed condition of the network. Changes to the network are nothing but improvements of the network and for improvement of the existing condition, traffic will generate in excess of the normal traffic. The measurement of the volume of traffic which generates on such an improvement was done using the gravity model developed in this research. It is assumed in this study that, traffic will generate for time savings and cost savings in the cases of passenger and freight movements respectively. If $(R_{ij})_1$ and $(R_{ij})_2$ are the separation factors for a particular O-D pair for present and after some improvements respectively and if the attraction and generation of traffic of these zones considered to be remain constant then,

$$T_2/T_1 = \{(t_{ij})_1/(t_{ij})_2\}^n \quad \text{for passenger movements}$$
$$= \{(c_{ij})_1/(c_{ij})_2\}^n \quad \text{for freight movements}$$

where, T_1 and T_2 are the volume of traffic between O-D pair (i-j) before and after improvement respectively. Again T_2 can be expressed as $T_2 = T_1 + f*T_1$, where, f is the factor by which the present traffic increases. So the generated traffic growth factors are

$$f = \{(t_{ij})_1/(t_{ij})_2\}^n - 1 \quad \text{for passenger movements}$$
$$= \{(c_{ij})_1/(c_{ij})_2\}^n - 1 \quad \text{for freight movements.}$$

Traffic assignment model - the next and final stage of the model building phase of this study - is applied to estimate the volume of traffic on various links of the road network. The traffic assignment process requires as input a complete description of either the proposed or existing transportation system, and a matrix of interzonal trip movements. The question which naturally arises at this final phase of travel estimation process is, "What are the factors that lead people to choose one route over another ?" Generally speaking, researchers have identified at least four: (1) travel times, (2) travel costs, (3) comfort, and (4) level of service (volume/capacity).

In this present study travel time has been selected as the major factor in traffic assignment, the main reason being the relative case by which travel time as opposed to the other three variables can be measured.

A variety of techniques for traffic assignment are available. They are discussed in Chapter 5. 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 assignments are based on the assumption that the path taken by vehicles travelling from zone of origin to zone of destination will be the one with least travel resistance. This travel resistance can be measured in terms of time. Although this method of traffic assignment is simple to understand and apply, one major drawback is that the technique takes no account of increasing congestion associated with increased volumes and assigns too many vehicles to the better routes as travel time on these routes will be better than on the multi-purpose streets. Also small differences in journey times by different routes between the same origin and destination can bring about unrealistic journey paths when the all-or-nothing assignment is used. In practice these things would result in the originally favourable links becoming overloaded, a situation which would not occur in real life [Salter, 1976].

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

In this study, the capacity restraint model proposed by Federal Highway Administration (FHWA) has been computerized for assignment of trip matrices into the national highway network. The updating of travel time on the basis of traffic flow volume is performed using the following capacity restraint function:

$$T = T_o * [1 + 0.15 * (V/C)^4]$$

where, T = updated (modified) travel time

T_o = journey time at zero volume

= 0.87* journey time at practical capacity

V = assigned traffic volume

C = capacity of a particular link.

3.4 SUMMARY

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

CHAPTER-4

COMPONENTS OF TRANSPORT SYSTEM

4.1 INTRODUCTION

The main components of transportation system are object and path. 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 vehicle. The vehicle gives the object mobility on particular type of path employed and it can be propelled on that path. The vehicle is identified as a third functional component of transport system.

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 at intersections and a single flow can be separated to follow two or more distinct paths at intersection.

Another component of transportation system is terminal. At terminals traffic is 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 the proper 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. The functions of these basic components of transportation system is illustrated in Fig. 4.1.

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, origin, to another, the destination. For road transport this facility is provided using road network and vehicle.

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.

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

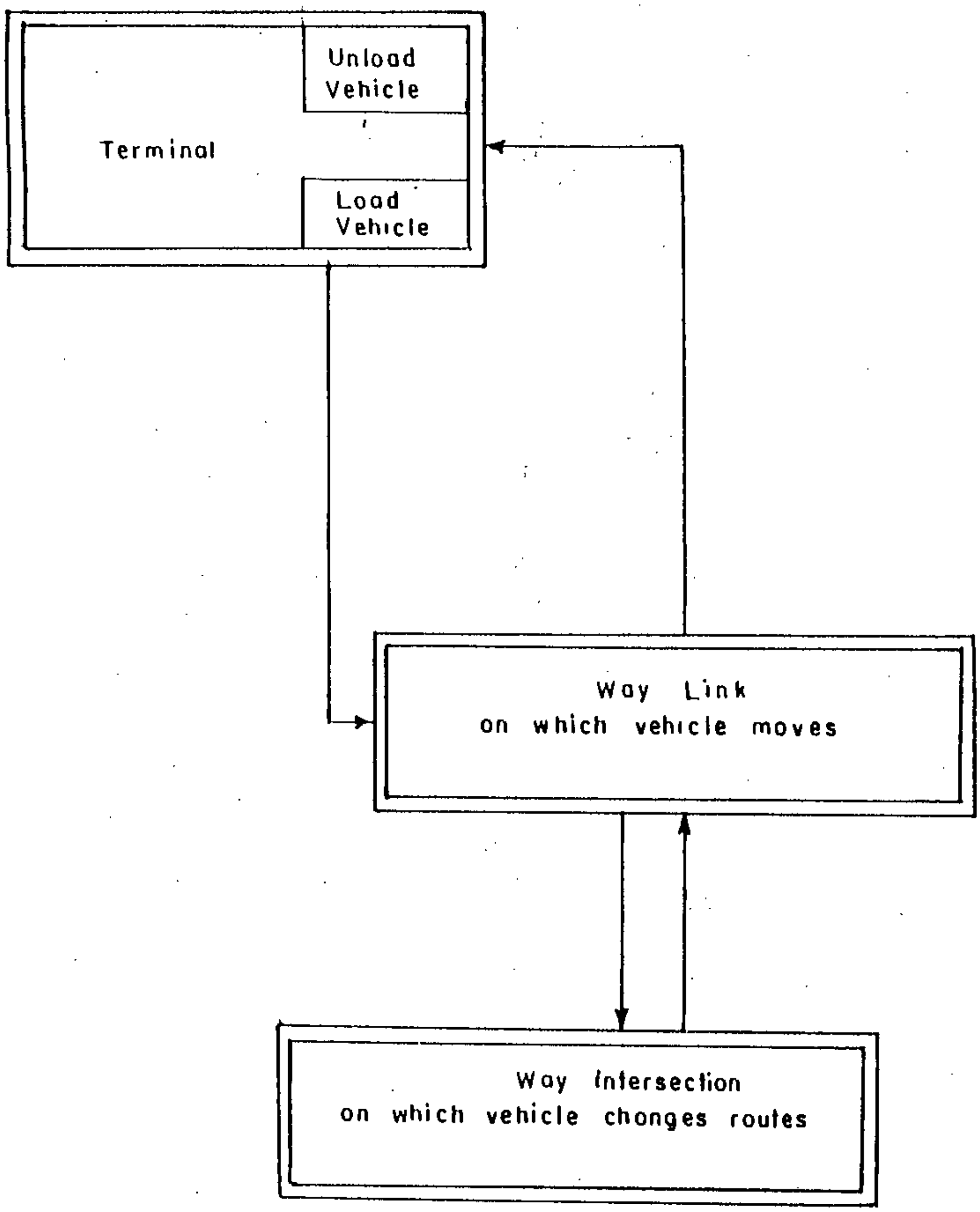

Fig.4.1 Transportation System Components
[Source: Morlok, 1978]

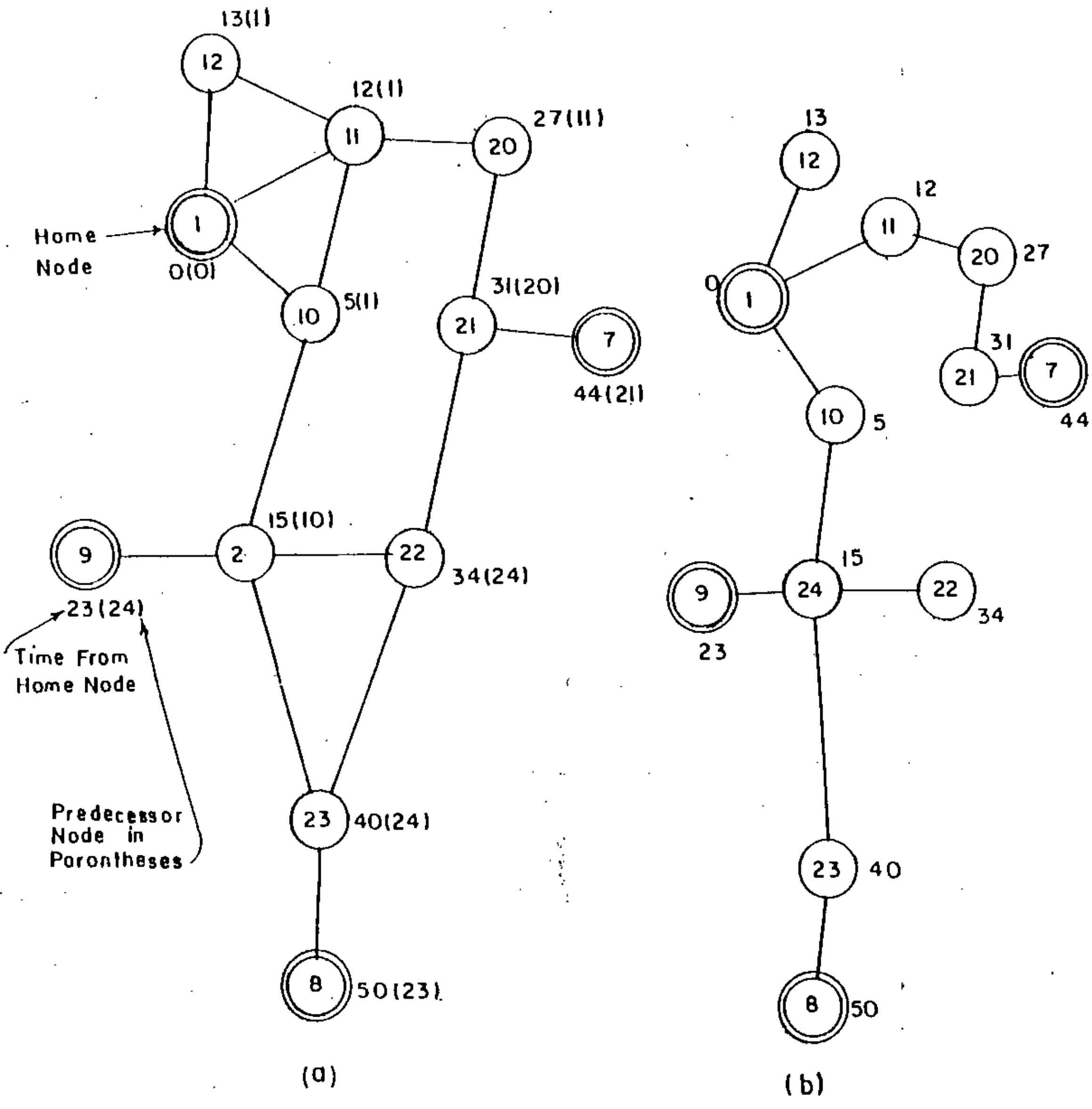

Fig. 4.2 Example Network

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.

Table 4.1 Connection matrix of the example network in Fig. 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 node 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 places corresponding to node which ends the link. Table 4.2 shows node-link incidence matrix for the same network in Figure 4.2.

Table 4.2 Node-link incidence matrix

	Links for traffic flow														
Node of Origin	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
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.

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 to one another. Some of the most important characteristics of the system are travel time and cost.

This can be illustrated by reference to Fig. 4.2, which is the example 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 min.

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

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

where, t_p = time from origin to destination

L_p = set of links

t_{ij} = time on link (i,j)

ij ϵ L_p 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 passenger movement, 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 rather 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 Fig. 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 in termed as 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 process for the whole network.

In performing analysis for finding minimum 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 paris of nodes can be usefully presented in 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			
		1	7	8	9
From node	1	0	44	50	23
	7	44	0	55	51
	8	50	55	0	43
	9	23	51	43	0

Another aspect of networks, which is very important, is capacity. For finding capacity of individual links the following equation may be used.

Service volume or capacity

$$S_v = 2000 * N * v/c * T_L$$

where, N = No of lanes

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

W = side clearance factor

T_L = Truck factor

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 4.5.

Table 4.5 PCU proposed by Roads and Highways Department (RHD), Bangladesh & by Indian Road Congress (IRC).
[Source: Shankland Cox, 1979 & Sharma,1988]

Vehicle	PCU proposed by RHD	PCU proposed by IRC
BUS/MINIBUS/ TRUCK	3	3
CAR	1	1
RICKSHAW/VAN	0.5	1.5
BABY_TAXI/ MOTORCYCLE	1	0.5

In this present study, for analysis of the traffic data collected within the study area, PCU values proposed by the Roads and Highways Department (RHD) have been used.

4.3 SUMMARY

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

CHAPTER-5

MATHEMATICAL PROGRAMMING METHODS AND THE COMPUTER MODEL

5.1 INTRODUCTION

The objective of this chapter is to provide a background understanding about the mathematical programming techniques used in developing the transport model and also to introduce the various features of the model. This chapter describes how a transport system can be defined in a network from and the mathematical techniques for calibration of the trip distribution model and the formulation of assignment model and also describes the input and output phases of the model and its limitations.

5.2 REPRESENTATION OF A TRANSPORT SYSTEM

A land-use/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 diagrammatically shown in Fig. 5.1.

At macroscopic level extended zones do exhibit a great deal of homogeneity and permit the laid-use plan of most cities to be divided into some twenty or 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 he 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, as in numeric form it is simply a two dimensional array of links and nodes of diagrammatic one.

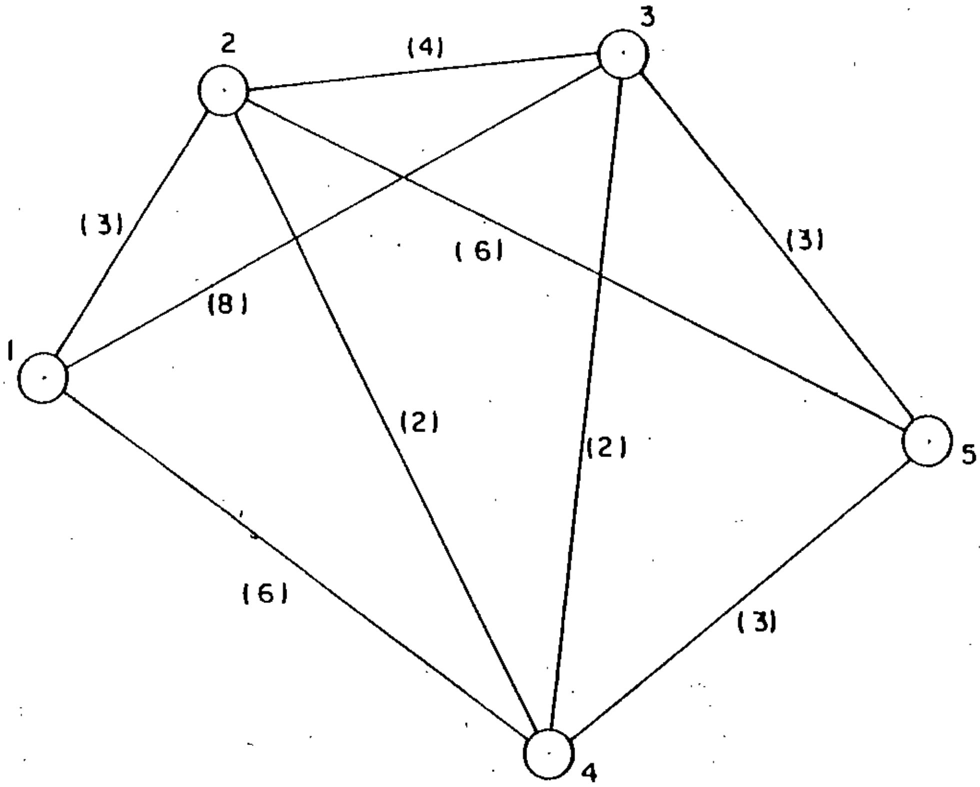

Figure 5.1 Example Network

For analytical purpose 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 Fig. 5.1 and its node-link matrix is given in Table 5.1.

Table 5.1 Node-link matrix for network shown in Figure 5.1.

		To Node				
		1	2	3	4	5
From Node	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 to specify the length, travel time, capacity or cost of links of the network.

5.3 MATHEMATICAL PROGRAMMING METHODS

5.3.1 Gravity Model for Trip Distribution

The gravity model is perhaps the most widely used synthetic method of trip distribution, because it is simple to understand and apply, and is well documented. It adapts the concept of gravity and is based on the assumption that trip interchange between zones is directly proportional to the relative attraction of each zone and is inversely proportional to some function of the spatial separation (travel time, cost, etc.) between zones.

The gravity model which is used in this present study for trip distribution is discussed in Chapter 3 (Study Design & Methodology). To predict the future flow-pattern of traffic with the help of a gravity model, it is first necessary to calibrate the model with the base year data. In simplest way calibration means that, after calibration the model will be able to calculate all the base year survey within a reasonable limit trips mathematically. The calibration technique used in this study is explained below:

Step 1: Input all the necessary data files to the gravity model. These files contain the values of time and cost needed to travel from each centroid to all others through the shortest path, and also the base year interzonal trip matrix.

Step 2: Calculate generation and attraction of traffic of each zone from the base year trip matrix.

Step 3: With the calculated generation and attraction of zones, calculate interzonal trips using the gravity model setting the exponent of the resistance parameters (travel-time cost) to 2.

Step 4: Calculate new attractions of each zone and compare it with the attractions calculated in step 2.

Step 5: If the variation of the two attractions exceeds 3%, calculate adjustment factor b_j as follows:

$$b_j^{(c)} = b_j^{(c)} \frac{A_j}{\sum_{i=1}^{n} T_{ij}^{(c-1)}}$$

where, $b_j^{(c)}$ = b_j value at c^{th} iteration

$b_j^{(c-1)}$ = b_j value at (c-1) th iteration

A_j = the actual attraction of zone j (calculated in step 2)

$\sum_{i=1}^{n} T_{ij}^{(c-1)}$ = new attraction of zone j as calculated at (c-1)th iteration.

Step 6: Modify the actual attractions by multiplying them with corresponding b_j factors.

Step 7: Repeat the Steps 3 to 6 until variations of the attractions (as described in step 4) of each zone are within a range of ± 3%.

Step 8: Compare the interzonal trips as calculated after step 7 with those of the base year trip matrix.

Step 9: If the variation of interzonal trips exceeds 3%, modify the resistance function R_{ij} as follows:

$R_{ij}^{(d)} = R_{ij}^{(d-1)}$ *[(No. of survey trips on link ij)/{No. of (d-1) th iteration gravity model trip on link ij}]

where, $R_{ij}^{(d)}$ = the d^{th} modified value of R_{ij}

$R_{ij}^{(d-1)}$ = the (d-1) th modified value of R_{ij}

Step 10: Calculate interzonal trips using the modified R_{ij} values.

Step 11: Repeat steps 8 to 10 until the variations in interzonal trip frequency are within a range of ± 3%.

Step 12: Check again the attractions of each zone after trip frequency adjustments and make further modification to b_j factors if necessary repeating the steps 3 to 7.

Step 13: Store the final b_j and R_{ij} values which satisfy both attraction and trip frequency criteria for the base year trip matrix.

The model is now calibrated and it can be employed for the prediction of future flow-patterns (interzonal trips) using the future predicted attraction and generation of traffic of each zone and the corresponding final b_j and R_{ij} values.

5.3.2 Shortest Path Algorithm

There is a 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 |-,0| and the next node to be labelled is found by determining the j for which

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

where x and $\bar{x}$ are the subjects of the universal set of nodes N which lie to either side of the section (known as a cut) which divide the labelled and unlabelled nodes at any stage.

Example:

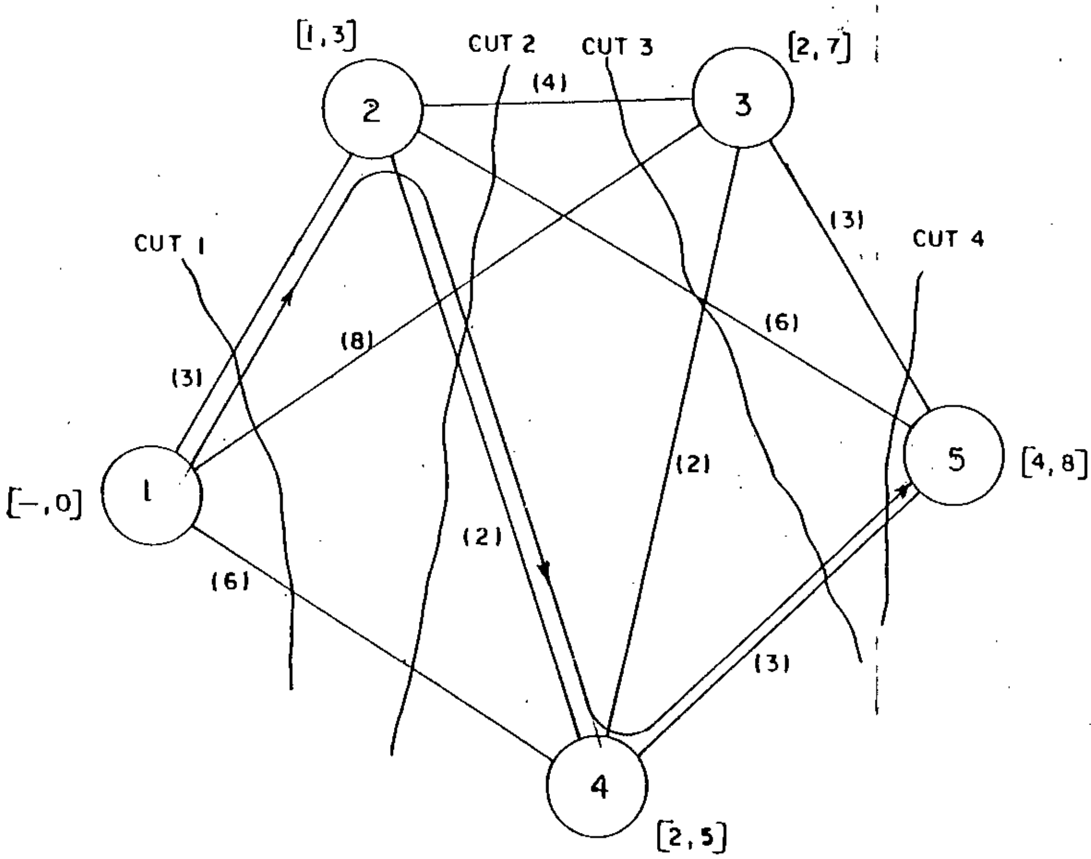

Figure 5.2 (Source: Blunden, 1971)

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

$p(1) = 0$

From

$$\min_{j \in \bar{X}} (l(i,j))$$

we get,

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

i.e. min (3,6 or 8)

i.e. 3 or l(1,2)

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

<u>For cut 2.</u>

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

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

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

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

Label of node 4 is (2,5)

<u>For cut 3</u>

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

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

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

[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 in the direction in which any of the links may be traversed. However one way streets may be dealt with by replacing the one-way link with links, having an arbitrarily large length and travel time, which will never be used in calculation.

5.3.3 Traffic Assignment to Road Network

Traffic assignment is that part of the process of estimating traffic volumes on any transportation networks. It deals with the steps which follow the trip distrihution and modal split of the traffic. There are various approaches to traffic assignment. These are explained in this section.

5.3.3.1 All-or-nothing Assignment

All-or-nothing assignment is basically an extension of the finding of minimum paths through a network. It is termed as all or nothing hecause 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 this type of assignment are:

Step 1: Find minimum path tree from each origin to all other destinations.

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

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

5.3.3.2 Capacity Restraint 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. The capacity restraint function used in this model 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 restraint assignment as used in this model is explained below:

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

Step 2: Assign some percentage 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. It may be mentioned here that assigning 100% traffic at a time will give the effect of all-or-nothing assignment.

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

Step 4: Find new minimum path tree.

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

The output of the model after the final step will be traffic volume on all the links of the network into which the Origin-Destination matrix has been assigned.

5.3.3.3 Equilibrium Assignment

An assignment model that does produce assigned volumes satisfying one of the Wardrop rules is equilibrium assignment. This model results from the expression of the assignment procedure as a mathematical programming problem, involving the constrained optimization of a non-linear objective. This is done as follows.[Young, et.al, 1988]

Given a network consisting of links e that connect nodes i to nodes j, i.e. link e = (i,j) means that the link goes from node i to node j, and given that T_{hd} is the number of trips from origin h to destination d (i.e. $\{T_{hd}\}$ is the origin-destination matrix), then the network flow-pattern (for fixed travel demand) which satisfies Wardrop's first rule is the solution of

$$Z = \min_{x} \left[\sum_{e} \int_{0}^{q(e)} t_e(x)dx \right]$$

subject to the continuity of flow constraints

$$T_{hd} = \sum_{r} X_{rhd} \qquad \textit{for all } i,j \qquad (5.1)$$

$$q(e) = \sum_{hdr} \delta_{ehdr} X_{rhd} \qquad \textit{for all } e \qquad (5.2)$$

$$q(e) \geq 0 \qquad \textit{for all } e \qquad (5.3)$$

and,

$$X_{rhd} \geq 0 \qquad \textit{for all } r,h,d \qquad (5.4)$$

In this system of equations q(e) is the traffic flow on link e, $t_e(q)$ is the travel time (cost) on link e corresponding to a link volume q, X_{rhd} is the number of trips using path r between h and d, and

$$\delta_{erhd} = 1 \quad \textit{if for pair hd path r contains e}$$
$$= 0 \quad \textit{otherwise}$$

The solution of this problem can be obtained using the frank-Wolfe algorithm for non-linear optimization. The algorithm generates a series of all-or-nothing assigned flow vectors V_k (k=0,1,2,3,.....,n) which are used to compile the equilibrium assigned flow vector Q_n. The elements of each flow vector are the link flows in the network, i.e. $Q_n = [q(e)]_n$ and $V_n = [V(e)]_n$, where q(e) is the assigned flow and V(e) is the all-or-nothing assigned flow on link e. Each successive vector V_k is generated using the travel costs set by the flows in the preceding vector V_{k-1}, with V_0 (the initial vector) being set usually on the basis of free flow travel costs. This is the same concept as used in iterative capacity restraint assignment. The difference is that equilibrium assignment uses a theoretically derived strategy for selecting the relative contribution of V_k to the final solution Q_n. This strategy guarantees a convergent solution towards the flow pattern satisfying Wardrop's user-minimization rule.

The strategy is to progressively update the vector Q_n, using the property that if Q_{n-1} and V_n are both feasible flow patterns for the network (i.e. they both satisfy the continuity of flow constraints), then a linear combination

$$Q_n = (1-a_n)Q_{n-1} + a_n V_n$$

where $0 < a_n < 1$, is also a feasible solution. In the Frank-Wolfe procedure Q_n is determined by selecting a_n such that,

$$Z = \min_a \left[\sum_e \int_0^{q(e,n,a)} C_e(x)\, dx \right]$$

$$q(e,n,a) = (1-a_n)\, q_{n-1}(e) + a_n V_n(e)$$

The procedure is repeated until a pre-set level of convergence on either Z or Q_n is reached, or a maximum number of cycles (n) is reached. Thus each successive iteration (i.e. each increase in n) will produce a solution that is closer to the real solution than the previous solution.

5.3.3.4 Stochastic Assignment

Assignment models that try to accommodate the imperfect knowledge and differing perceptions of drivers are known as stochastic assignment models. There are stochastic models equivalent to each of the three deterministic models described above.

An assignment procedure that satisfies Wardrop's first rule- that drivers will seek a path minimizing their own travel times, whether by a deterministic or stochastic algorithm, may be taken as a simulation of actual driver behaviour. The assigned flow pattern satisfying Wardrop's second rule- the minimization of vehicle hours of travel in the network- for a fixed travel demand is given by the solution of the mathematical programming problem with objective function defined by [Young, et.al, 1988]

$$Z = \min_{q} \left[\sum_{e} t_e(q(e))\, q(e) \right]$$

and constraints defined by equations (5.1) to (5.4).

5.3.3.5 Selection of Traffic Assignment Method

The methods of traffic assignment described above vary from each other with respect to the assumptions made to formulate them. The equilibrium method and the capacity restraint method have the same concept, the difference being the theoretical approach of the equilibrium assignment to the traffic assignment problem. The stochastic method on the otherhand, tries to accommodate the imperfect knowledge and differing perceptions of drivers which results in a time consuming and complex models. Due to the simplicity of mathematical method and requirement of less data that can be easily obtainable, capacity restraint assignment technique has been selected to develop traffic assignment model in this study. For inter-district traffic flow, there are limited scopes for the vehicles to select alternative routes at this present condition of the network. Also it has been pointed out from the past trend that traffic volume on the network of Bangladesh is well below the capacity of the road sections. Considering these facts, it can be stated that an all-or-nothing assignment model can be used for estimation of traffic. The reason for selecting the capacity restraint assignment is that, Bangladesh is a developing country and with course of development its transport network is also undergoing changes. These changes or may be stated as improvements on the otherhand initiate a high increase of traffic on the highway network. To examine the effect of volume/capacity ratio on the route choice phenomena, capacity restraint method is the most easiest and effective tool for assignment modelling. It may be mentioned here that, assigning all the trips at a time an all-or-nothing assignment can be performed using the capacity restraint traffic assignment model.

5.4 THE COMPUTER MODEL

The foregoing sections of this chapter and also the preceding chapters of this thesis provide an introduction to the model developed in this research. The following sections introduce the model along with its input and output phases.

The models developed have been based on a well defined and established mathematical technique. This proposed technique is reliable, well documented and also easy to use. easily available microcomputers (IBM AT compatible) will be enough to handle all the mathematical calculations. The models developed in this study have been programmed in TURBO C (MS DOS System) for IBM AT compatible microcomputers. The users can use the models 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 models are to be accepted by traffic engineering professionals. The models were designed in such a way that input data required are very few and easily obtainable. All the outputs of future flow-patterns and traffic volume on links are presented independently so that the user can get information and interpret them according to his requirements.

5.4.1 Aim and Capability of the Model

The model was developed by computerizing traffic distribution and assignment for the prediction of future flow-patterns and link traffic volume. It 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 planning tool without large amount of input data. It permits a reasonable level of land-use/transport interaction modelling with only limited resources. The model can handle traffic flow in different conditions of demand.

5.4.2 Input Procedure

Data input medium for this model is a computer file or an interactive procedure. The user selects the task to be carried out in an interactive way. 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) Link length

iii) Link capacity

iv) Average link speed

v) Free flow travel time and travel cost between zones

b) Trip demand data

i) Origin-Destination (O-D) matrix

ii) Zonal traffic growth factors

Different input files are given in Appendix-A.

5.4.3 Output Procedure

The output from the traffic models can take many forms and level of details. Typically the output will be used to produce overall measures of traffic systems performance and to answer specific queries about that performance.

It is better to present outputs in such a form with which the user is familiar.

This model presents output in two familiar ways:
i) On screen display
ii) Storing output on computer files.

5.4.4 Validity of the Model

The validity of the model was checked using base year (1990) traffic data. The efficiency of the model in calibrating a gravity model can be tested by just checking the base year survey O-D trip matrix and its calibrated form as presented in tables 7.3.1 to 7.3.4 of Chapter 7. For the validity of the assignment model, volume on Jessore-Khulna road section of Dhaka-Khulna highway was considered. These results are presented in Appendix-C.

5.4.5 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. Route choice behaviour is modelled on the basis of minimum path theory, that all the trips are made through the minimum path between a particular origin and destination. The model does not consider vehicle movement disturbances, car following acceleration, deceleration or lane changing.

5.4.6 Step wise Execution of the Model

This section describes different steps for executing the model on micro-computer. The model is designed for the users who have a minimum idea about the transport models. The steps to be followed are:

Step1: Necessary files required are the execution file MODEL.EXE and the data files described in chapter 6. Store all the files in the hard disk of the computer you are going to use or in your floppy disks. Select the appropriate drive and then enter MODEL.EXE or simply MODEL. The program will start and names of the model and the persons worked for developing this model will appear on the screen. A massage will appear at the bottom of the screen "Press any Key to continue..". To move on to the next step, press any key of the keyboard.

Step2: this step will perform the conversion of traffic into PCU (passenger car unit). Input files for this step are bus, minibus, light motorized vehicle and truck trip matrices and the PCU values for these four types of vehicles. After that you will be asked to give the name of the output files which will store the trip matrices in PCU for both passenger and freight movements. Passenger trips are the combination of bus, minibus and light vehicle trips and freight trips are the truck trips.

Step 3: the calibration of gravity model of trip distribute begins this stage. There is a option for selecting data (passenger or freight) that will be used for calibration of the gravity model. The output files asked by the model are for storing the calibrated from of the trip matrix b_j values and the R_{ij} values. Depending on the speed of the machine, a message "Calibration is going on" may appear on the screen. After calibration of the model, the regression of R_{ij} on t_{ij} or C_{ij} along with their statistical measures will appear on the screen. Pressing any key you will move on to the next step.

Step 4: At this stage, there is an option for traffic projections i.e. prediction of future flow patterns. Depending on the choice, you will be asked to given the traffic growth rate file name and length of projections and also the output file that will store the projected trip matrix. If the answer is no, you will move on to step 5 directly.

Step 5: This is the final step which will perform the works to be carried out in traffic assignment phase of the model. The input files are the O-D trip matrix that will be assigned into the network and the network data file. Again depending on the speed of the machine, a massage "Traffic Assignment is going on" may appear on screen. After the completion of assignment, you will be asked to give the names of the output files that will store the traffic volume on all the links of the network.

5.5 SUMMARY

Mathematical programming methods used for the model developed in this research were explained in this chapter. Analytical description of these methods and the step wise procedure have also been provided for better understanding.

The various features the computer model have also been explained in this chapter. As shown in this chapter the model is a fully menudriven one. The menu is presented 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 6

DATA COLLECTION AND DATA FILES

6.1 INTRODUCTION

As mentioned earlier in Chapter 3, no field survey programmes were undertaken for the collection of data in the present study. Necessary data were collected from the past transport studies undertaken in connection with various projects in this country. The main objective of this chapter is to describe the various types of data collected from the report of those transport studies and preparation of data files. The data files are input to the model developed. The sources of the data and their conversion, where needed, are discussed in detail. Some of the data files/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.

6.2 COLLECTION OF DATA

In this section, the various types of data used in this model have been discussed. It also includes the methods followed in collecting data from the reports of the past transport studies in this country.

6.2.1 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 was collected from the Final Report of Road Master Plan Project. This study estimated AADT on almost all the links of the country's network for the year 1990. The main reason of collecting these data is to assess the acceptability of the base year (1990) trip matrices. In Road Master Plan Project (RMPP), available data relating to traffic counts were collected from Roads and Highways Department (RHD) and from past and on going studies. The main sources in the study were the Annual Traffic Survey Reports-RHD Traffic Engineering Division (Planning & Development). In addition to the data collected, further data was provided by the study's traffic surveys. The study's main traffic count programme included counts at 105 stations over the country.

The results of these survey programmes are given in Table 1.1.1 and 1.1.2 of Appendix Volume 1 "ROAD TRAFFIC" of Final Report of Road Master Plan Project.

6.2.2 Traffic Flow Pattern

Traffic flow patterns between zones (old 20 districts) for the year 1990 were collected from both the reports of Intermodal Transport Study (1985) and Second Road Improvement Project (1991). These data were collected through Origin-destination (O-D) traffic survey programmes. The trip matrices for Trucks, Bus, Minibus and Light motorized vehicles prepared with the help of these reports are given in Appendix-A.

It may be questionable that, the validity of the trip matrices were assessed comparing traffic volume of this study with that of Road Master Plan Project while the trip matrices were mainly prepared with the help of the reports of second Road Improvement Project (SRIP). Still it is reasonable because of the fact that, during the contract negotiations the consultants were advised to cooperate with the Road Master Plan Study in order to ensure that the basic assumptions and data were compatible [SRIP, 1991].

6.2.3 Demographic and Economic Factors

It has been already mentioned in Chapter 3 that zonal traffic growth is a function of some demographic and economic factors of that zone namely population growth rate per capita GDP (Gross domestic product) growth rate, income elasticity of transport demand, etc. These factors have been collected from the reports of Second Road Improvement project (1991). A complete listing of these factor in a zonal basis are given in Appendices 2.1 and 2.1 of Appendix Volume 1 of Second Road Improvement Project. Zonal Traffic growth rates as calculated in this study from these factors are given in Appendix-A.

6.2.4 Highway Length and Speed

Description of base year network and future network for both passenger and freight transport modelling require data on length and speed of road sections of the national highway network. These are taken from the feasibility report of Jamuna Bridge Project (1989). Network description for passenger transport modelling are given in section H-12.2, Volume VI, Phase II Study of Jamuna Bridge Project. Incase of freight transport modelling, it was assumed that speed on road sections is 18 kmph. [Section H.4.4.6, Volume V of Jamuna Bridge Project]. This fictitious value of speed was adopted to calculate unit value of travel time and distance which showed good agreement between transport costs calculated and the actual transport fare.

6.2.5 Delay at Ferry

Ferry delays in minutes for passenger vehicles and trucks have been collected from Road Master Plan Reports (1991) and they are presented in Table 6.1. Delays in hours at the Bangladesh Inland Water Transport Corporation (BIWTC) ferries (Aricha-Nagarbari, Aricha-Daulatdia & Bhuapur-Sirajgonj) have been collected from Jamuna Bridge Study (1989) which is given in Table 6.2. These information have been incorporated in the 'Network Data Files' to calculate the travel time and travel cost between zones.

Table 6.1 Ferry delay (minutes)

Location (ferry)	Truck	Bus	Light vehicles
Rupsha	32	38	27
Bheramara	58	48	50
Ashuganj	40	38	37
Daudkandi	57	37	36
Dhawleswari I	14	15	13
Dhawleswari II	19	20	19

[Source: Road Master Plan Project,1991]

Table 6.2 Truck Operation between East and North-West: Estimated time per trip (hrs)

	Present system	Bridge
Travel time	20	20
Ferry delay	40	-
Ferry crossing	3	0.5
Load/unload	22	22
Time transfer	-	8
Total	85	50.5

[Source: Jamuna Bridge Study, Table H.4.15 of Volume V].

6.2.6 Highway Capacity

For calculating traffic volume on different road sections, in all the recent transport studies in this country all-or-nothing assignment model was used and as a result capacity of road sections were not reported in these studies. In Intermodal Transport Study (1985), the consultants classified the road section into three groups - type A, type B and type C of which type A belongs to the national highway road sections and the capacity is 8600 vehicles / day

(capacity of type B and type C was reported to be 4800 vehicles /day and 990 PCU/day). With the traffic composition accepted in that report and applying PCU (passenger car unit) values proposed by Roads and Highways Department (RHD), the capacity was found to be 23,220 PCU /day in both directions.

6.2.7 Vehicle Operating Cost

For freight transport modelling, cost of transporting goods between zones is a key factor. The costs used are financial costs and is defined as the generalized cost which is a combination of time value and distance value between zones. All the necessary data were collected from Jamuna Bridge Study (1989) and the unit values of time and distance for truck operation after modification for present rate of fuel (disel- Tk. 14.60/litre) are 36.62 Tk/hr and 6.65 Tk/km respectively.

6.3 DATA FILES

The model developed in this study uses various files in various stages of its execution. The files were prepared with the data collected from different transport studies as explained in the foregoing sections of this chapter. The forms of the files are given below and all the data files are given in Appendix-A.

6.3.1 Data Files for Calibration of Gravity Model

The files required for this phase of the model are TIME.DAT and COST.DAT and are used for passenger and freight modelling respectively. Another input file is trip file i.e. the trips that can be made between old twenty districts of this country. This file is prepared by the model using four other input files- TRUCK. DAT, BUS.DAT, MBUS.DAT and LMV.DAT. These files contain number of trips made by truck, bus, minibus and light motorized vehicles (4 wheel) respectively. All the files are 20x20 matrices of which the cells represent time, cost, trips, etc. between zones (Zilla).

6.3.2 Data Files for Prediction of Traffic

These data files are zonal traffic growth rates of twenty old districts calculated using the demographic and economic factors of the zones. Growth factors for the years 1995, 2000, 2005 and 2010 are calculated for both passenger and freight traffic and there are eight data files for growth rate four each for passenger and freight traffic. These files are:

Passenger traffic	Freight traffic
TGRP_95.DAT	TGRF_95.DAT
TGRP_00.DAT	TGRF_00.DAT
TGRP_05.DAT	TGRF_05.DAT
TGRP_10.DAT	TGRF_10.DAT

All these files are 20x1 matrices of which the cells represent growth rate of traffic.

6.3.3 Data Files for Traffic Assignment

The data files required for this stage contain description of the network for both passenger and freight movements and the data files which are the outputs of the stages described in sections 6.3.1 and 6.3.2. the network data files are band as PASS_NET.DAT and FRGT_NET.DAT. Information given in these files are link designation, link length. Link capacity and average link speed for all the links of the national highway network. For better understanding of the data files, the node numbers and their descriptions are given in Table 6.3.

It is to be noted that, this is not mandatory to name the files as described here such as BUS.DAT, TGRP_95.DAT, etc. The user can name the files in a different style according to their choice.

Table 6.3 Nodes of the National Highway Network

Node number	Name of the place
0	Chittagong
1	Chittagong Hill Tracts
2	Comilla
3	Noakhali
4	Sylhet
5	Dhaka
6	Faridpur
7	Jamalpur
8	Mymensingh
9	Tangail
10	Barisal
11	Jessore
12	Khulna
13	Kushtia
14	Patuakhali
15	Bogra
16	Dinajpur
17	Pabna
18	Rajshahi
19	Rangpur
20	Feni
21	Daudkandi
22	Bhairab
23	Sarail
24	Kishoregonj
25	Joydevpur
26	Elenga
27	Bhuapur
28	Aricha ghat

Table 6.3 Continued......

29	Mawa
30	Sirajgonj
31	Nagarbari
32	Daulatdia
33	Mawa (Faridpur portion)
34	Hatikamrul
35	Natore
36	Dasuria
37	Kashinathpur
38	Ahladipur
39	Jhenaidah
40	Jamuna bridge (west)
41	Jamuna bridge (east)
42	Bonpara

6.4 SUMMARY

The main objective of this chapter was to describe various types of data and the data files used by the model developed in this study. Data required for this model have been described in details giving references to their sources from which they were collected. A brief and clear description of the data files required by the models at various stages of execution have also been outlined in this chapter. It can be concluded from this chapter that, various types of data required by this model are easily obtainable which is a key factor for a transport model to be handy and easy to use.

CHAPTER-7

MODEL APPLICATION AND RESULTS

7.1 INTRODUCTION

This chapter describes the various applications of the model developed in this study. The following sections describe the results on acceptability of proposed base year trip matrix, calibration of gravity model for trip distribution, and prediction of future flow pattern and traffic volume on various links of the national highway network under prevailing condition as well as under some possible changes to the network.

7.2 MODEL PERFORMANCE TEST

7.2.1 Validity of the Model

The validity of the model can be defined as its efficiency of computing traffic volume on links . Link 11-12 (Jessore-Khulna) is considered for this purpose. The reason behind selecting this link is that, all the trips that originated at or attracted to Khulna must follow the link 11-12 - the only possible link to reach Khulna from Jessore under the existing condition of the national highway network of Bangladesh. From the trip matrix (1990) for passenger movements, the attraction as well as the generation of traffic (sum of the trips of row 13 and column 13) of Khulna is 1389 PCU. So the traffic on link 11-12 should be 1389 PCU/day in either direction and it is seen from the output of the model that, each of the links 11-12 and 12-11 has a volume of 1389 PCU/day. The results on this validation is given in Appendix-C. This testing provides the model with enough confidence to be valid for practical use.

7.2.2 Acceptability of Base year (1990) Trip Matrices

The base year trip matrices, as mentioned earlier, were prepared from the reports of the past transport studies conducted in connection with various road improvement projects in this country. The matrices were then assigned into the network using the assignment model. The output of this model i.e. link traffic volumes were compared with the traffic count data mentioned in the report of the Road Master Plan Project. To take into account the local traffic, the base matrices were adjusted to get a close agreement between the output of the assignment model and the link traffic volumes (AADT) estimated for the year 1990 in Road Master Plan Project. The results are given in Tables 7.1.1 to 7.1.4 for truck, bus, minibus and light vehicles (4 wheel) which show that the base matrices are satisfactory for prediction of traffic on almost all major links. The graphical representations of these results are given in Appendix-B. The last column of these tables show the ratio of traffic volume in the present study to that of Road Master Plan Project. A ratio equal to one means predictions made in these two studies are exactly equal and it is seen from the tables that almost all the major links have a ratio nearly equal to one which is a prerequisite for the matrices to serve as the base year trip matrices because, these matrices will be used later for traffic forecasting. Also it is seen that the comparative ratio improves when total traffic is compared which is given in Table 7.2 which indicates the fact that variations are compensating to each other. Ratios which are very way out from one need some explanations. As for example, ratios for minibus traffic volume on links 4-23 and 6-39 are 2.25 and 1.8 respectively. The reason behind this is that, as this study considers only the old 20 districts as trip producing and attracting zones, the trips of minibuses and other light vehicles which have normally shorter trip lengths than buses and trucks have sometimes been destined to a zone which is far from their actual destinations. As in this case, minibus trips between O-D pair Dhaka-Sylhet have origin at Dhaka and destination to Sylhet and the trips having destinations to Narshingdi or to Bhairab have also been considered in this study to be destined to Sylhet.

TABLE 7.1.1 COMPARISON OF TRAFFIC VOLUME (AADT) [a] ON MAJOR ROAD SECTIONS OF NATIONAL HIGHWAY NETWORK, 1990.

(NO. OF BUS)

ROAD SECTION	PRESENT STUDY	ROAD MASTER PLAN	Ratio
Dhaka-Aricha (5-28) [b]	652	700	0.93
Nagarbari-Kashinathpur (31-37)	348	300	1.16
Kashinathpur-Pabna (37-17)	270	290	0.93
Kashinathpur-Hatikamrul(37-34)	201	210	0.96
Hatikamrul-Bogra (34-15)	180	180	1.00
Bogra-Natore (15-35)	220	180	1.22
Natore-Rajshahi (35-18)	188	180	1.04
Bogra-Rangpur (15-19)	302	220	1.37
Faridpur-Jhenaidah (6-39)	340	280	1.21
Jhenaidah-Jessore (39-11)	538	590	0.91
Jessore-Khulna (11-12)	624	620	1.01
Daudkandi-Comilla (21-2)	880	880	1.00
Comilla-Feni (2-20)	562	560	1.00
Feni-Chittagong (20-0)	858	850	1.01
Sarail-Sylhet (23-4)	201	180	1.12
Joydevpur-Mymensingh (25-8)	221	210	1.05
Joydevpur-Tangail (25-9)	229	200	1.15

a. Annual Average Daily Traffic.

b. Node numbers as designated in the network data file.

TABLE 7.1.2 COMPARISON OF TRAFFIC VOLUME (AADT) [a] ON MAJOR ROAD SECTIONS OF NATIONAL HIGHWAY NETWORK, 1990.

(NO. OF MINIBUS)

ROAD SECTION	PRESENT STUDY	ROAD MASTER PLAN	Ratio
Dhaka-Aricha (5-28) [b]	330	320	1.03
Nagarbari-Kashinathpur (31-37)	193	180	1.07
Kashinathpur-Pabna (37-17)	175	240	0.73
Kashinathpur-Hatikamrul (37-34)	142	140	1.01
Hatikamrul-Bogra (34-15)	170	180	0.94
Bogra-Natore (15-35)	98	90	1.09
Natore-Rajshahi (35-18)	276	300	0.92
Bogra-Rangpur (15-19)	99	70	1.41
Faridpur-Jhenaidah (6-39)	36	20	1.80
Jhenaidah-Jessore (39-11)	183	180	1.02
Jessore-Khulna (11-12)	207	200	1.04
Daudkandi-Comilla (21-2)	229	220	1.04
Comilla-Feni (2-20)	145	140	1.04
Feni-Chittagong (20-0)	266	270	0.99
Sarail-Sylhet (23-4)	225	100	2.25
Joydevpur-Mymensingh (25-8)	153	160	0.96
Joydevpur-Tangail (25-9)	249	370	0.67

a. Annual Average Daily Traffic.

b. Node numbers as designated in the network data file.

TABLE 7.1.3 COMPARISON OF TRAFFIC VOLUME (AADT) [a] ON MAJOR ROAD SECTIONS OF NATIONAL HIGHWAY NETWORK, 1990.

(NO. OF LIGHT VEHICLES)

ROAD SECTION	PRESENT STUDY	ROAD MASTER PLAN	Ratio
Dhaka-Aricha (5-28) [b]	400	390	1.03
Nagarbari-Kashinathpur (31-37)	231	200	1.16
Kashinathpur-Pabna (37-17)	147	110	1.34
Kashinathpur-Hatikamrul (37-34)	132	110	1.20
Hatikamrul-Bogra (34-15)	208	420	0.50
Bogra-Natore (15-35)	149	150	0.99
Natore-Rajshahi (35-18)	237	190	1.25
Bogra-Rangpur (15-19)	120	120	1.00
Faridpur-Jhenaidah (6-39)	126	130	0.97
Jhenaidah-Jessore (39-11)	261	270	0.97
Jessore-Khulna (11-12)	293	300	0.98
Daudkandi-Comilla (21-2)	436	440	0.99
Comilla-Feni (2-20)	247	240	1.03
Feni-Chittagong (20-0)	676	750	0.91
Sarail-Sylhet (23-4)	150	130	1.15
Joydevpur-Mymensingh (25-8)	209	200	1.05
Joydevpur-Tangail (25-9)	219	220	1.00

a. Annual Average Daily Traffic.

b. Node numbers as designated in the network data file.

TABLE 7.1.4 COMPARISON OF TRAFFIC VOLUME (AADT) [a] ON MAJOR ROAD SECTIONS OF NATIONAL HIGHWAY NETWORK, 1990.

(NO. OF TRUCKS)

ROAD SECTION	PRESENT STUDY	ROAD MASTER PLAN	Ratio
Dhaka-Aricha (5-28) [b]	1638	1600	1.02
Nagarbari-Kashinathpur (31-37)	1034	920	1.12
Kashinathpur-Pabna (37-17)	720	720	1.00
Kashinathpur-Hatikamrul (37-34)	646	730	0.88
Hatikamrul-Bogra (34-15)	496	1010	0.49
Bogra-Natore (15-35)	672	730	0.92
Natore-Rajshahi (35-18)	462	370	1.25
Bogra-Rangpur (15-19)	710	730	0.97
Faridpur-Jhenaidah (6-39)	694	700	0.99
Jhenaidah-Jessore (39-11)	1160	1170	0.99
Jessore-Khulna (11-12)	1094	1110	0.99
Daudkandi-Comilla (21-2)	2265	2280	0.99
Comilla-Feni (2-20)	2381	2300	1.04
Feni-Chittagong (20-0)	2533	2540	0.98
Sarail-Sylhet (23-4)	408	370	1.10
Joydevpur-Mymensingh (25-8)	749	750	1.00
Joydevpur-Tangail (25-9)	670	670	1.00

a. Annual Average Daily Traffic.

b. Node numbers as designated in the network data files.

TABLE 7.2 COMPARISON OF TRAFFIC VOLUME (AADT) [a] ON MAJOR ROAD SECTIONS OF NATIONAL HIGHWAY NETWORK, 1990.

(TOTAL NUMBER OF VEHICLES) [b]

ROAD SECTION	PRESENT STUDY	ROAD MASTER PLAN	Ratio
Dhaka-Aricha (5-28) [c]	3020	3010	1.00
Nagarbari-Kashinathpur (31-37)	1806	1600	1.13
Kashinathpur-Pabna (37-17)	1312	1360	0.96
Kashinathpur-Hatikamrul (37-34)	1121	1190	0.94
Hatikamrul-Bogra (34-15)	1054	1790	0.59
Bogra-Natore (15-35)	1139	1150	0.99
Natore-Rajshahi (35-18)	1163	1040	1.12
Bogra-Rangpur (15-19)	1231	1140	1.08
Faridpur-Jhenaidah (6-39)	1196	1130	1.06
Jhenaidah-Jessore (39-11)	2142	2210	0.97
Jessore-Khulna (11-12)	2218	2230	1.00
Daudkandi-Comilla (21-2)	3810	3820	1.00
Comilla-Feni (2-20)	3335	3240	1.03
Feni-Chittagong (20-0)	4333	4410	0.98
Sarail-Sylhet (23-4)	984	780	1.26
Joydevpur-Mymensingh (25-8)	1332	1320	1.01
Joydevpur-Tangail (25-9)	1367	1460	0.94

a. Annual Average Daily Traffic.

b. Total of truck, bus, minibus and light motorized vehicles.

c. Node numbers as designated in the network data files.

The results also show that, the ratio of traffic volume on link 34-15 for light vehicles and trucks is around 0.5. It has been found from RMP that, traffic volume on link 34-15 is unusually higher than the traffic volume on the other connecting links 37-34 and 15-19. This indicates that, Hatikamrul (node 34) produces a significant number of truck and light vehicle trips which have destinations to Bogra (zone 15). But this study does not consider Hatikamrul as a trip producing zone and also the O-D surveys as reported in RMP (1991) and SRIP (1991) give no indication of sudden rise of traffic volume on link 34-15.

7.2.3 Calibration of Gravity Model

The gravity model developed in this study was calibrated with the base year (1990) trip matrices of passenger and freight movements. The passenger trip matrix is the sum of bus, minibus and light motorized vehicle trip matrices while the freight trip matrix is the truck trip matrix. Both the trip matrices were converted into passenger car equivalents (PCU) taking PCU values for bus, minibus, truck and light vehicles (4 wheel) as 3,3,3 and 1 respectively. The results show that, the model is calibrated within a range of $\pm$ 3% of trips as presented in base year trip matrix which is very much satisfactory. The base year trip matrices and their calibrated form for both and their calibrated form for both passenger and freight movements are given in Table 7.3.1 to 7.3.4. This is clear from these tables that, for both passenger and freight movements the gravity model developed in this study can reproduce the trip values as same as those of the base year trip matrices. These tables also show the efficiency of the model for calibrating the gravity model.

The results of gravity model calibration were the used to formulate regression equations to measure separation factor (R_{ij}) which is a function of travel time (t_{ij}) for passenger movements and travel cost (C_{ij}) for freight movements. The equations show reasonable values of coefficient of correlation (r) as given below:

Table 7.3.1 Origin-Destination (O-D) trip matrix in PCU for Passenger movements, 1990.

		Destination Nodes																			
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Origin Nodes	0	0	294	264	1205	63	375	8	8	0	0	0	8	8	0	0	0	0	34	7	0
	1	294	0	0	0	10	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	264	0	0	0	131	983	7	0	7	7	0	7	7	0	0	0	0	34	13	0
	3	1205	0	0	0	31	280	0	0	0	0	0	0	19	0	0	0	0	37	0	0
	4	63	10	131	31	0	478	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	375	34	983	280	478	0	337	240	669	635	70	43	206	114	16	171	73	136	170	140
	6	8	0	7	0	0	337	0	0	0	0	68	98	40	0	0	0	0	21	14	0
	7	8	0	0	0	0	240	0	0	0	118	0	0	0	0	0	0	0	0	0	0
	8	0	0	7	0	0	669	0	0	0	0	0	8	0	0	0	0	0	0	0	0
	9	0	0	7	0	0	635	0	118	0	0	0	3	5	0	0	245	0	190	0	0
	10	0	0	0	0	0	70	68	0	0	0	0	43	61	0	147	0	0	0	0	0
	11	8	0	7	0	0	43	98	0	8	3	43	0	644	143	20	0	0	96	0	0
	12	8	0	7	19	0	206	40	0	0	5	61	644	0	40	24	50	64	107	94	20
	13	0	0	0	0	0	114	0	0	0	0	0	143	40	0	0	0	0	107	235	0
	14	0	0	0	0	0	16	0	0	0	0	147	20	24	0	0	0	0	0	0	0
	15	0	0	0	0	0	171	0	0	0	245	0	0	50	0	0	0	133	131	105	51
	16	0	0	0	0	0	73	0	0	0	0	0	0	64	0	0	133	0	35	46	233
	17	34	0	34	37	0	136	21	0	0	190	0	96	107	107	0	131	35	0	59	29
	18	7	0	13	0	0	170	14	0	0	0	0	0	94	235	0	105	46	59	0	72
	19	0	0	0	0	0	140	0	0	0	0	0	0	20	0	0	51	233	29	72	0

Table 7.3.2 Calibrated form of the matrix presented in Table 7.3.1

		Destination Nodes																			
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Origin Nodes	0	0	294	264	1205	63	375	8	8	0	0	0	8	8	0	0	0	0	34	7	0
	1	294	0	0	0	10	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	264	0	0	0	131	983	7	0	7	7	0	7	7	0	0	0	0	34	13	0
	3	1205	0	0	0	31	280	0	0	0	0	0	0	19	0	0	0	0	37	0	0
	4	63	10	131	31	0	478	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	375	34	983	280	478	0	337	240	669	635	70	43	206	114	16	171	73	136	170	140
	6	8	0	7	0	0	337	0	0	0	0	68	98	40	0	0	0	0	21	14	0
	7	8	0	0	0	0	240	0	0	0	118	0	0	0	0	0	0	0	0	0	0
	8	0	0	7	0	0	669	0	0	0	0	0	8	0	0	0	0	0	0	0	0
	9	0	0	7	0	0	635	0	118	0	0	0	3	5	0	0	245	0	190	0	0
	10	0	0	0	0	0	70	68	0	0	0	0	43	61	0	147	0	0	0	0	0
	11	8	0	7	0	0	43	98	0	8	3	43	0	643	143	20	0	0	96	0	0
	12	8	0	7	19	0	206	40	0	0	5	61	644	0	40	24	50	64	107	94	20
	13	0	0	0	0	0	114	0	0	0	0	0	143	40	0	0	0	0	107	235	0
	14	0	0	0	0	0	16	0	0	0	0	147	20	24	0	0	0	0	0	0	0
	15	0	0	0	0	0	171	0	0	0	245	0	0	50	0	0	0	133	131	105	51
	16	0	0	0	0	0	73	0	0	0	0	0	0	64	0	0	133	0	35	46	233
	17	34	0	34	37	0	136	21	0	0	190	0	96	107	107	0	131	35	0	59	29
	18	7	0	13	0	0	170	14	0	0	0	0	0	94	235	0	105	46	59	0	72
	19	0	0	0	0	0	140	0	0	0	0	0	0	20	0	0	51	233	29	72	0

Table 7.3.3 Origin-Destination (O-D) trip matrix in PCU for freight movements, 1990.

		Destination Nodes																			
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Origin Nodes	0	0	6	375	594	267	1605	21	21	102	48	18	135	93	51	0	90	60	93	126	60
	1	6	0	0	0	0	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	375	0	0	0	78	387	0	0	9	9	0	15	6	6	0	6	6	18	6	9
	3	594	0	0	0	9	225	3	3	12	15	0	21	3	3	0	6	12	0	9	45
	4	267	0	78	9	0	120	15	3	9	3	0	18	12	18	0	6	9	12	27	3
	5	1605	42	387	225	120	0	60	114	984	789	12	273	180	87	0	183	105	210	165	120
	6	21	0	0	3	15	60	0	0	0	3	180	45	117	75	0	0	0	0	0	0
	7	21	0	0	3	3	114	0	0	0	150	0	0	3	0	0	0	0	0	0	0
	8	102	0	9	12	9	984	0	0	0	150	0	0	18	0	0	3	0	90	9	3
	9	48	0	9	15	3	789	3	150	150	0	0	0	6	0	0	0	0	150	9	0
	10	18	0	0	0	0	12	180	0	0	0	0	18	9	0	72	0	0	0	0	0
	11	135	0	15	21	18	273	45	0	0	0	18	0	651	138	3	12	36	9	18	9
	12	93	0	6	3	12	180	117	3	18	6	9	651	0	141	0	105	60	72	60	105
	13	51	0	6	3	18	87	75	0	0	0	0	138	141	0	0	159	144	270	6	33
	14	0	0	0	0	0	0	0	0	0	0	72	3	0	0	0	0	0	0	0	0
	15	90	0	6	6	6	183	0	0	3	0	0	12	105	159	0	0	60	33	126	18
	16	60	0	6	12	9	105	0	0	0	0	0	36	60	144	0	60	0	51	78	60
	17	93	0	18	0	12	210	0	0	90	150	0	9	72	270	0	33	51	0	30	15
	18	126	0	6	9	27	165	0	0	9	9	0	18	60	6	0	126	78	30	0	24
	19	60	0	9	45	3	120	0	0	3	0	0	9	105	33	0	18	60	15	24	0

Table 7.3.4 Calibrated form of the trip matrix presented in table 7.3.3

		Destination Nodes																			
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Origin Nodes	0	0	6	375	595	267	1605	21	21	102	48	18	135	93	51	0	90	60	93	126	60
	1	6	0	0	0	0	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	374	0	0	0	78	387	0	0	9	9	0	15	6	6	0	6	6	18	6	9
	3	594	0	0	0	9	225	3	3	12	15	0	21	3	3	0	6	12	0	9	45
	4	267	0	78	9	0	120	15	3	9	3	0	18	12	18	0	6	9	12	27	3
	5	1605	42	387	225	120	0	60	114	984	789	12	273	180	87	0	183	105	210	165	120
	6	21	0	0	3	15	60	0	0	0	3	180	45	117	75	0	0	0	0	0	0
	7	21	0	0	3	3	114	0	0	0	150	0	0	3	0	0	0	0	0	0	0
	8	102	0	9	12	9	983	0	0	0	149	0	0	18	0	0	3	0	90	9	3
	9	48	0	9	15	3	789	3	150	150	0	0	0	6	0	0	0	0	150	9	0
	10	18	0	0	0	0	12	180	0	0	0	0	18	9	0	72	0	0	0	0	0
	11	135	0	15	21	18	273	45	0	0	0	18	0	652	138	3	12	36	9	18	9
	12	93	0	6	3	12	180	117	3	18	6	9	651	0	141	0	105	60	72	60	105
	13	51	0	6	3	18	87	75	0	0	0	0	138	141	0	0	159	144	270	6	33
	14	0	0	0	0	0	0	0	0	0	0	72	3	0	0	0	0	0	0	0	0
	15	90	0	6	6	6	183	0	0	3	0	0	12	105	159	0	0	60	33	126	18
	16	60	0	6	12	9	105	0	0	0	0	0	36	60	144	0	60	0	51	78	60
	17	93	0	18	0	12	210	0	0	90	150	0	9	72	271	0	33	51	0	30	15
	18	126	0	6	9	27	165	0	0	9	9	0	18	60	6	0	126	78	30	0	24
	19	60	0	9	45	3	120	0	0	3	0	0	9	105	33	0	18	60	15	24	0

$R_{ij} = t_{ij}^{-2.05}$ with a correlation coefficient of 0.98 and

$R_{ij} = C_{ij}^{-1.76}$ with a correlation coefficient of 0.83.

The graphical representation of these equations are given in Fig. 7.1 and Fig. 7.2. These figures reveal the fact that, the more the values of travel time and travel cost between a particular pair of zones, the less will be the separation factor which will ultimately result in less number of trips that can be made between those zones.

7.3 APPLICATION OF THE MODEL IN THE STUDY AREA

The model developed in this present study was applied to get the future traffic flow-pattern between zones (Zilla) and traffic volume on the road sections of the national highway network of Bangladesh. These predictions were made under both present condition of the network and probable change in the network in future. These are explained in the following sections.

7.3.1 Prediction on existing Condition of the Network

7.3.1.1 Input Data to the Model

Input data required for prediction of traffic are:

Trip Matrix: Base year (1990) trip (0-D) matrix of bus, minibus and light motorized vehicle (4 wheel) for passenger movements and truck for freight movements.

Passenger Car Unit (PCU): These values are mentioned in Chapter 4 (components of Transport System). The PCU values provided by Roads and Highways Department of Bangladesh were used in this model.

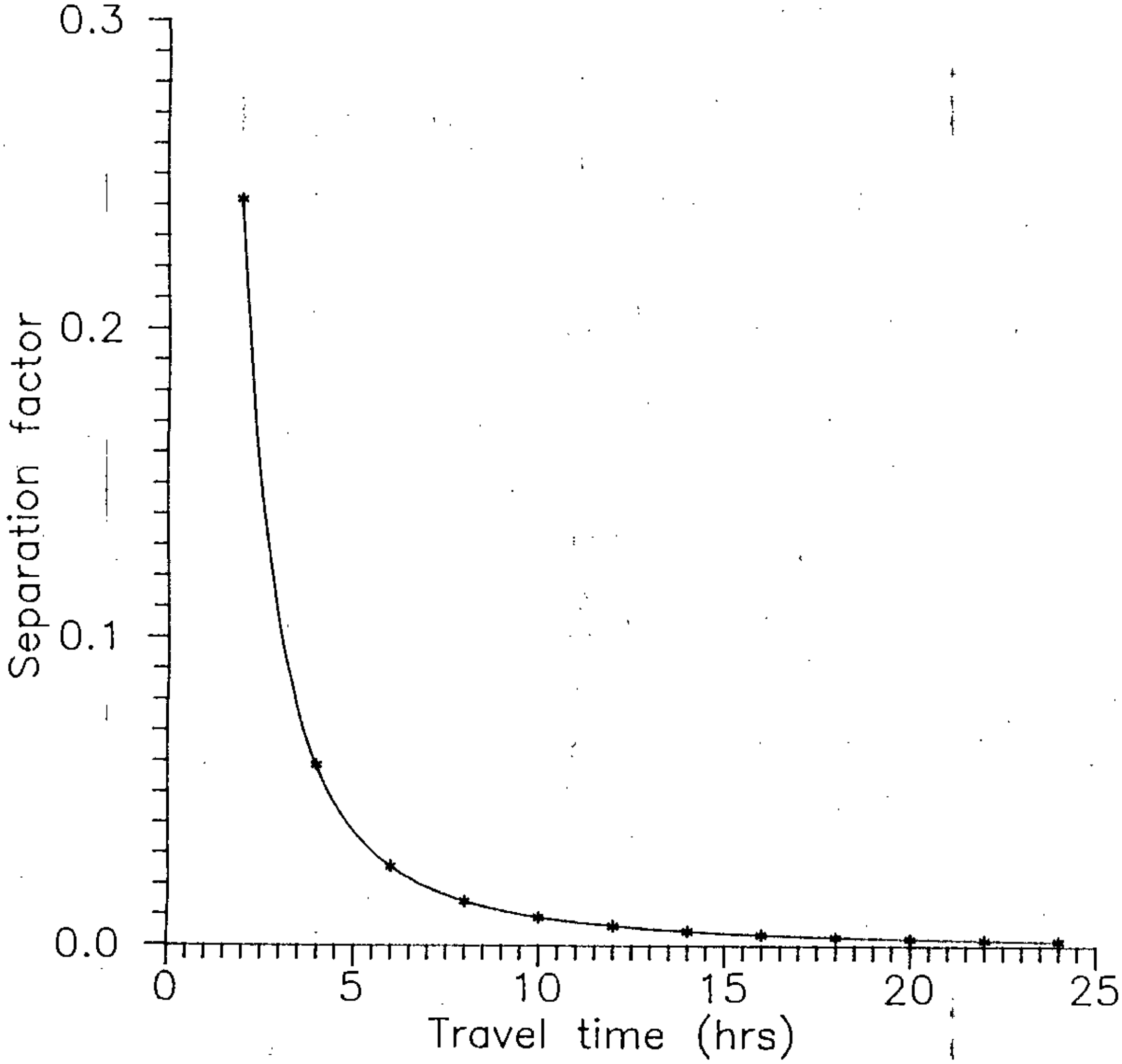

Fig 7.1 Variation of separation factor (R_{ij}) with travel time (t_{ij}) for passenger movements

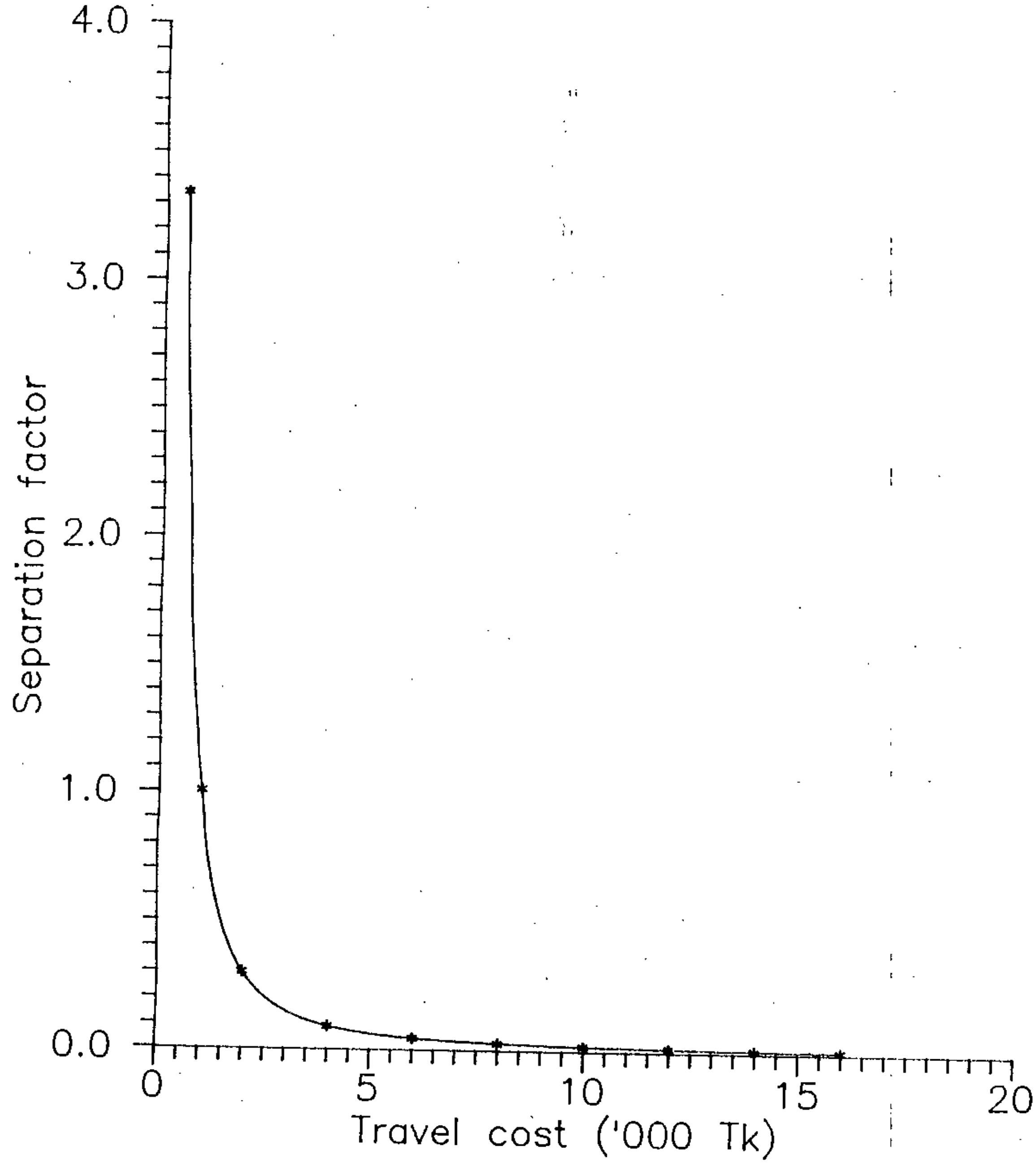

Fig 7.2 Variation of separation factor (R_{ij}) with travel cost (c_{ij}) for freight movements.

Traffic Growth Rate: Zonal growth rates of traffic for both passenger and freight traffics were calculated considering traffic growth is a function of demographic and socio-economic condition of that zone. These growth rates were applied to the zonal production and attraction of traffic.

Road Network: network data files for both passenger and freight movements are input to the traffic assignment model. Each link (road section) of the network has been defined by 'from node', 'to node', 'link length', 'link capacity' and 'average speed on the link'.

7.3.1.2 Output of the Model

The output of the model is the traffic volume on all the links of the national highway network of Bangladesh. Traffic Volume is expressed as the annual average daily traffic (AADT) in passenger car unit (PCU). The O-D trip matrices for years 1995, 2000, 2005 and 2010 were prepared with the help of the gravity model applying the zonal traffic growth rates to the generation and attraction of the respective zones. These were then assigned into the national highway network to get the link traffic volume. Traffic volume on some major links for the years 1990 to 2010 are given in table 7.4.1 to 7.4.3. Traffic volume on almost all links of the network are given in Appendix-B. These predictions indicate that, freight traffic will increase at a lower rate than passenger traffic and by the year 2000, passenger traffic on most of the links will increase around 80% and freight traffic will increase around 65%. In 2010, it is seen from the results that traffic volume will be around three times of the traffic in 1990.

Table 7.4.1 Traffic Volume on National Highway Network.

Road Section	Passenger traffic volume (AADT) in PCU								
	1990	1995	% increase	2000	% increase	2005	% increase	2010	% increase
Daudkandi -Comilla	3766	5106	1.36	6899	1.83	9842	2.61	14038	3.73
Comilla-Feni	2371	3197	1.35	4437	1.87	6355	2.68	9083	3.83
Feni-Chittagong	4048	5411	1.34	7551	1.87	10600	2.62	14837	3.67
Dhaka-Aricha	3345	4486	1.34	6028	1.80	8456	2.53	11836	3.54
Faridpur-Jhenaidah	1254	1632	1.30	2192	1.75	2971	2.37	4028	3.21
Jhenaidah-Jessore	2427	3115	1.28	4143	1.71	5564	2.29	7468	3.08
Jessore-Khulna	2778	3545	1.28	4746	1.71	6351	2.29	8499	3.06
Hatikamrul-Bogra	1258	1641	1.30	2184	1.74	2999	2.38	4117	3.27
Bogra-Natore	1104	1398	1.27	1853	1.68	2449	2.22	3235	2.93
Natore-Rajshahi	1630	2082	1.28	2782	1.71	3725	2.29	4983	3.06

Table 7.4.2 Traffic Volume on National Highway Network.

Road Section	Freight traffic volume (AADT) in PCU								
	1990	1995	% increase	2000	% increase	2005	% increase	2010	% increase
Daudkandi -Comilla	6798	8696	1.28	11052	1.63	14732	2.17	19667	2.89
Comilla-Feni	7146	9122	1.28	11635	1.63	15599	2.18	20928	2.93
Feni-Chittagong	7602	9702	1.28	12382	1.63	16574	2.18	22197	2.92
Dhaka-Aricha	4914	6263	1.27	7740	1.58	9577	1.95	12183	2.48
Faridpur-Jhenaidah	2081	2668	1.28	3408	1.64	4434	2.13	5764	2.77
Jhenaidah-Jessore	3480	4417	1.27	5628	1.62	7241	2.08	9326	2.68
Jessore-Khulna	3281	4190	1.28	5342	1.63	6812	2.08	8692	2.65
Hatikamrul-Bogra	1487	1852	1.25	2337	1.57	3055	2.05	3992	2.68
Bogra-Natore	2016	2483	1.23	3153	1.56	3963	1.97	4982	2.47
Natore-Rajshahi	1385	1768	1.28	2254	1.63	2885	2.08	3675	2.65

Table 7.4.3 Traffic Volume on National Highway Network.

Road Section	Total traffic volume (AADT) in PCU								
	1990	1995	% increase	2000	% increase	2005	% increase	2010	%increase
Daudkandi-Comilla	10564	13802	1.31	17951	1.70	24574	2.33	33705	3.19
Comilla-Feni	9517	12319	1.29	16072	1.69	21954	2.31	30011	3.15
Feni-Chittagong	11650	15113	1.30	19933	1.71	27174	2.33	37034	3.18
Dhaka-Aricha	8259	10749	1.30	13768	1.67	18033	2.18	24019	2.91
Faridpur-Jhenaidah	3335	4300	1.29	5600	1.68	7405	2.22	9792	2.94
Jhenaidah-Jessore	5907	7532	1.28	9771	1.65	12805	2.17	16794	2.84
Jessore-Khulna	6059	7735	1.28	10088	1.66	13163	2.17	17191	2.84
Hatikamrul-Bogra	2745	3493	1.27	4521	1.65	6054	2.21	8109	2.95
Bogra-Natore	3120	3881	1.24	5006	1.60	6412	2.06	8217	2.63
Natore-Rajshahi	3015	3850	1.28	5036	1.67	6610	2.19	8658	2.87

7.3.2 Prediction on Changed Condition of Network in Future

The most probable and major change in near future is the completion of Jamuna Bridge. The following sections describe the results of prediction of traffic on Jamuna bridge.

7.3.2.1 Input to the Model

O-D trip matrix: traffic will generate with the completion of this bridge due to the reduction of resistance of travelling between different O-D pairs which is measured in terms of travel time for passenger movements and in terms of travel cost for freight movements. The factors by which the present traffic will increase are calculated using the method described in chapter 3 (Study Design & Methodology). These generated traffic growth factors are given in tables 7.5.1 and 7.5.2. The O-D (Origin-Destination) pairs between Dhaka and Chittagong to the zones of north-west are considered in this case. The main reason behind this is that, Dhaka and Chittagong are the biggest traffic

Generating and attracting centres compared to the other zones in the east portion of Bangladesh. From the tables it is seen that, trips from Dhaka and Chittagong to Bogra are most benefitted while least benefitted trips are from Dhaka and Chittagong to Pabna for time and cost savings due to the inclusion of Jamuna bridge in the network. Generated traffic for different O-D pairs which will be routed through the bridge have been calculated and are given in table 7.6.1 and 7.6.2 for passenger and freight movements respectively. The revised trip matrices are given in Appendix-D. These revised matrices are prepared taking into account the local traffic. While calculating the diverted traffic for jamuna bridge, 20 - 30% of trips presented in the 1990 trip matrix has been deducted between O-D pairs which will contribute traffic to the bridge.

Road Network: The new links as proposed in the jamuna bridge Study have been incorporated in this present study. Improvements of certain road sections of Dhaka-Chittagong highway, Dhaka-Tangail highway and completion of Meghna-Gumti bridge have also been considered. The necessary data have been collected from Jamuna Bridge Study and from the reports of the Road Master Plan Project.

Table 7.5.1 Generated traffic growth factors for Jamuna bridge, Passenger movements.

O-D Pair	Travel time (hrs)		Factor
	without bridge, t_1	with bridge, t_2	$\{(t_1/t_2)^{2.05}-1\}$
Dhaka-Bogra	8.4	5.4	1.47
Dhaka-Dinajpur	13.2	10.2	0.70
Dhaka-Pabna	7.1	6.3	0.28
Dhaka-Rajshahi	9.9	7.3	0.87
Dhaka-Rangpur	10.9	7.9	0.93
Ctg.-Bogra	15.8	11.9	0.79
Ctg.-Dinajpur	20.6	16.7	0.54
Ctg.-Pabna	14.5	12.8	0.29
Ctg.-Rajshahi	17.3	13.8	0.59
Ctg.-Rangpur	18.3	14.4	0.63

Table 7.5.2 Generated traffic growth factors for Jamuna bridge, Freight movements.

O-D Pair	Travel cost (taka)		Factor $\{(c_1/c_2)^{1.76}-1\}$
	without bridge, c_1	with bridge, c_2	
Dhaka-Bogra	4252	2957	0.89
Dhaka-Dinajpur	5952	4650	0.54
Dhaka-Pabna	3690	3321	0.20
Dhaka-Rajshahi	4635	3532	0.61
Dhaka-Rangpur	5267	3946	0.67
Ctg.-Bogra	6554	5197	0.50
Ctg.-Dinajpur	8217	6893	0.36
Ctg.-Pabna	5955	5564	0.13
Ctg.-Rajshahi	6900	5771	0.37
Ctg.-Rangpur	7532	6189	0.41

Table 7.6.1 Generated traffic for Jamuna bridge:Passenger movements (No. of vehicles, One way)

O-D Pair	Diverted Traffic			factor	Generated Traffic			Total Traffic		
	bus	mini bus	LMV		bus	mini bus	LMV	bus	mini bus	LMV
Dhaka-Bogra	20	19	21	1.47	29	28	31	49	47	52
Dhaka-Dinajpur	20	2	3	0.70	14	1	2	34	3	5
Dhaka-Pabna	10	19	18	0.28	3	6	5	13	25	23
Dhaka-Rajshahi	30	16	8	0.87	26	14	7	56	30	15
Dhaka-Rangpur	30	7	14	0.93	28	6	13	58	13	27
Ctg - Bogra	0	0	0	0.79	0	0	0	0	0	0
Ctg - Dinajpur	0	0	0	0.54	0	0	0	0	0	0
Ctg - Pabna	10	1	1	0.29	3	0	0	13	1	1
Ctg - Rajshahi	1	1	1	0.59	1	1	1	2	2	2
Ctg - Rangpur	0	0	0	0.63	0	0	0	0	0	0

Table 7.6.2 Generated Traffic for Jamuna bridge: Freight movements (No. of Trucks, One way)

O-D Pair	Diverted Traffic	Growth Factor	Generated Traffic	Total traffic
Dhaka - Bogra	43	0.89	38	81
Dhaka - Dinajpur	25	0.54	14	39
Dhaka - Pabna	49	0.20	10	59
Dhaka - Rajshahi	39	0.61	24	63
Dhaka - Rangpur	28	0.67	19	47
Chittagong - Bogra	21	0.50	11	32
Chittagong - Dinajpur	14	0.36	5	19
Chittagong - Pabna	22	0.13	3	25
Chittagong - Rajshahi	29	0.37	11	40
Chittagong - Rangpur	14	0.41	6	20

7.3.2.2 Output of the Model

In this study, it is assumed that the Jamuna bridge will open to traffic in 1997. Traffic volume on Jamuna bridge is given in table 7.7. In addition to this, volume of traffic in 1994 is also given in table 7.8 to compare the predictions made in this study and Jamuna Bridge Study. These comparisons show that, the predictions made in these two studies vary 4% for passenger traffic and 17% for freight traffic and the variation is 5.5% for total traffic which is quite satisfactory.

Table 7.7 Traffic Volume over Jamuna Bridge in 1997.

passenger Traffic, AADT in PCU.	Freight Traffic, AADT in PCU.	Total Traffic, AADT in PCU.
4896	4480	9376

Table 7.8 Comparison of Traffic Volume, AADT over jamuna Bridge in 1994.

passenger traffic volume in PCU			Freight traffic Volume in PCU			Total Traffic Volume in PCU		
Present Study	Jamuna Bridge Study	Ratio[a]	Present Study	Jamuna Bridge Study	Ratio	Present Study	Jamuna Bridge Study	Ratio
4126	4301	0.96	3885	3300	1.17	8011	7601	1.05

a. Ratio of Present study to Jamuna bridge study.

Due to the diversion of traffic for the Jamuna bridge, there will be a significant change in traffic volume on a number of links. Some links of this type have been identified and are presented in table 7.9 showing traffic volume in 1997 under the existing condition and also considering Jamuna bridge in the network.

Table 7.9 Change in traffic Volume for Jamuna bridge in 1997.

Road Section	Traffic volume (PCU) under existing condition of network			Traffic volume (PCU) considering Jamuna bridge in the network		
	Passenger	Freight	Total	Passenger	Freight	Total
Dhaka-Aricha (5-28)	5045	6900	11945	2242	2966	5208
Tangail-Joydevpur (9-25)	2618	2849	5467	6677	6735	13412
Tangail-Elenga (9-26)	2270	1663	3933	5904	5375	11279
Kashinathpur-Hatikamrul (37-34)	1708	2667	4375	1024	1224	2248

The results reveal that, Dhaka-Aricha road section will lose more than half of its traffic while traffic volume on Tangail-Elenga road section will increase around two times of its traffic under existing condition. The percent reduction and increase of traffic for the links in table 7.9 are given in table 7.10. High increase in traffic volume for the links Tangail-Joydevpur and

Tangail-Elenga is not only due to the diversion of traffic for the presence of Jamuna bridge but also due to the fact that traffic will generate for the inclusion of Jamuna bridge in the network.

Table 7.10 Percent reduction/increase in traffic volume for Jamuna bridge in 1997.

Road Section	Percent reduction/increase[a] of traffic volume(PCU), 1997		
	Passenger	Freight	Total
Dhaka-Aricha (5-28)	-55	-57	-56
Tangail-Joydevpur (9-25)	+155	+136	+145
Tangail-Elenga (9-26)	+160	+223	+187
Kashinathpur-Hatikamrul (37-34)	-40	-54	-49

a. Plus (+) sign indicates increase and minus sign (-) indicates decrease.

7.4 SUMMARY

This chapter provides the output of the models and analysis procedure. The validity of the models was tested using data within the study area and the results indicate that the models can be applied with enough confidence for practical use. Traffic forecasting has been made for a period of 20 years spanning from 1990 to 2010. The forecasting of traffic was tested comparing results found in this study with that of Jamuna bridge study for the year 1994 and the variation of prediction between these two studies are 4% for passenger traffic, 17% for freight traffic and 5.5% for total traffic which is quite satisfactory. In 1997- the opening year of Jamuna bridge as assumed in this study- traffic volume over Jamuna bridge will be 4896 PCU/ day of passenger traffic and 4480 PCU/ day of freight traffic. The results also show that for the construction of Jamuna bridge, Dhaka-Aricha highway will lose around half of its traffic while the traffic volume on Tangail-Elenga road section will be doubled in 1997.

CHAPTER-8

SUMMARY AND CONCLUSIONS

8.1 INTRODUCTION

A transport modelling system has been developed in this study to forecast traffic flow-pattern and traffic volume on the national highway network of Bangladesh. The model and the described procedure are intended to provide highway planners with a tool for simple, fast and inexpensive estimation of traffic projections. Some problems and limitations of the model and suggestions to overcome the prohlems have been discussed in this chapter. This chapter summarizes the results of this present study and makes recommendations for future studies in this field.

8.2 SUMMARY OF RESULTS AND CONCLUSIONS

The principal objective of this research was to develop transport models of trip distribution and traffic assignment to predict traffic flow-pattern and traffic volume on the national highway network of Bangladesh. The conclusions reached from this study are summarized below.

1. Gravity models of trip distribution for passenger and freight movements and a capacity restraint traffic assignment model have been developed. It is postulated that, the shortest path will be selected on the basis of minimum travel time and minimum travel cost for passenger and freight movements respectively. Data requirement of the models include road inventory and traffic data. The road inventory data comprises link length, link speed and capacity, and traffic data include base year origin-destination (O-D) trip matrix and the link traffic volume. A calibration of the gravity models using the base year data showed that the models can satisfactorily synthesize the flow-patterns that exist between the old 20 districts of Bangladesh.

The final form of the gravity models are as follows:

For passenger movements

$$T_{ij} = P_i \frac{A_j b_j R_{ij}}{\sum_{j=1}^{n} A_j b_j R_{ij}}$$

Where, $R_{ij} = (t_{ij})^{-2.05}$, t_{ij} is in hours.

For freight movements

$$T_{ij} = P_i \frac{A_j b_j R_{ij}}{\sum_{j=1}^{n} A_j b_j R_{ij}}$$

Where, $R_{ij} = (c_{ij})^{-1.76}$, c_{ij} is in thousand taka.

Good correlation between separation function (R_{ij}) and the variables time (t_{ij}) and cost (c_{ij}) have been found with a correlation coefficient of 0.98 and 0.83 for time and cost respectively. The applicability of the assignment model was examined using the base year data and the results showed that, the model can calculate link traffic volume accurately.

2. For traffic projection, the average zonal traffic growth rates were calculated assuming that growth rate is a function of population, gross domestic product and income elasticity of transport demand. This study used a constant elasticity of 2 and 1.5 for passenger and freight transport respectively. Projections were made using base year trip matrices after ensuring that the base matrices are acceptable. This study projects traffic volume on links of the national highway network for a period of 20 years at an interval of 5 years from 1990 to 2010.

3. The results of traffic projection indicate that, Dhaka-Chittagong highway is the most loaded highway of which Feni-Chittagong bears the highest traffic. Also it has been found from the results that, traffic volumes on links Feni-Chittagong and Daudkandi-Comilla exceed the capacity in 2005

and the volumes on links Comilla-Feni and Dhaka-Aricha sections exceed the capacity in the year 2010. All other links bear traffic up to 2010 which is well below the capacity.

4. These models were also applied to forecast traffic under a changed condition of the network. The inclusion of the Jamuna bridge was considered for this purpose and it was assumed that it will be opened to traffic in 1997. Using the models, traffic volume over the Jamuna bridge in 1997 for both passenger and freight movements were calculated. Traffic volume over Jamuna bridge in 1994 was also calculated to compare the forecasting made in this study and Jamuna bridge study. Variations of these two predictions were found to be 4% for passenger traffic, 17% for freight traffic and 5.5% for total traffic which is quite satisfactory.

5. The impact of a changed condition of the network on link traffic volume was also pointed out. For the inclusion of the Jamuna bridge, the links which will undergo some changes in terms of traffic volume have been identified. It was found that, one of the heavily loaded Dhaka-Aricha highway will lose more than half of its traffic due to the Jamuna bridge.

8.3 PROBLEMS, LIMITATIONS AND SUGGESTIONS

A few problems may appear as soon as users begin to use the model to predict traffic flow-patterns and volume on a national level road network. The most serious problem in the application of this model is one that is common to all forecasting processes: the accuracy of the model is determined to a large extent by the accuracy of the input, especially the future values of the predictor variables. The predictor variables used in this study are: (1) population, (2) Gross domestic product (GDP) and (3) Income elasticities of transport demand.

The future values of these variables have been collected in this study from the reports of the past transport studies in this country. Values of these variables can also be found from the annual reports of Bangladesh Bureau of Statistics.

The road inventory data can be obtained from Roads and Highway Department (RHD) or City Development Corporation. The main problem is the estimation of average speed which can be collected from the Roads and Highways Department or past transport studies in this country or multiplying design highway speed by a speed reduction factor for a particular level of service. Capacity of road sections can be calculated from the road inventory and traffic data and assuming a particular level of service for a particular link or for the whole network. In this case, the equation for capacity mentioned in Chapter 4 (Components of transport system) should be used.

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 involves more sophisticated and expensive analysis [Salter, 1983]. the sophisticated and expensive analysis is against the principles that the models should be easy to understand and less costly. But, when new census data become available, the elasticities could be recalculated and the appropriateness of earlier values could be checked.

8.4 RECOMMENDATION FOR FUTURE STUDY

This study was based on data from some selected count stations reported in past transport studies undertaken in this country. There is no continuous counting station in this country though data from continuous count stations are required to implement such models for practical purpose. Further studies on traffic estimation will he 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 country stations, it may become possible to divide the whole network into zones of concentrations or otherwise separate different historical growth rates. The development of models for each sector or zones would be similar to the model developed in this study.

A detailed study on traffic volume, capacity and travel time should be made. The capacity used in this study was incorporated from the reports of a past transport study undertaken 1985. Also, the capacity should be route specific, not like that used in this study i.e. same capacity for all the links or road sections of the national highway network. The use of such values of capacity caused no problem in predicting traffic volume on national highway network at this present stage of the network because there is no scope for the vehicles to choose other routes depending on traffic volume. But if the model is applied in urban networks as for example, in a metropolitan area there will be a wide scope of route selection and then capacity of road sections will play a significant role while assigning traffic into the network.

The gravity model is formulated on the assumption that, the separation factors between a particular pair of zones are function of travel time and travel cost for passenger and freight movements respectively. It is a better approach to select separation factor which is a function of such variables that can be easily obtainable and accurate. Though travel cost is more appropriate than distance and time as a separation factor for modelling freight traffic, this is hard and expensive to get reliable data on transport cost. So, other types of variables such as travel distance between zones can be accepted for trip distribution modelling of freight traffic.

The models developed in this study deal with the trip distribution and assignment part of four step traffic planning process - trip generation, distribution, modal split and traffic assignment. The inclusion of the other two steps - trip generation and modal split will enhance the field of application and effectiveness of the models.

The traffic growth rates used in this study are the zonal (district) growth rates and were applied to the zonal production and attraction of traffic for future prediction. But there is evidence that, growth rates for all types of vehicle are not same. So, determination of growth rates for each type of vehicles in zonal basis is necessary for better results and more studies on these issues and their implementation on the models will increase their acceptability which ultimately will provide the planner with more reliable data.

Glossary

Accessibility: A term frequently used in a general sense to mean the degree of access to a particular place in terms of distance, time or cost. Specifically, the term also implies the number of opportunities available, for a given amount of travel cost.

Assignment: The process whereby trips surveyed or forecast from an origin zone to a destination zone are assigned (allocated) to definite routes, based on factors known to influence route selection.

Calibration: A process, usually mathematical, whereby survey information is used to establish or fix a relationship between two or more variables.

Correlation coefficient: A statistical term used to quantify the degree with which one variable relates to another. It takes a value between 0 and 1, and the closer the coefficient is to 1 the more the two variables are said to be correlated.

Elasticity of demand: The ratio of the percentage change in travel to the percentage change in travel costs.

Generation: A term defined as the home end of a home-based trip; the origin of a non-home-based trip.

Gravity model: A commonly used trip distribution model based on Newton's second law of gravity.

Home-based trip: Trips which have one end at the home of the person making the trip.

Interzonal trips: Trips which have an origin in one internal zone and a destination in another.

Intrazonal trips: Trips which have both origin and destination in an internal zone.

Journey speed: The speed of traffic including running speeds and intersection delay.

Level of service: A qualitative measure of the effect of a number of factors on travel flow, which include speed and travel time, safety, comfort and convenience.

Link: An element in a network which connects two nodes.

Matrix: An arrangement of values in the form of a table. In transport planning, the values often arranged are intrazonal and interzonal trips in the form of a trip matrix.

Model building: A mathematical process used to formulate relationships between two or more variables.

Network: A road, rail, bus or other transport system; an arrangement of links which represent a transport system.

Node: A numbered point which defines the end of a link in a network. In a road network each node generally represents either a road intersection or a zone centroid.

Non-home-based trips: A trip which has neither end at the home of the person making the trip.

Running speed: The speed of traffic between intersections, excluding intersection delay.

Transport model: The series of models including the trip end model, distribution model, modal split and assignment model.

Trip attraction: The non-home end of a home-based trip; the destination end of a non-home-based trip.

Trip distribution: The mathematical process of distributing trip ends to produce a trip matrix.

Trip ends: The origin or destination of a trip.

Trip generation: Often used as a general term to describe the trip-end forecasting models of generation and attraction.

Zone centroid: A point which represents a traffic zone for the purposes of traffic analysis.

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APPENDIX-A

DATA FILES

Table A.1 BUS.DAT

Bus trip matrix, 1990 for the old 20 districts of Bangladesh

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	55	65	240	5	95	1	1	0	0	0	1	1	0	0	0	0	10	1	0
1	55	0	0	0	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	65	0	0	0	26	221	1	0	1	1	0	1	1	0	0	0	0	10	3	0
3	240	0	0	0	8	70	0	0	0	0	0	0	4	0	0	0	0	10	0	0
4	5	2	26	8	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	95	7	221	70	60	0	40	23	109	90	22	10	65	30	4	20	20	10	30	30
6	1	0	1	0	0	40	0	0	0	0	20	27	11	0	0	0	0	5	3	0
7	1	0	0	0	0	23	0	0	0	24	0	0	0	0	0	0	0	0	0	0
8	0	0	1	0	0	109	0	0	0	0	0	1	0	0	0	0	0	0	0	0
9	0	0	1	0	0	90	0	24	0	0	0	0	1	0	0	20	0	30	0	0
10	0	0	0	0	0	22	20	0	0	0	0	12	18	0	45	0	0	0	0	0
11	1	0	1	0	0	10	27	0	1	0	12	0	130	25	4	0	0	6	0	0
12	1	0	1	4	0	65	11	0	0	1	18	130	0	8	6	15	20	15	13	4
13	0	0	0	0	0	30	0	0	0	0	0	25	8	0	0	0	0	15	10	0
14	0	0	0	0	0	4	0	0	0	0	45	4	6	0	0	0	0	0	0	0
15	0	0	0	0	0	20	0	0	0	20	0	0	15	0	0	0	40	30	14	10
16	0	0	0	0	0	20	0	0	0	0	0	0	20	0	0	40	0	10	10	30
17	10	0	10	10	0	10	5	0	0	30	0	6	15	15	0	30	10	0	7	4
18	1	0	3	0	0	30	3	0	0	0	0	0	13	10	0	14	10	7	0	3
19	0	0	0	0	0	30	0	0	0	0	0	0	4	0	0	10	30	4	3	0

Source: ITS (1985), SRIP (1991). (Modified to get the AADT,1991 reported in RMP,1991)

Notes: 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Table A.2 MBUS.DAT

Minibus trip matrix, 1990 for the old 20 districts of Bangladesh

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	31	13	85	15	10	1	1	0	0	0	1	1	0	0	0	0	1	1	0
1	31	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	13	0	0	0	1	65	1	0	1	1	0	1	1	0	0	0	0	1	1	0
3	85	0	0	0	1	20	0	0	0	0	0	0	2	0	0	0	0	2	0	0
4	15	1	1	1	0	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	10	3	65	20	95	0	55	53	80	90	1	1	1	1	1	27	3	27	23	10
6	1	0	1	0	0	55	0	0	0	0	1	1	1	0	0	0	0	1	1	0
7	1	0	0	0	0	53	0	0	0	11	0	0	0	0	0	0	0	0	0	0
8	0	0	1	0	0	80	0	0	0	0	0	1	0	0	0	0	0	0	0	0
9	0	0	1	0	0	90	0	11	0	0	0	1	0	0	0	45	0	30	0	0
10	0	0	0	0	0	1	1	0	0	0	0	1	1	0	3	0	0	0	0	0
11	1	0	1	0	0	1	1	0	1	1	1	0	58	14	2	0	0	25	0	0
12	1	0	1	2	0	1	1	0	0	0	1	58	0	2	1	1	1	20	10	2
13	0	0	0	0	0	1	0	0	0	0	0	14	2	0	0	0	0	20	60	0
14	0	0	0	0	0	1	0	0	0	0	3	2	1	0	0	0	0	0	0	0
15	0	0	0	0	0	27	0	0	0	45	0	0	1	0	0	0	3	10	5	1
16	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	3	0	1	5	35
17	1	0	1	2	0	27	1	0	0	30	0	25	20	20	0	10	1	0	12	4
18	1	0	1	0	0	23	1	0	0	0	0	0	10	60	0	5	5	12	0	20
19	0	0	0	0	0	10	0	0	0	0	0	0	2	0	0	1	35	4	20	0

Source: ITS (1985), SRIP (1991). (Modified to get the AADT,1991 reported in RMP,1991)

Notes: 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Table A.3 LMV.DAT

Light vehicle (4-wheel) trip matrix,1990 for old 20 districts of Bangladesh

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	36	30	230	3	60	2	2	0	0	0	2	2	0	0	0	0	1	1	0
1	36	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	30	0	0	0	50	125	1	0	1	1	0	1	1	0	0	0	0	1	1	0
3	230	0	0	0	4	10	0	0	0	0	0	0	1	0	0	0	0	1	0	0
4	3	1	50	4	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	60	4	125	10	13	0	52	12	102	95	1	10	8	21	1	30	4	25	11	20
6	2	0	1	0	0	52	0	0	0	0	5	14	4	0	0	0	0	3	2	0
7	2	0	0	0	0	12	0	0	0	13	0	0	0	0	0	0	0	0	0	0
8	0	0	1	0	0	102	0	0	0	0	0	2	0	0	0	0	0	0	0	0
9	0	0	1	0	0	95	0	13	0	0	0	0	2	0	0	50	0	10	0	0
10	0	0	0	0	0	1	5	0	0	0	0	4	4	0	3	0	0	0	0	0
11	2	0	1	0	0	10	14	0	2	0	4	0	80	26	2	0	0	3	0	0
12	2	0	1	1	0	8	4	0	0	2	4	80	0	10	3	2	1	2	25	2
13	0	0	0	0	0	21	0	0	0	0	0	26	10	0	0	0	0	2	25	0
14	0	0	0	0	0	1	0	0	0	0	3	2	3	0	0	0	0	0	0	0
15	0	0	0	0	0	30	0	0	0	50	0	0	2	0	0	0	4	11	48	18
16	0	0	0	0	0	4	0	0	0	0	0	0	1	0	0	4	0	2	1	38
17	1	0	1	1	0	25	3	0	0	10	0	3	2	2	0	11	2	0	2	5
18	1	0	1	0	0	11	2	0	0	0	0	0	25	25	0	48	1	2	0	3
19	0	0	0	0	0	20	0	0	0	0	0	0	2	0	0	18	38	5	3	0

Source: ITS (1985), SRIP (1991). (Modified to get the AADT,1991 reported in RMP,1991)

Notes: 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Table A.4 TRUCK.DAT

Truck trip matrix, 1990 for the old 20 districts of Bangladesh

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	2	125	198	89	535	7	7	34	16	6	45	31	17	0	30	20	31	42	20
1	2	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	125	0	0	0	26	129	0	0	3	3	0	5	2	2	0	2	2	6	2	3
3	198	0	0	0	3	75	1	1	4	5	0	7	1	1	0	2	4	0	3	15
4	89	0	26	3	0	40	5	1	3	1	0	6	4	6	0	2	3	4	9	1
5	535	14	129	75	40	0	20	38	328	263	4	91	60	29	0	61	35	70	55	40
6	7	0	0	1	5	20	0	0	0	1	60	15	39	25	0	0	0	0	0	0
7	7	0	0	1	1	38	0	0	0	50	0	0	1	0	0	0	0	0	0	0
8	34	0	3	4	3	328	0	0	0	50	0	0	6	0	0	1	0	30	3	1
9	16	0	3	5	1	263	1	50	50	0	0	0	2	0	0	0	0	50	3	0
10	6	0	0	0	0	4	60	0	0	0	0	6	3	0	24	0	0	0	0	0
11	45	0	5	7	6	91	15	0	0	0	6	0	217	46	1	4	12	3	6	3
12	31	0	2	1	4	60	39	1	6	2	3	217	0	47	0	35	20	24	20	35
13	17	0	2	1	6	29	25	0	0	0	0	46	47	0	0	53	48	90	2	11
14	0	0	0	0	0	0	0	0	0	0	24	1	0	0	0	0	0	0	0	0
15	30	0	2	2	2	61	0	0	1	0	0	4	35	53	0	0	20	11	42	6
16	20	0	2	4	3	35	0	0	0	0	0	12	20	48	0	20	0	17	26	20
17	31	0	6	0	4	70	0	0	30	50	0	3	24	90	0	11	17	0	10	5
18	42	0	2	3	9	55	0	0	3	3	0	6	20	2	0	42	26	10	0	8
19	20	0	3	15	1	40	0	0	1	0	0	3	35	11	0	6	20	5	8	0

Source: ITS (1985), SRIP (1991). (Modified to get the AADT,1991 reported in RMP,1991)

Notes: 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Table A.5 PASS_NET.DAT[a]

Network description for passenger vehicles

```
96
16 19 81 5375 35.47
19 15 114 5375 45.00
15 35 72 5375 38.92
15 34 60 5375 46.75
18 35 49 5375 39.73
35 36 34 5375 40.80
30 34 20 5375 21.82
34 37 55 5375 50.00
17 36 26 5375 33.91
17 37 47 5375 42.73
31 37 6 5375 51.43
13 36 32 5375 21.82
13 39 52 5375 43.33
6 39 83 5375 37.16
6 38 20 5375 41.38
32 38 10 5375 50.00
11 39 45 5375 39.13
11 12 61 5375 37.35
6 33 52 5375 26.22
6 10 144 5375 26.42
10 33 132 5375 24.91
10 14 40 5375 17.14
27 30 1 3760 0.31
28 31 1 5375 0.31
28 32 1 5375 0.37
29 33 1 3225 0.20
26 27 22 5375 25.38
5 28 88 5375 36.16
5 29 40 5375 16.00
5 25 34 5375 26.84
5 21 14 5375 17.87
8 25 88 5375 43.64
9 25 64 5375 30.97
9 26 15 5375 30.00
8 26 82 5375 30.37
7 26 79 5375 37.03
7 8 91 5375 29.35
8 24 69 5375 27.97
22 24 57 5375 36.52
21 22 79 5375 37.92
2 21 83 5375 30.18
22 23 14 5375 14.74
4 23 171 5375 40.23
2 23 86 5375 38.80
```

a. See notes

Table A.5 continued......

2	20	54	5375	40.50
0	20	107	5375	41.96
3	20	42	5375	30.36
0	1	76	5375	32.81
19	16	81	5375	35.47
15	19	114	5375	45.00
35	15	72	5375	38.92
34	15	60	5375	46.75
35	18	49	5375	39.73
36	35	34	5375	40.80
34	30	20	5375	21.82
37	34	55	5375	50.00
36	17	26	5375	33.91
37	17	47	5375	42.73
37	31	6	5375	51.43
36	13	32	5375	21.82
39	13	52	5375	43.33
39	6	83	5375	37.16
38	6	20	5375	41.38
38	32	10	5375	50.00
39	11	45	5375	39.13
12	11	61	5375	37.35
33	6	52	5375	26.22
10	6	144	5375	26.42
33	10	132	5375	24.91
14	10	40	5375	17.14
30	27	1	3760	0.31
31	28	1	5375	0.31
32	28	1	5375	0.37
33	29	1	3225	0.20
27	26	22	5375	25.38
28	5	88	5375	36.16
29	5	40	5375	16.00
25	5	34	5375	26.84
21	5	14	5375	17.87
25	8	88	5375	43.64
25	9	64	5375	30.97
26	9	15	5375	30.00
26	8	82	5375	30.37
26	7	79	5375	37.03
8	7	91	5375	29.35
24	8	69	5375	27.97
24	22	57	5375	36.52
22	21	79	5375	37.92
21	2	83	5375	30.18
23	22	14	5375	14.74
23	4	171	5375	40.23
23	2	86	5375	38.80
20	2	54	5375	40.50

Table A.5 continued......

20	0	107	5375	41.96
20	3	42	5375	30.36
1	0	76	5375	32.81

Notes: Each row (Except the first row) of Table A.5 contains five elements. These are 'from node', 'to node', 'link length (km)', 'capacity (PCU/day)' and 'link average speed (km/h)'.
The first row contains only one element which represents number of data items i.e. number of rows.

Table A.6 FRGT_NET.DAT[a]

Network description for truck movement

```
96
16 19 81 5676 18.00
19 15 114 5676 18.00
15 35 72 5676 18.00
15 34 60 5676 18.00
18 35 49 5676 18.00
35 36 34 5676 18.00
30 34 20 5676 18.00
34 37 55 5676 18.00
17 36 26 5676 18.00
17 37 47 5676 18.00
31 37 6 5676 18.00
13 36 32 5676 18.00
13 39 52 5676 18.00
6 39 83 5676 18.00
6 38 20 5676 18.00
32 38 10 5676 18.00
11 39 45 5676 18.00
11 12 61 5676 18.00
6 33 52 5676 18.00
6 10 144 5676 18.00
10 33 132 5676 18.00
10 14 40 5676 18.00
27 30 1 3975 0.015
28 31 1 5676 0.015
28 32 1 5676 0.015
29 33 1 3410 0.01
26 27 22 5676 18.00
5 28 88 5676 18.00
5 29 40 5676 18.00
5 25 34 5676 18.00
5 21 14 5676 18.00
8 25 88 5676 18.00
9 25 64 5676 18.00
9 26 15 5676 18.00
8 26 82 5676 18.00
7 26 79 5676 18.00
7 8 91 5676 18.00
8 24 69 5676 18.00
22 24 57 5676 18.00
21 22 79 5676 18.00
2 21 83 5676 18.00
22 23 14 5676 18.00
4 23 171 5676 18.00
2 23 86 5676 18.00
2 20 54 5676 18.00
```

---

a. See notes

Table A.6 continued....

0	20	107	5676	18.00
3	20	42	5676	18.00
0	1	76	5676	18.00
19	16	81	5676	18.00
15	19	114	5676	18.00
35	15	72	5676	18.00
34	15	60	5676	18.00
35	18	49	5676	18.00
36	35	34	5676	18.00
34	30	20	5676	18.00
37	34	55	5676	18.00
36	17	26	5676	18.00
37	17	47	5676	18.00
37	31	6	5676	18.00
36	13	32	5676	18.00
39	13	52	5676	18.00
39	6	83	5676	18.00
38	6	20	5676	18.00
38	32	10	5676	18.00
39	11	45	5676	18.00
12	11	61	5676	18.00
33	6	52	5676	18.00
10	6	144	5676	18.00
33	10	132	5676	18.00
14	10	40	5676	18.00
30	27	1	3975	0.015
31	28	1	5676	0.015
32	28	1	5676	0.015
33	29	1	3410	0.01
27	26	22	5676	18.00
28	5	88	5676	18.00
29	5	40	5676	18.00
25	5	34	5676	18.00
21	5	14	5676	18.00
25	8	88	5676	18.00
25	9	64	5676	18.00
26	9	15	5676	18.00
26	8	82	5676	18.00
26	7	79	5676	18.00
8	7	91	5676	18.00
24	8	69	5676	18.00
24	22	57	5676	18.00
22	21	79	5676	18.00
21	2	83	5676	18.00
23	22	14	5676	18.00
23	4	171	5676	18.00
23	2	86	5676	18.00
20	2	54	5676	18.00

Table A.6 continued....

20 0 107 5676 18.00
20 3 42 5676 18.00
1 0 76 5676 18.00

Notes: Each row (Except the first row) of Table A.6 contains five elements. These are 'from node', 'to node', 'link length (km)', 'capacity (PCU/day)' and 'link average speed (km/h)'.
The first row contains only one element which represents number of data items i.e. number of rows.

Table A.7 ZONAL TRAFFIC GROWTH RATES (1990-2010)

Passenger Traffic (Bus, Minibus and Light vehicles)

Zones	1990-1995	1995-2000	2000-2005	2005-2010
0	6.23	6.54	7.20	7.37
1	6.47	6.60	6.59	6.76
2	5.79	6.10	6.50	6.69
3	5.56	5.81	6.23	6.38
4	5.57	5.69	6.18	6.28
5	6.15	6.27	7.10	7.24
6	5.53	5.69	6.13	6.12
7	5.31	5.29	5.93	5.88
8	5.07	5.36	5.75	5.79
9	5.35	5.64	6.02	6.04
10	5.42	5.51	5.88	5.91
11	5.36	5.58	6.00	6.04
12	5.47	5.76	6.19	6.31
13	5.14	5.44	5.86	6.05
14	5.18	5.23	5.82	5.80
15	5.28	5.53	5.94	5.98
16	5.30	5.48	6.02	6.17
17	5.35	5.58	5.93	6.09
18	5.30	5.51	5.90	5.88
19	5.08	5.30	5.79	5.79

Notes: 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Income elasticity of transport demand (E) is 2.

Table A.8 ZONAL TRAFFIC GROWTH RATES (1990-2010)

Freight Traffic (Trucks)

Zones	1990-1995	1995-2000	2000-2005	2005-2010
0	5.24	5.41	5.87	5.96
1	5.42	5.46	5.42	5.50
2	4.88	5.06	5.33	5.43
3	4.75	4.88	5.17	5.24
4	4.73	4.76	5.10	5.13
5	5.17	5.21	5.80	5.87
6	4.67	4.74	5.03	4.99
7	4.53	4.44	4.91	4.83
8	4.37	4.53	4.80	4.78
9	4.55	4.71	4.96	4.94
10	4.66	4.67	4.91	4.90
11	4.60	4.71	4.99	4.98
12	4.67	4.83	5.12	5.17
13	4.48	4.65	4.93	5.03
14	4.44	4.42	4.83	4.77
15	4.49	4.62	4.90	4.89
16	4.52	4.60	4.97	5.05
17	4.60	4.72	4.95	5.03
18	4.55	4.65	4.91	4.86
19	4.39	4.49	4.84	4.79

Notes: 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Income elasticity of transport demand (E) is 1.5.

Table A.9 TIME.DAT

Free flow travel time(hrs) between old 20 districts of Bangladesh for passenger vehicles

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0.0	2.5	4.1	4.1	10.5	7.6	13.4	13.6	10.9	10.9	18.8	16.8	18.4	16.7	21.1	15.8	20.6	14.5	17.3	18.3
1	2.5	0.0	6.4	6.4	12.8	9.9	15.7	15.9	13.2	13.2	21.1	19.1	20.7	19.0	23.4	18.1	22.9	16.8	19.6	20.6
2	4.1	6.4	0.0	2.9	6.6	3.7	9.5	9.7	7.0	7.0	14.9	12.9	14.5	12.8	17.2	11.9	16.7	10.6	13.4	14.4
3	4.1	6.4	2.9	0.0	9.4	6.4	12.2	12.4	9.7	9.8	17.6	15.6	17.2	15.6	19.9	14.6	19.4	13.3	16.2	17.1
4	10.5	12.8	6.6	9.4	0.0	8.2	14.0	12.5	9.4	11.6	19.4	17.4	19.0	17.4	21.8	16.4	21.2	15.1	18.0	19.0
5	7.6	9.9	3.7	6.4	8.2	0.0	6.0	6.1	3.5	3.5	11.4	9.3	11.0	9.3	13.7	8.4	13.2	7.1	9.9	10.9
6	13.4	15.7	9.5	12.2	14.0	6.0	0.0	11.6	9.2	9.0	5.6	3.6	5.2	3.6	8.0	7.8	12.6	5.8	7.1	10.3
7	13.6	15.9	9.7	12.4	12.5	6.1	11.6	0.0	3.3	2.8	17.1	14.1	15.8	11.8	19.4	8.6	13.4	9.5	11.7	11.2
8	10.9	13.2	7.0	9.7	9.4	3.5	9.2	3.3	0.0	3.4	14.7	12.6	14.3	12.3	17.0	9.2	14.0	10.1	12.3	11.7
9	10.9	13.2	7.0	9.8	11.6	3.5	9.0	2.8	3.4	0.0	14.4	12.5	14.1	10.1	16.8	7.0	11.8	7.9	10.1	9.5
10	18.8	21.1	14.9	17.6	19.4	11.4	5.6	17.1	14.7	14.4	0.0	9.0	10.6	9.1	2.5	13.2	18.0	11.3	12.6	15.7
11	16.8	19.1	12.9	15.6	17.4	9.3	3.6	14.1	12.6	12.5	9.0	0.0	1.8	2.5	11.3	6.7	11.5	4.8	6.1	9.2
12	18.4	20.7	14.5	17.2	19.0	11.0	5.2	15.8	14.3	14.1	10.6	1.8	0.0	4.2	13.0	8.3	13.1	6.4	7.7	10.8
13	16.7	19.0	12.8	15.6	17.4	9.3	3.6	11.8	12.3	10.1	9.1	2.5	4.2	0.0	11.4	4.3	10.8	2.4	3.7	6.9
14	21.1	23.4	17.2	19.9	21.8	13.7	8.0	19.4	17.0	16.8	2.5	11.3	13.0	11.4	0.0	15.5	20.4	13.6	14.9	18.1
15	15.8	18.1	11.9	14.6	16.4	8.4	7.8	8.6	9.2	7.0	13.2	6.7	8.3	4.3	15.5	0.0	5.0	3.6	3.3	2.7
16	20.6	22.9	16.7	19.4	21.2	13.2	12.6	13.4	14.0	11.8	18.0	11.5	13.1	10.8	20.4	5.0	0.0	8.6	16.7	2.5
17	14.5	16.8	10.6	13.3	15.1	7.1	5.8	9.5	10.1	7.9	11.3	4.8	6.4	2.4	13.6	3.6	8.6	0.0	3.0	6.2
18	17.3	19.6	13.4	16.2	18.0	9.9	7.1	11.7	12.3	10.1	12.6	6.1	7.7	3.7	14.9	3.3	16.7	3.0	0.0	5.8
19	18.3	20.6	14.4	17.1	19.0	10.9	10.3	11.2	11.7	9.5	15.7	9.2	10.8	6.9	18.1	2.7	2.5	6.2	5.8	0.0

Notes: 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14-Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Table A.10 COST.DAT

Travel cost[a] (Tk.) for trucks between old 20 districts[b] of Bangladesh

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	651	1400	1283	3621	2265	5766	3944	3332	3136	7016	6873	7389	6487	7356	6554	8217	5955	6900	7532
1	651	0	2052	1972	4310	2953	6418	4596	3984	3788	7668	7525	8041	7139	8007	7206	8905	6607	7552	8184
2	1400	2052	0	821	2221	864	4365	2544	1932	1736	5616	5473	5989	5087	5955	5154	6853	4555	5500	6132
3	1283	1972	821	0	3079	1722	5187	3365	2790	2557	6438	6295	6810	5909	6777	5975	7675	5377	6321	6953
4	3621	4310	2221	3079	0	2434	5899	4114	3502	3306	7149	7043	7558	6657	7525	6687	8387	6125	7069	7701
5	2265	2953	864	1722	2434	0	3464	1679	1067	834	4715	4572	5124	4222	5054	4252	5952	3690	4635	5267
6	5766	6418	4365	5187	5899	3464	0	5144	4532	4336	1250	1107	1659	1190	1589	2401	4100	6125	7069	3415
7	3944	4596	2544	3365	4114	1679	5144	0	788	808	6394	5779	6295	4914	6734	4030	5729	4382	5054	5007
8	3332	3984	1932	2790	3502	1067	4532	788	0	828	5782	5639	6191	4934	6122	4049	5749	4402	5110	5027
9	3136	3788	1736	2557	3306	834	4336	808	828	0	5586	5207	5759	4379	5962	3457	5157	3847	4518	4472
10	7016	7668	5616	6438	7149	4715	1250	6394	5782	5586	0	2358	2910	2441	339	3651	5351	2973	3462	4666
11	6873	7525	5473	6295	7043	4572	1107	5779	5639	5207	2358	0	515	828	2697	2075	3775	1396	1885	3053
12	7389	8041	5989	6810	7558	5124	1659	6295	6191	5759	2910	515	0	1380	3249	2590	4290	1912	2401	3605
13	6487	7139	5087	5909	6657	4222	1190	4914	4934	4379	2441	828	1380	0	2780	1247	2946	532	1021	2225
14	7356	8007	5955	6777	7525	5054	1589	6734	6122	5962	339	2697	3249	2780	0	3991	5690	3312	3801	5005
15	6554	7206	5154	5975	6687	4252	2401	4030	4049	3457	3651	2075	2590	1247	3991	0	1699	1134	1060	977
16	8217	8905	6853	7675	8387	5952	4100	5729	5749	5157	5351	3775	4290	2946	5690	1699	0	2833	2760	721
17	5955	6607	4555	5377	6125	3690	6125	4382	4402	3847	2973	1396	1912	532	3312	1134	2833	0	944	2148
18	6900	7552	5500	6321	7069	4635	7069	5054	5110	4518	3462	1885	2401	1021	3801	1060	2760	944	0	2038
19	7532	8184	6132	6953	7701	5267	3415	5007	5027	4472	4666	3053	3605	2225	5005	977	721	2148	2038	0

a. Financial costs (= Distance*36.62 + Time*6.65) [Unit costs of distance and time are 36.62 Tk/km and 6.65 Tk/hr respectively]

b. 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

APPENDIX-B

PREDICTED TRAFFIC VOLUME (1990-2010)

Figure B.1 Prediction of Traffic Volume, 1990-2010

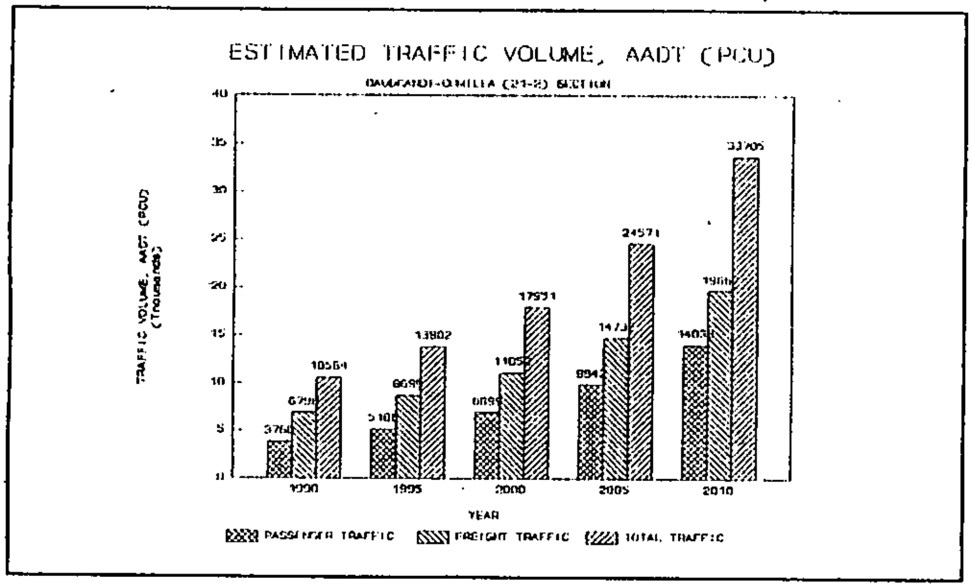


Figure B.2 Prediction of Traffic Volume, 1990-2010.

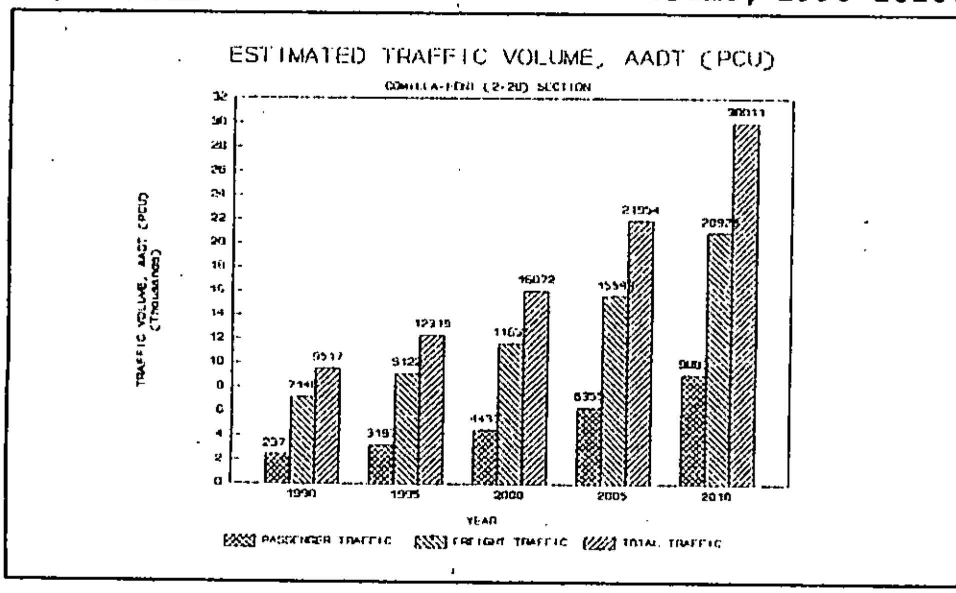


Figure B.3 Prediction of Traffic Volume, 1990-2010.

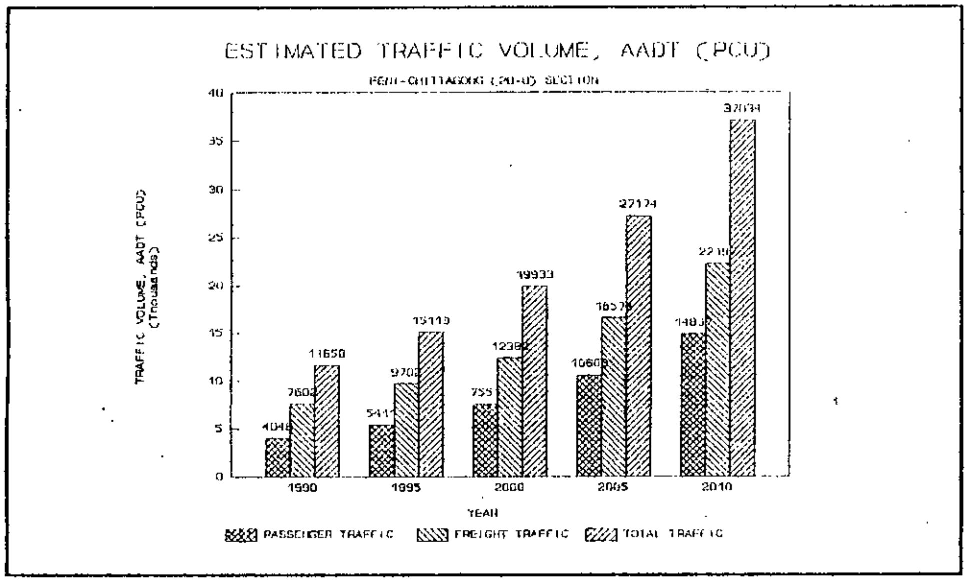


Figure B.4 Prediction of Traffic Volume, 1990-2010.

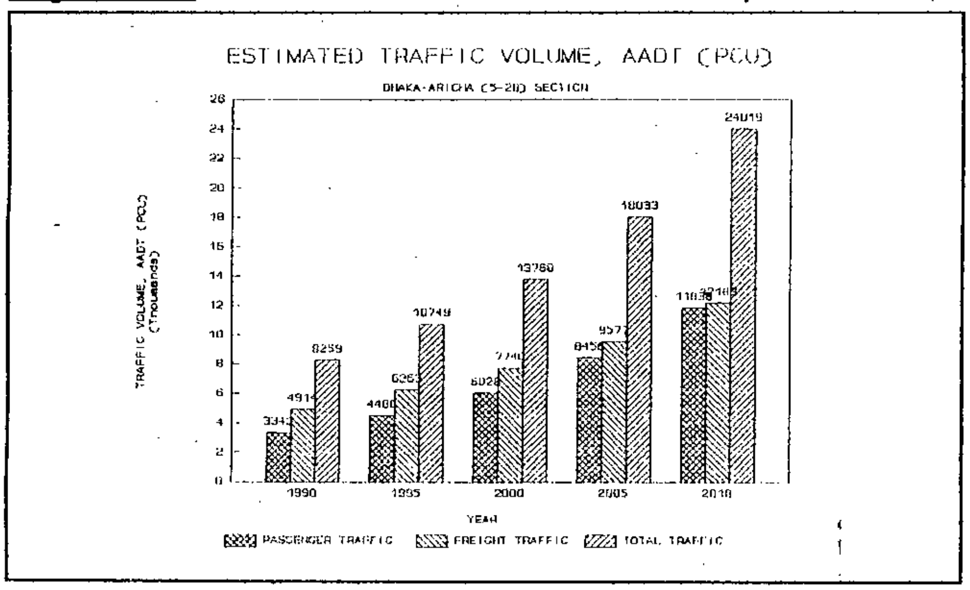


Figure B.5 Prediction of Traffic Volume, 1990-2010.

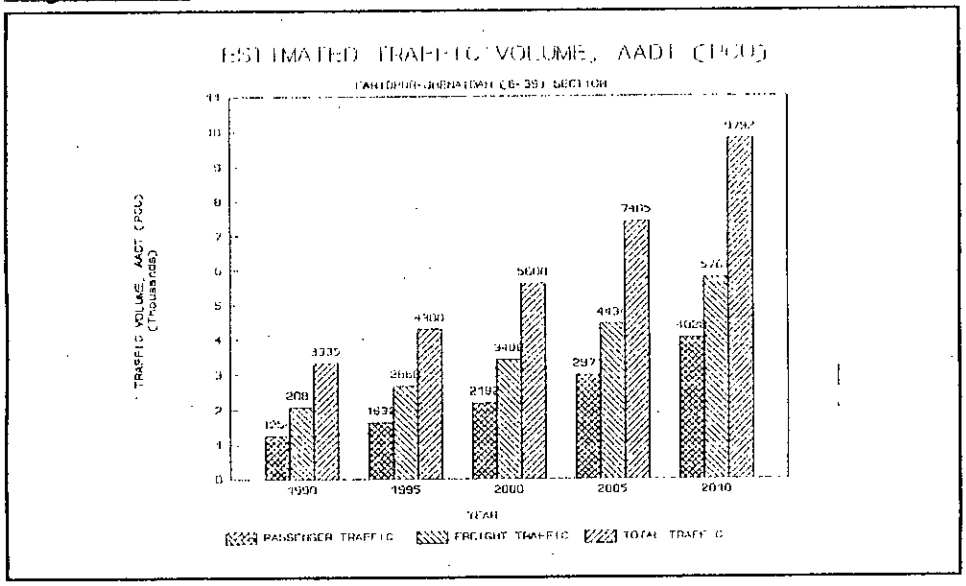


Figure B.6 Prediction of Traffic Volume, 1990-2010.

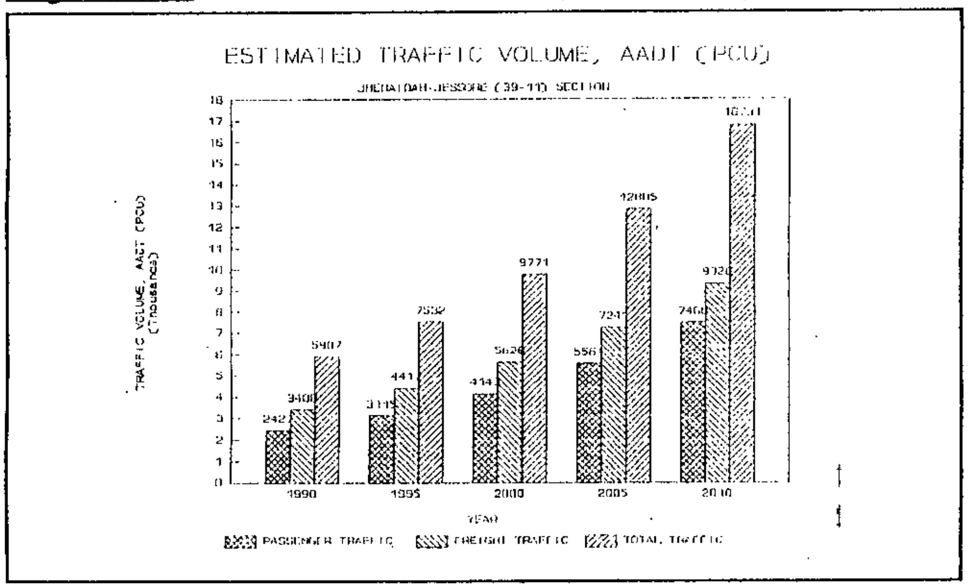


Figure B.7 Prediction of Traffic Volume, 1990-2010.

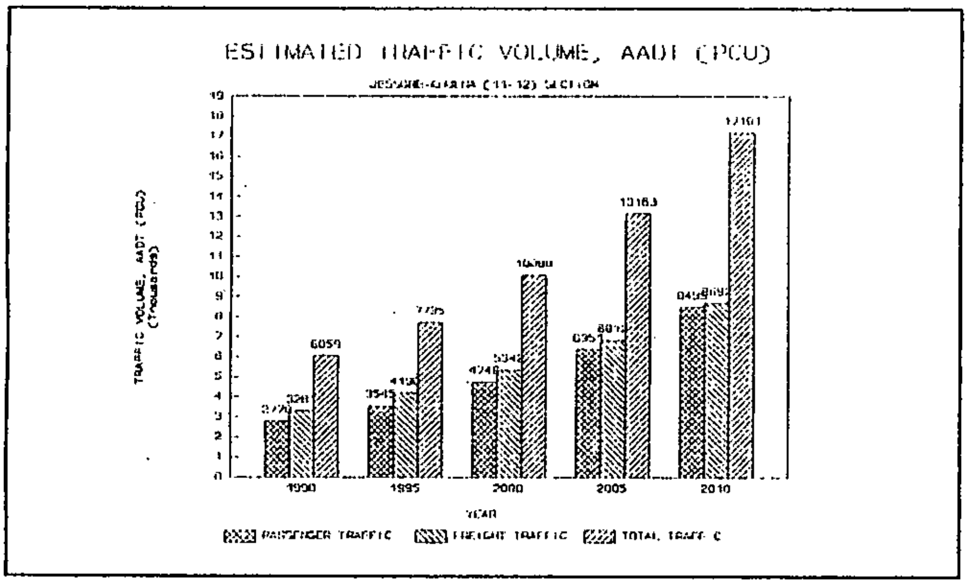


Figure B.8 Prediction of Traffic Volume, 1990-2010.

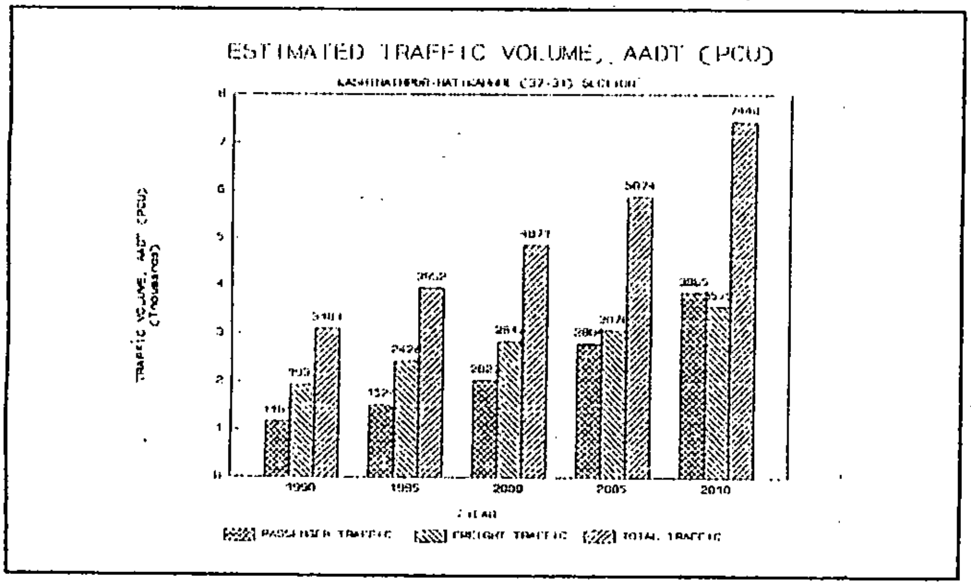


Figure B.9 Prediction of Traffic Volume, 1990-2010.

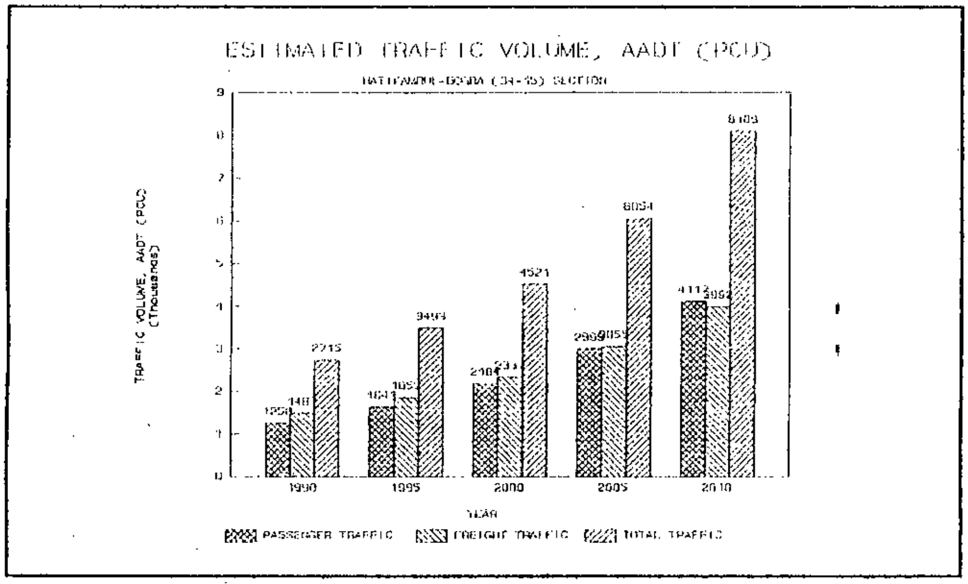


Figure B.10 Prediction of Traffic Volume,1990-2010.

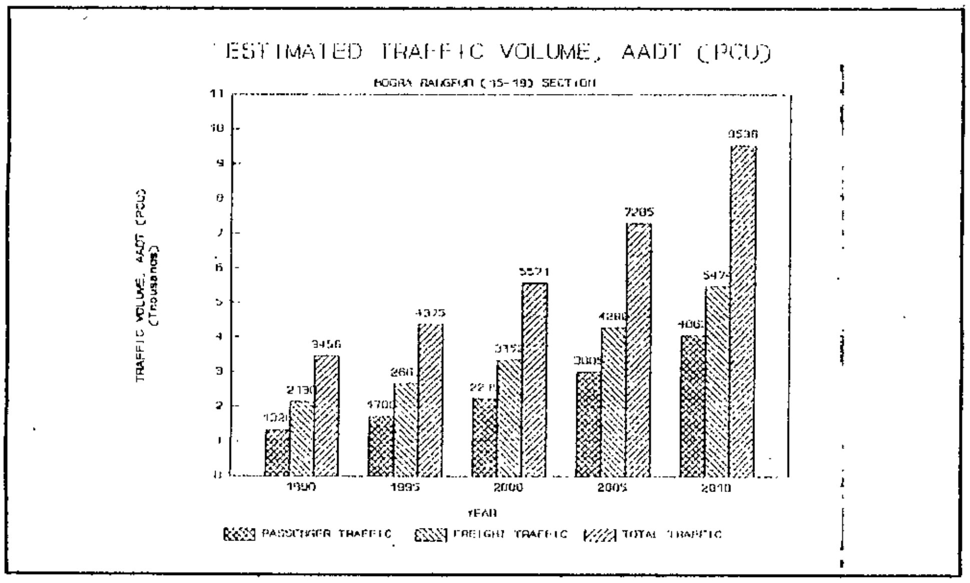


Figure B.11 Prediction of Traffic Volume,1990-2010.

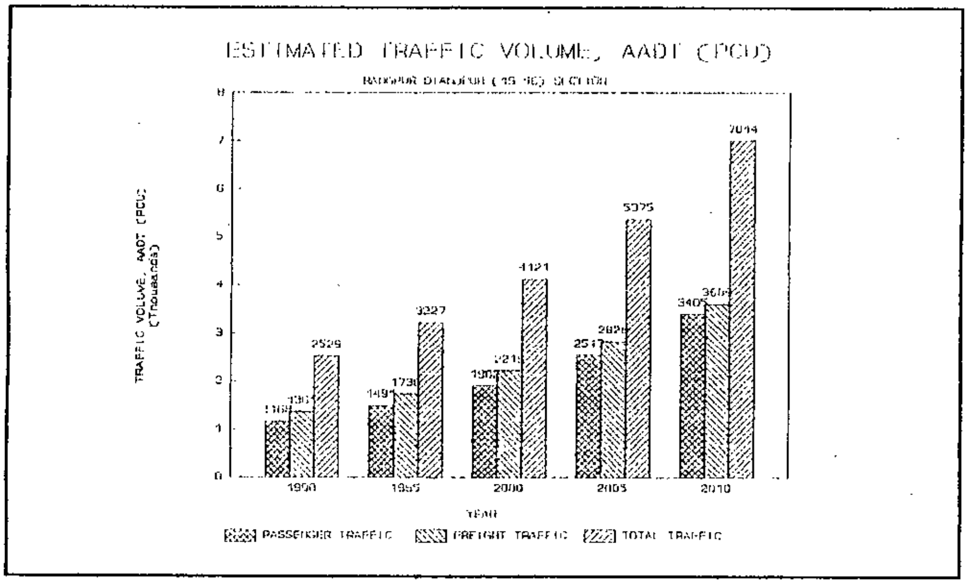


Figure B.12 Prediction of Traffic Volume,1990-2010.

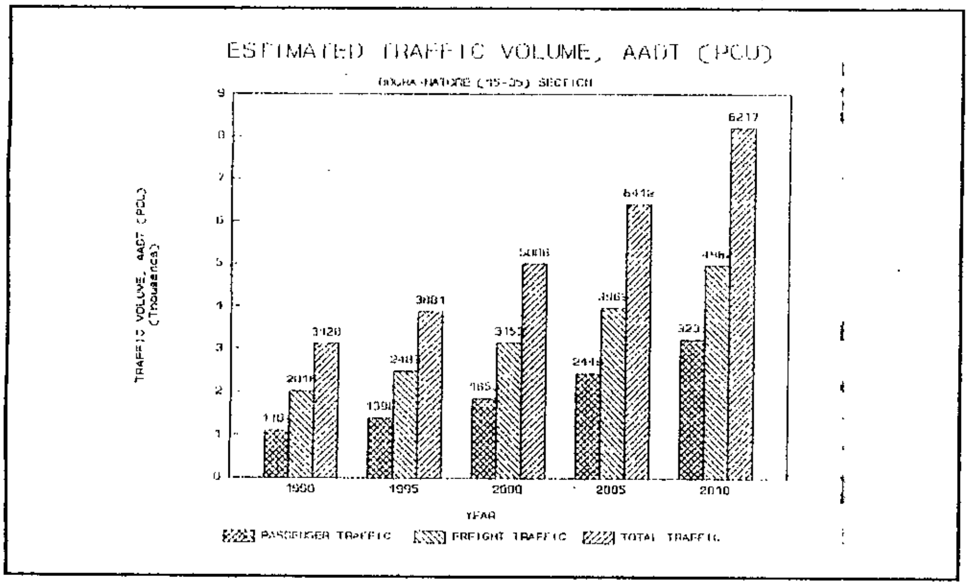


Figure B.13 Prediction of Traffic Volume,1990-2010.

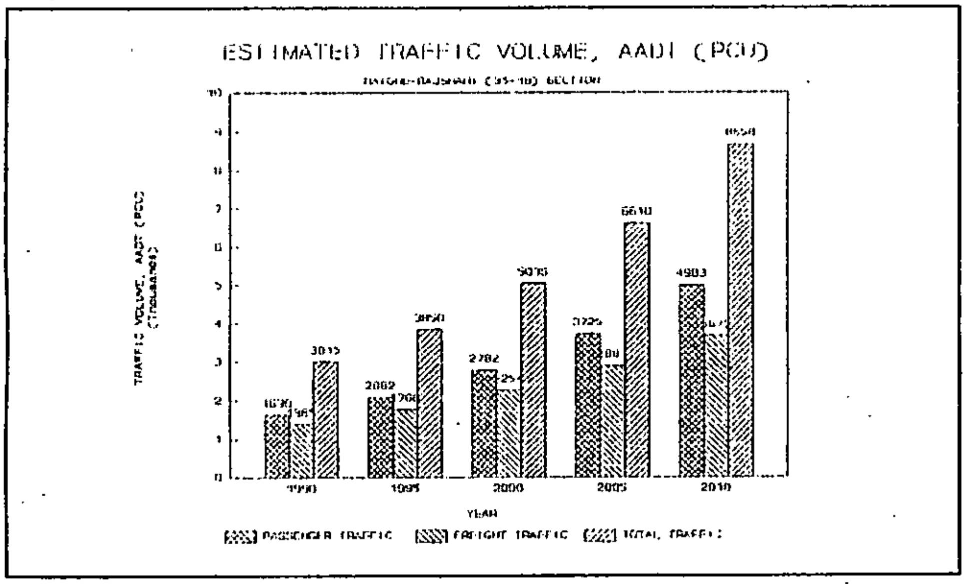
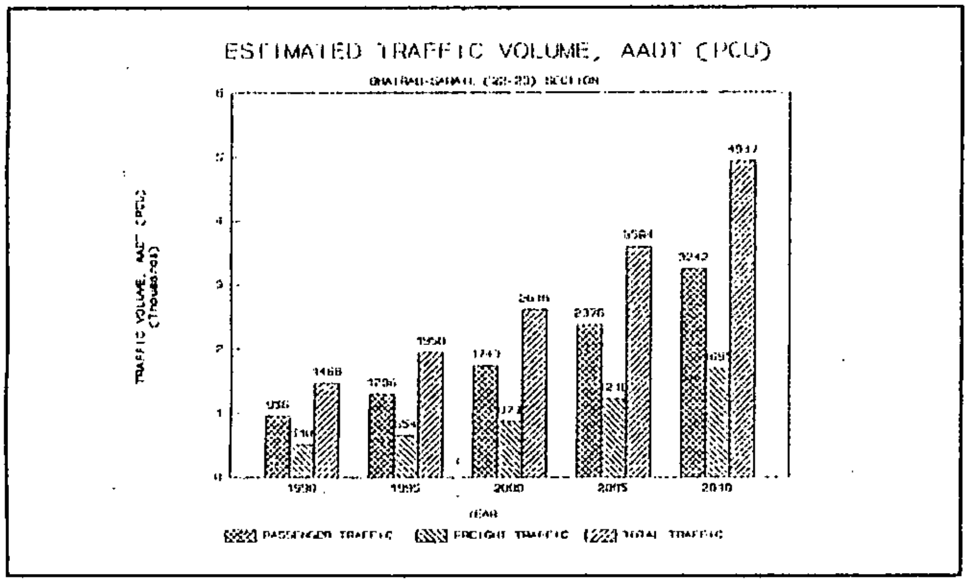
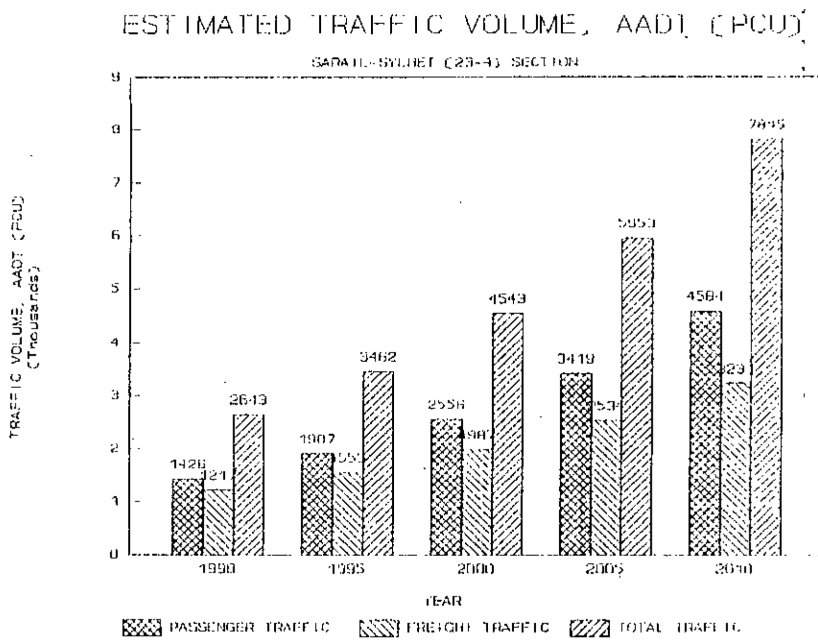


Figure B.14 Prediction of Traffic Volume,1990-2010.



<u>Figure B.15</u> Prediction of Traffic Volume,1990-2010.



APPENDIX-C

SAMPLE OUTPUT, ACCEPTABILITY OF TRIP MATRICES & VALIDITY OF MODELS

Figure C.1 Comparison of Traffic Volume (Dhaka-Chittagong highway)[a]

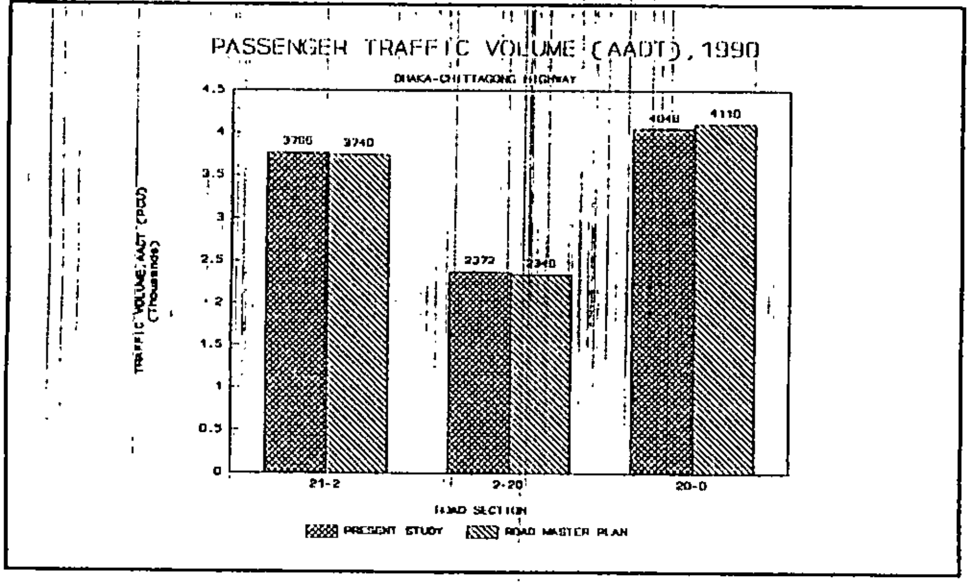
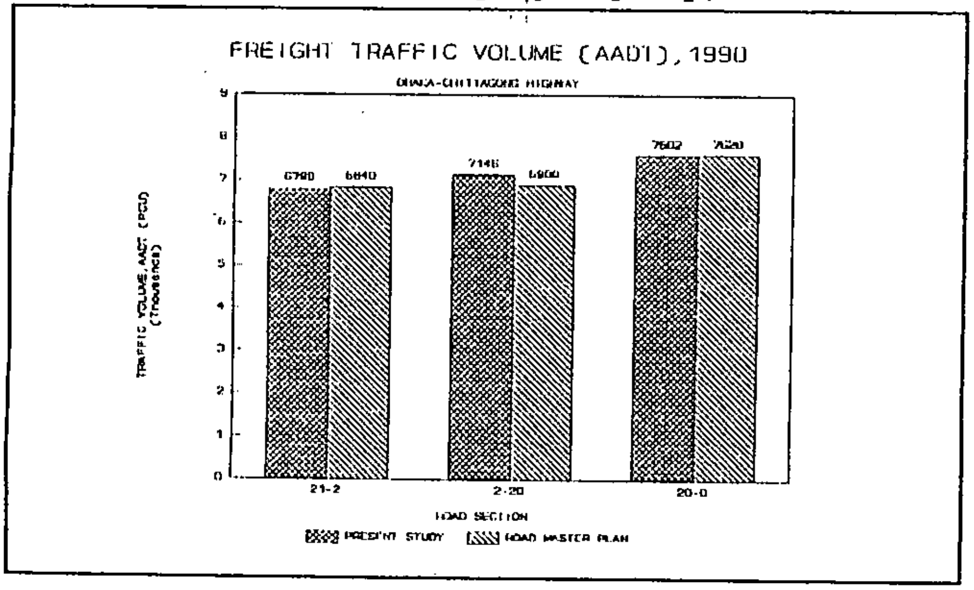
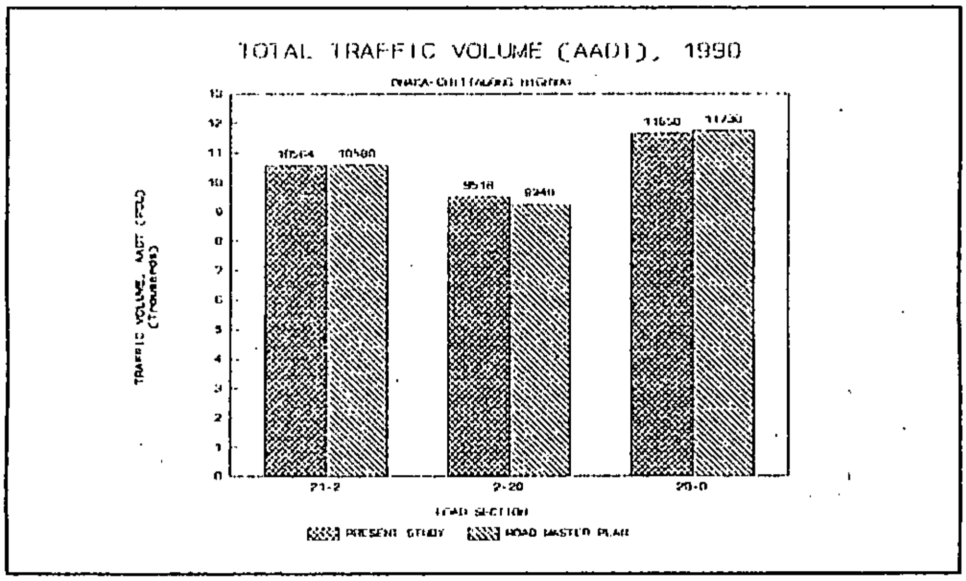


Figure C.2 Comparison of Traffic Volume (Dhaka-Chittagong highway)[a]



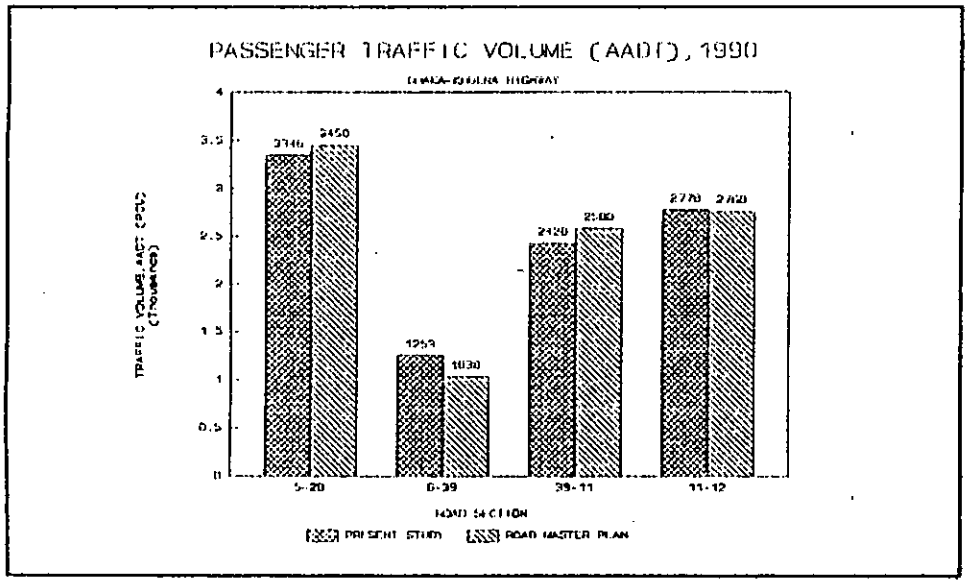
a. Link 21-2:Daudkandi-Comilla
Link 2-20:Comilla-Feni
Link 20-0:Feni-Chittagong

Figure C.3 Comparison of traffic Volume (Dhaka-Chittagong highway)[a]



a. Link 21-2:Daudkandi-Comilla
Link 2-20:Comilla-Feni
Link 20-0:Feni-Chittagong

Figure C.4 Comparison of Traffic Volume (Dhaka-Khulna highway)[b]



b. Link 5-28:Dhaka-Aricha
Link 6-39:Faridpur-Jhenaidah
Link 39-11:Jhenaidah-Jessore
Link 11-12:Jessore-Khulna

Figure C.5 Comparison of Traffic Volume (Dhaka-Khulna highway)[a]

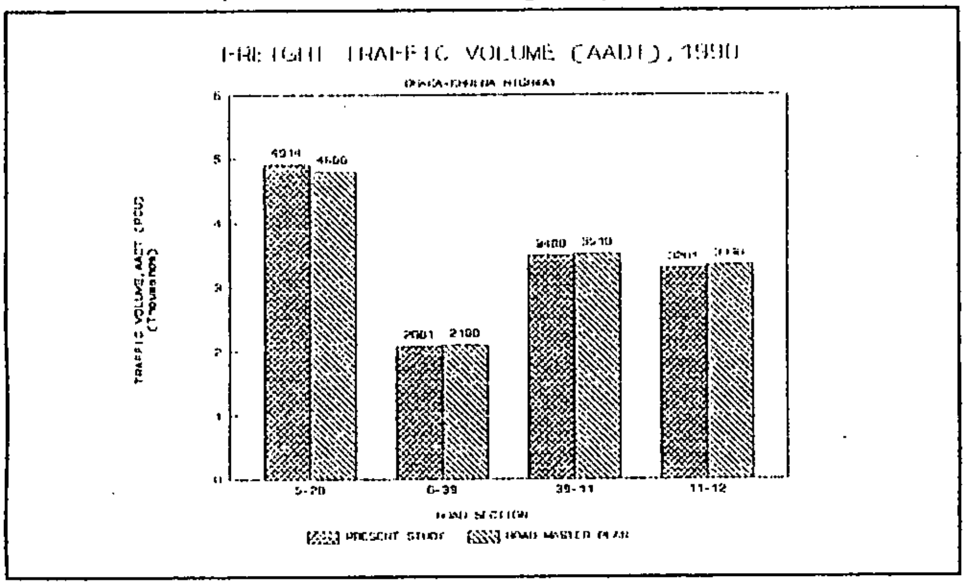
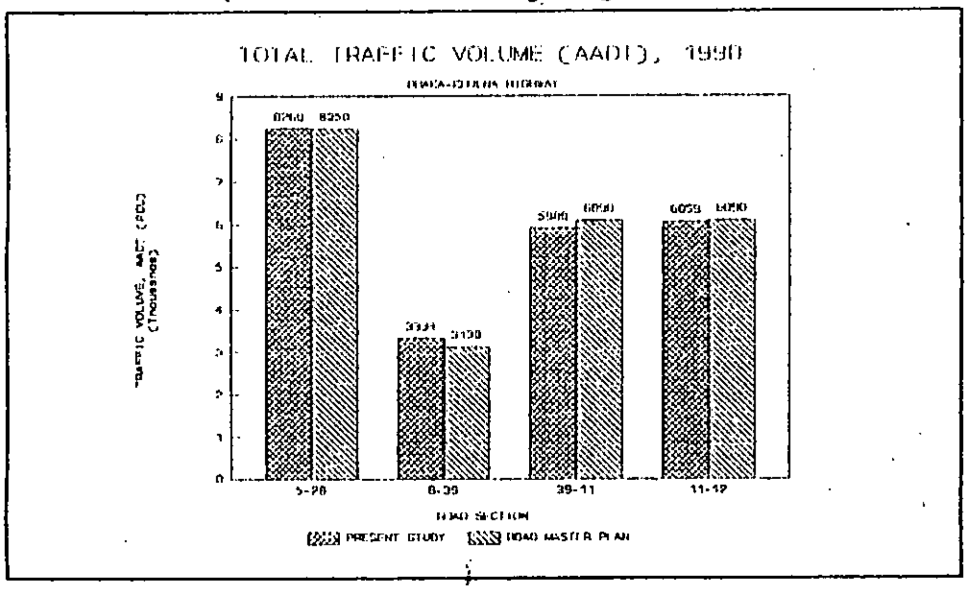


Figure C.6 Comparison of Traffic Volume (Dhaka-Khulna highway)[a]



a. Link 5-28:Dhaka-Aricha
Link 6-39:Faridpur-Jhenaidah
Link 39-11:Jhenaidah-Jessore
Link 11-12:Jessore-Khulna

Figure C.7 Comparison of Traffic Volume (Dhaka-Northwest Highway)[a]

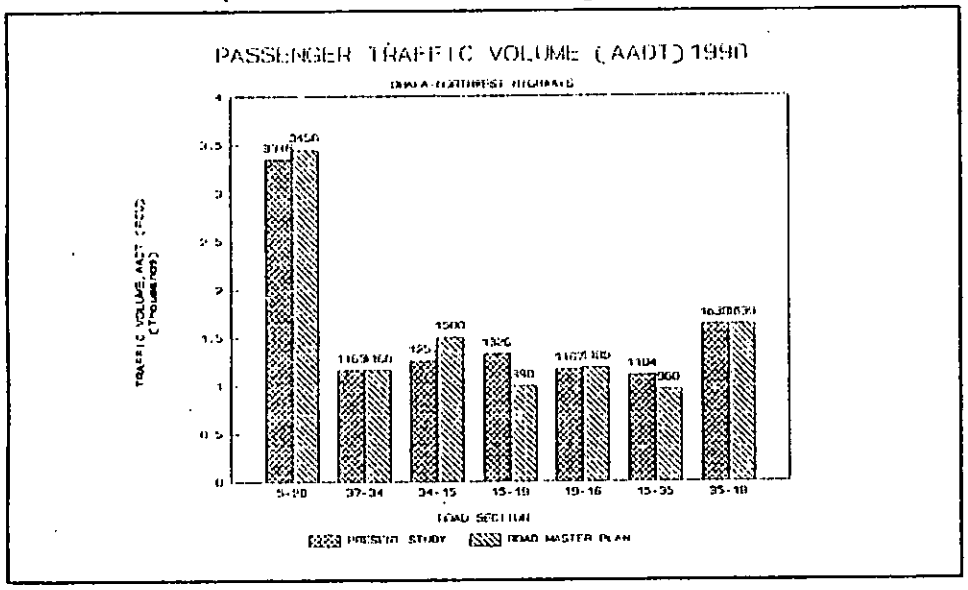
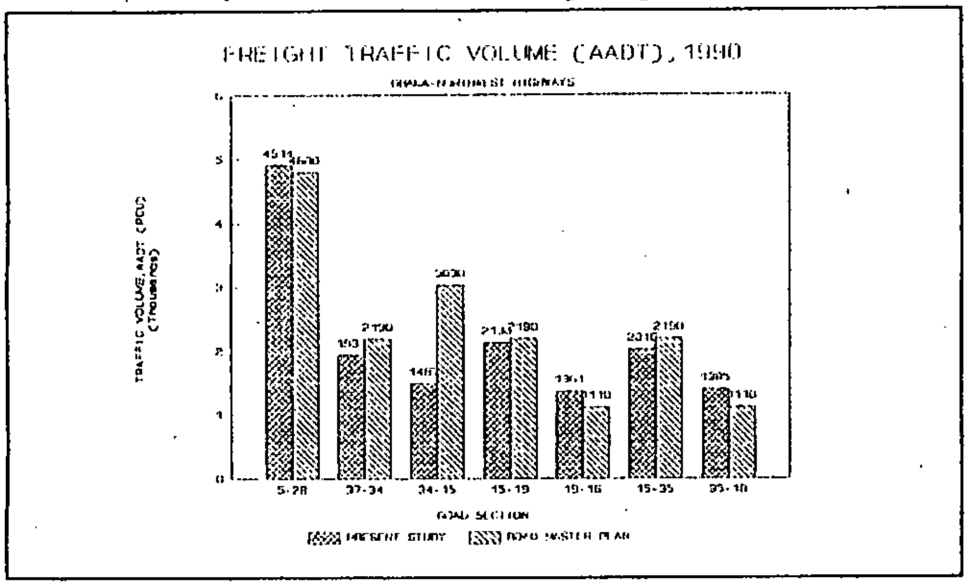
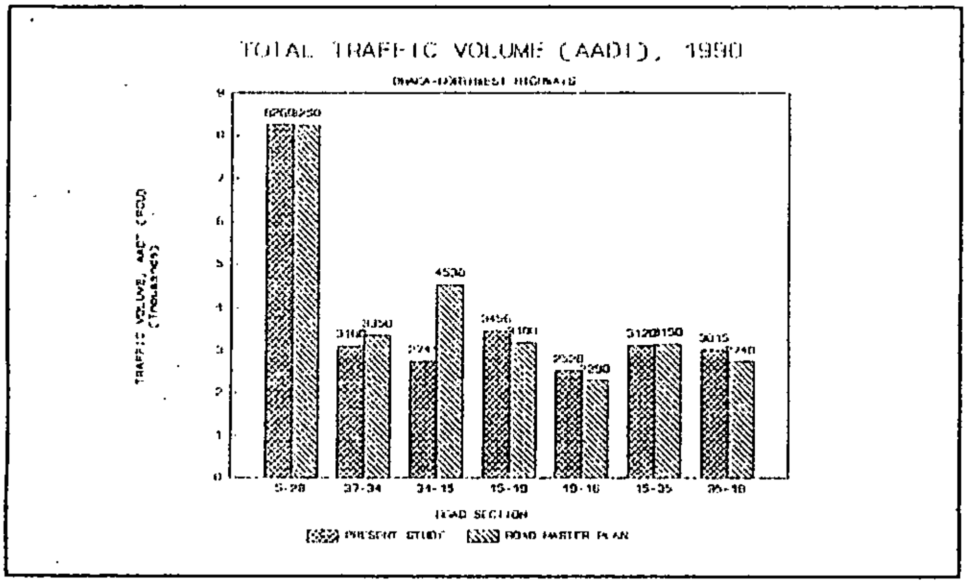


Figure C.8 Comparison of Traffic Volume (Dhaka-Nortwest highway)[a]



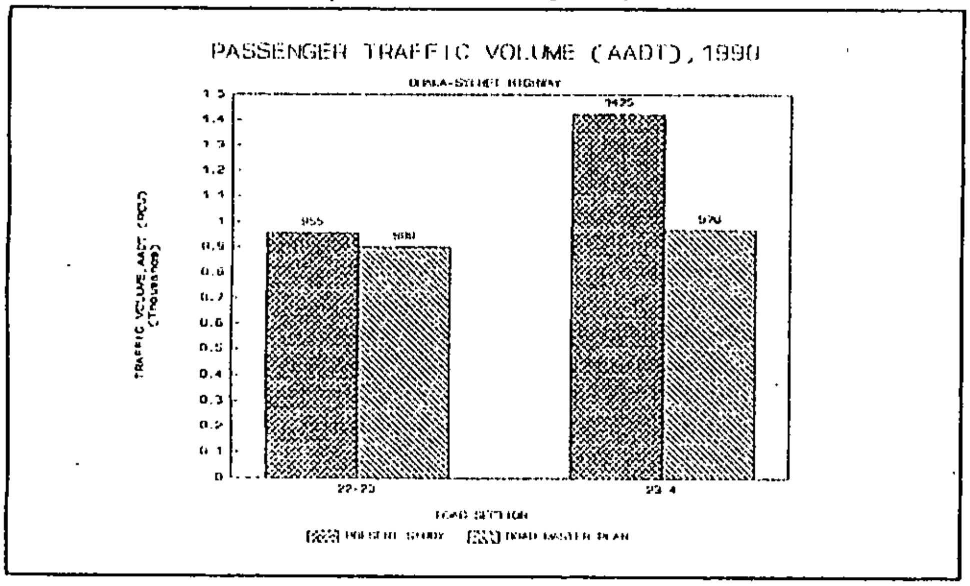
a. Link 5-28:Dhaka-Aricha
   Link 37-34:Kashinathpur-Hatikamrul
   Link 34-15:Hatikamrul-Bogra
   Link 15-19:Bogra-Rangpur
   Link 19-16:Rangpur-Dinajpur
   Link 15-35:Bogra-Natore
   Link 35-18:Natore-Rajshahi

Figure C.9 Comparison of Traffic Volume (Dhaka-Nortwest highway)[a]



a. Link 5-28:Dhaka-Aricha
   Link 37-34:Kashinathpur-Hatikamrul
   Link 34-15:Hatikamrul-Bogra
   Link 15-19:Bogra-Rangpur
   Link 19-16:Rangpur-Dinajpur
   Link 15-35:Bogra-Natore
   Link 35-18:Natore-Rajshahi

Figure C.10 Comparison of Traffic Volume (Dhaka-Sylhet highway)[b]



b. Link 22-23:Bhairab-Sarail
   Link 23-4:Sarail-Sylhet

Figure C.11 Comparison of Traffic volume (Dhaka-Sylhet highway)[a]

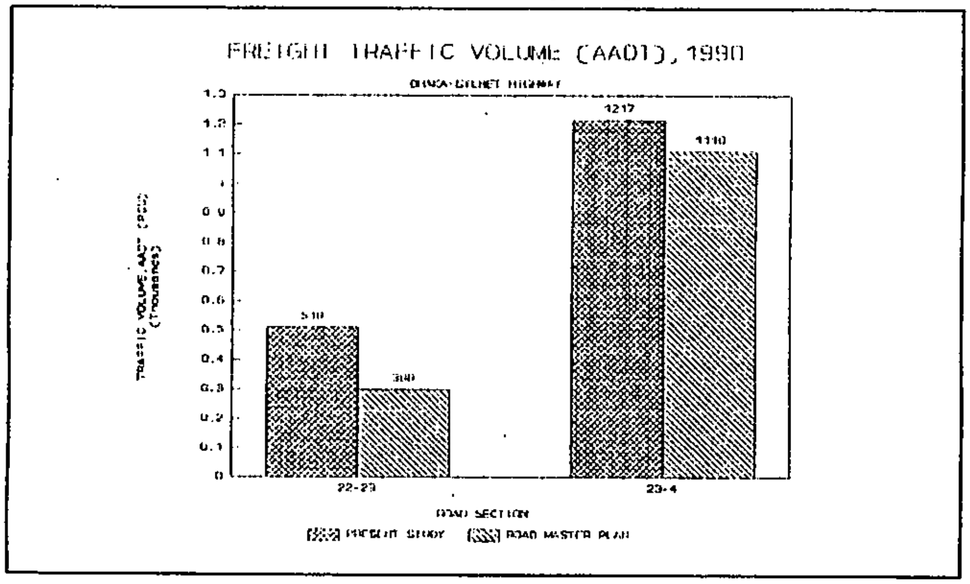
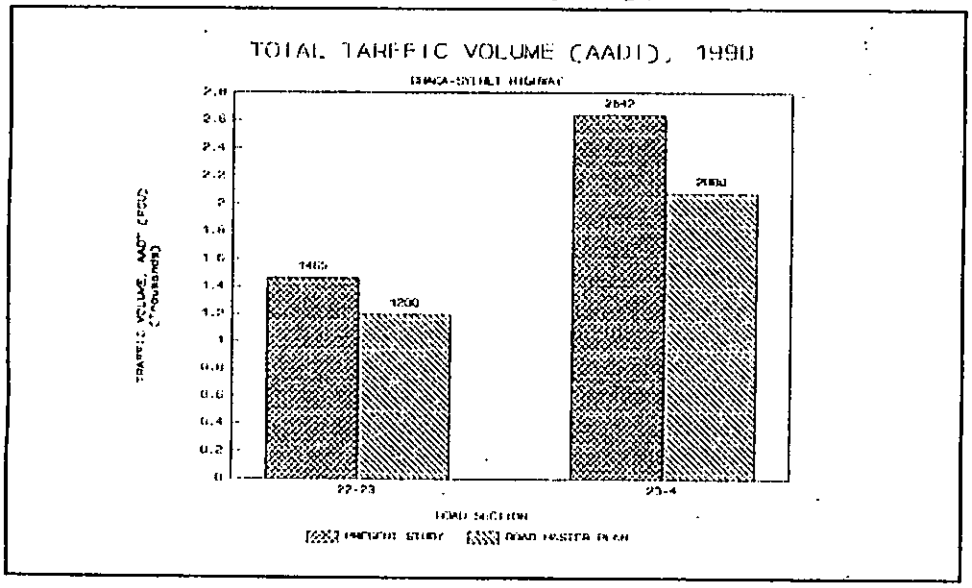


Figure C.12 Comparison of Traffic volume (Dhaka-Sylhet highway)[a]



a. Link 22-23:Bhairab-Sarail
Link 23-4:Sarail-Sylhet

Figure C.13 Comparison of Traffic Volume (Dhaka-Mymensingh Highway)[a]

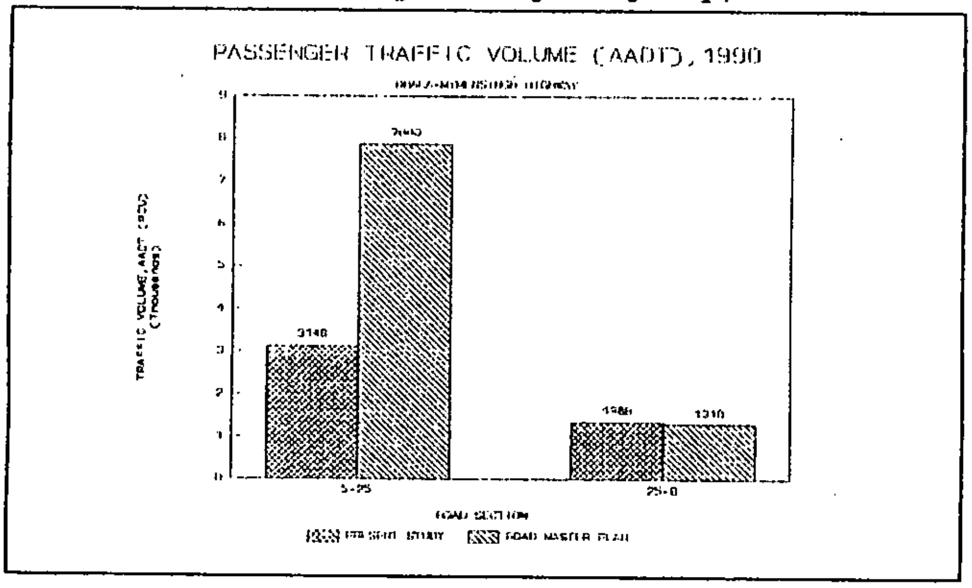
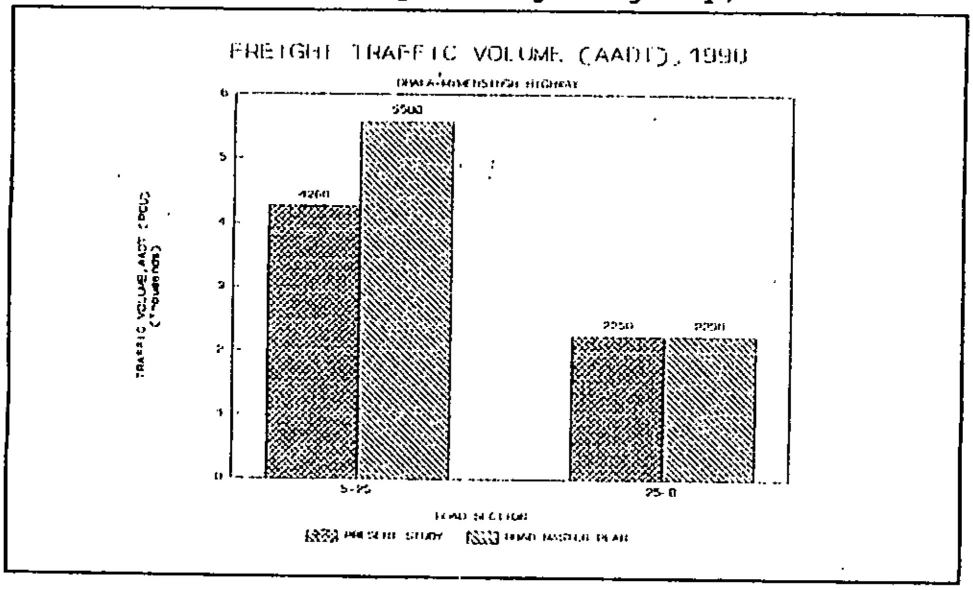
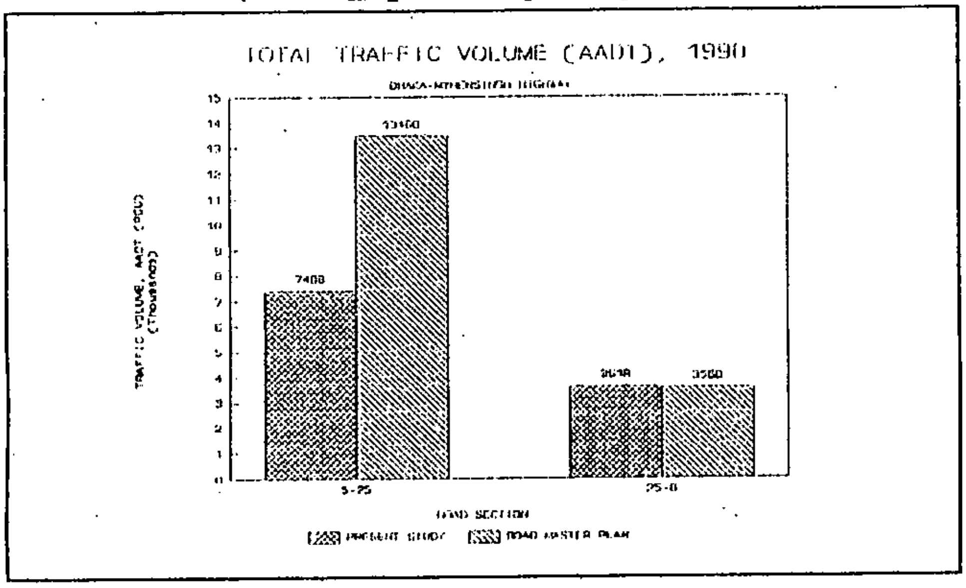


Figure C.14 Comparison of Traffic Volume (Dhaka-Mymensingh highway)[a]



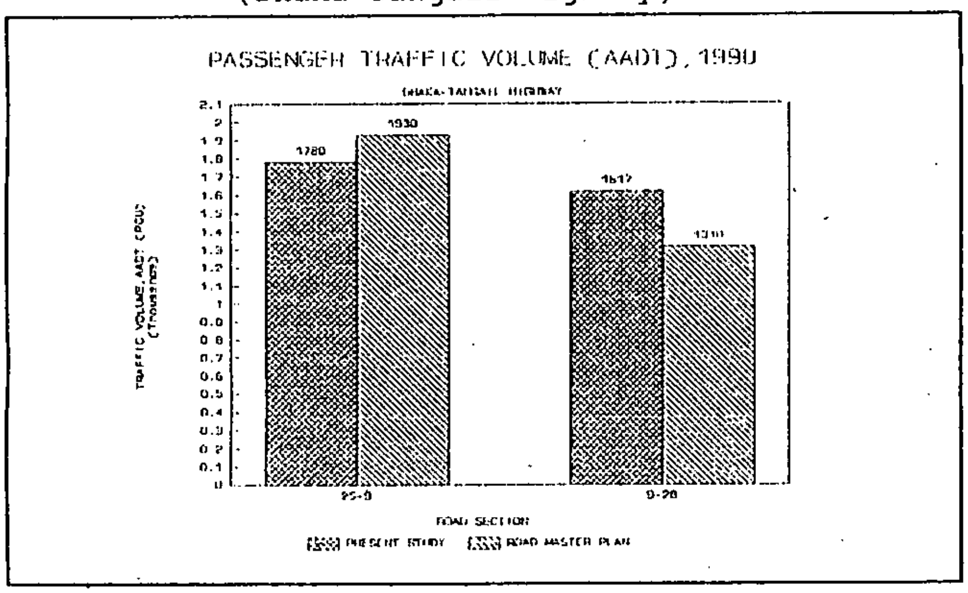
a. Link 5-25:Dhaka-Joydevpur
Link 25-8:Joydevpur-Mymensingh

Figure C.15 Comparison of Traffic Volume (Dhaka_Mymensingh highway)[a]



a. Link 5-25:Dhaka-Joydevpur
Link 25-8:Joydevpur-Mymensingh

Figure C.16 Comparison of Traffic Volume (Dhaka-Tangail highway)[b]



b. Link 25-9:Joydevpur-Tangail
Link 9-26:Tangail-Elenga

Figure C.17 Comparison of Traffic Volume (Dhaka-Tangail highway)[a]

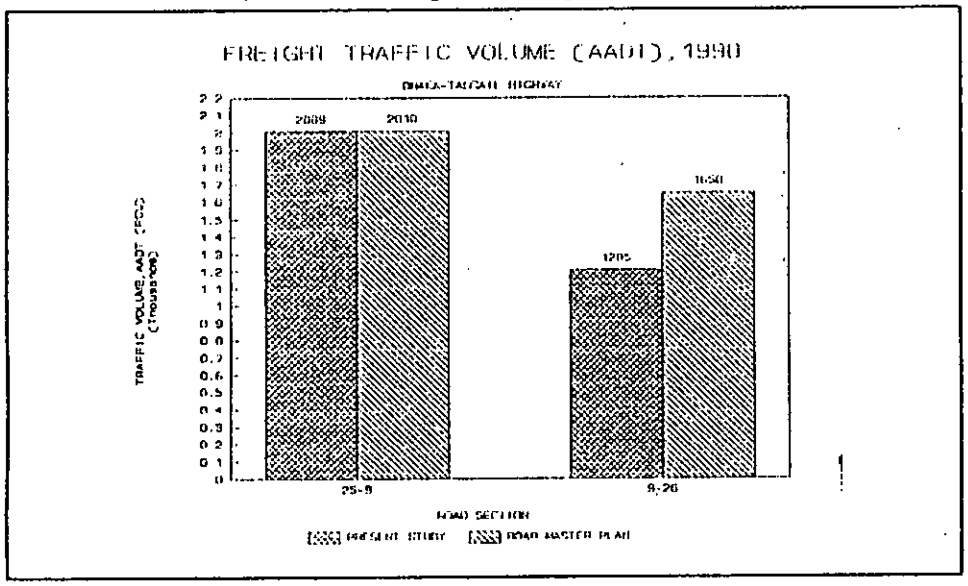
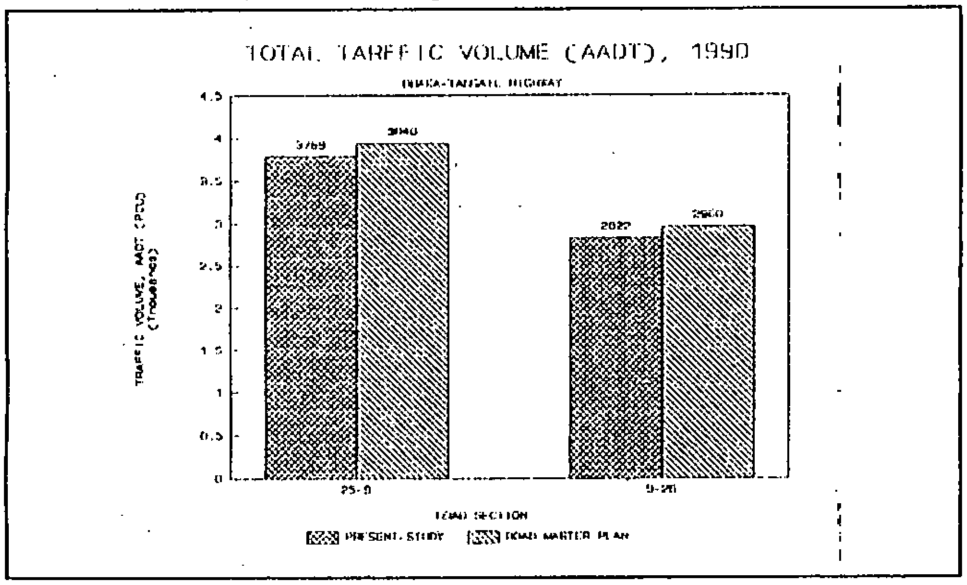


Figure C.18 Comparison of Traffic Volume (Dhaka-Tangail highway)[a]



a. Link 25-9:Joydevpur-Tangail
Link 9-26:Tangail-Elenga

Table C.1 Results of Calibration of Gravity Model

b_j (zonal correction factors) Values for 20 districts after Calibration of Gravity Model (Passenger movements)

Chittagong:	1.186775
Chittagong Hill Tracts:	0.854324
Comilla:	0.686657
Noakhali:	1.371084
Sylhet:	2.953246
Dhaka:	0.892701
Faridpur:	1.246937
Jamalpur:	1.593255
Mymensingh:	1.046865
Tangail:	0.816109
Barisal:	2.929699
Jessore:	0.569406
Khulna:	1.066793
Kushtia:	0.942806
Patuakhali:	1.897565
Bogra:	1.091377
Dinajpur:	2.534634
Pabna:	0.763561
Rajshahi:	1.239324
Rangpur:	0.892670

Table C.2 Results of Calibration of Gravity Model

b_j (zonal correction factors) Values for 20 Districts after Calibration of Gravity Model (Freight movements)

Chittagong:	2.469072
Chittagong Hill Tracts:	0.259721
Comilla:	0.413508
Noakhali:	0.702893
Sylhet:	2.588268
Dhaka:	1.116696
Faridpur:	1.738256
Jamalpur:	1.481896
Mymensingh:	0.756153
Tangail:	0.461700
Barisal:	3.172040
Jessore:	0.527990
Khulna:	1.216003
Kushtia:	0.692357
Patuakhali:	0.688916
Bogra:	1.346616
Dinajpur:	2.690704
Pabna:	0.868120
Rajshahi:	1.381994
Rangpur:	0.985814

Table C.3 R_{ij} Values for Passenger Movements between 20 Districts of Bangladesh.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0.000	0.158	0.041	0.087	0.005	0.013	0.002	0.002	0.008	0.008	0.003	0.002	0.001	0.004	0.002	0.004	0.002	0.007	0.001	0.003
1	0.158	0.000	0.024	0.024	0.007	0.011	0.004	0.004	0.006	0.006	0.002	0.003	0.002	0.003	0.002	0.003	0.002	0.004	0.003	0.002
2	0.041	0.024	0.000	0.119	0.026	0.089	0.004	0.011	0.004	0.003	0.005	0.005	0.002	0.006	0.003	0.007	0.004	0.018	0.006	0.005
3	0.087	0.024	0.119	0.000	0.003	0.012	0.007	0.007	0.011	0.010	0.003	0.004	0.002	0.004	0.003	0.005	0.003	0.009	0.004	0.003
4	0.005	0.007	0.026	0.003	0.000	0.021	0.005	0.006	0.011	0.007	0.003	0.003	0.003	0.003	0.002	0.004	0.002	0.004	0.003	0.003
5	0.013	0.011	0.089	0.012	0.021	0.000	0.041	0.037	0.085	0.059	0.006	0.006	0.013	0.017	0.004	0.016	0.005	0.016	0.015	0.026
6	0.002	0.004	0.004	0.007	0.005	0.042	0.000	0.007	0.012	0.012	0.034	0.088	0.015	0.077	0.016	0.016	0.006	0.015	0.008	0.009
7	0.002	0.004	0.011	0.007	0.006	0.037	0.007	0.000	0.092	0.087	0.003	0.005	0.004	0.007	0.003	0.014	0.006	0.011	0.007	0.008
8	0.008	0.006	0.004	0.011	0.011	0.085	0.012	0.092	0.000	0.087	0.005	0.007	0.005	0.007	0.003	0.012	0.005	0.010	0.007	0.007
9	0.008	0.006	0.003	0.010	0.007	0.059	0.012	0.087	0.087	0.000	0.005	0.002	0.001	0.010	0.004	0.109	0.007	0.105	0.010	0.011
10	0.003	0.002	0.005	0.003	0.003	0.006	0.034	0.003	0.005	0.005	0.000	0.025	0.015	0.012	0.138	0.006	0.003	0.008	0.006	0.004
11	0.002	0.003	0.005	0.004	0.003	0.006	0.088	0.005	0.007	0.002	0.025	0.000	0.289	0.158	0.035	0.022	0.008	0.083	0.027	0.012
12	0.001	0.002	0.002	0.002	0.003	0.013	0.015	0.004	0.005	0.001	0.015	0.289	0.000	0.019	0.017	0.015	0.012	0.039	0.026	0.011
13	0.004	0.003	0.006	0.004	0.003	0.017	0.077	0.007	0.007	0.010	0.012	0.158	0.019	0.000	0.008	0.054	0.009	0.097	0.163	0.021
14	0.002	0.002	0.003	0.003	0.002	0.004	0.016	0.003	0.003	0.004	0.138	0.033	0.017	0.008	0.000	0.004	0.002	0.005	0.005	0.003
15	0.004	0.003	0.007	0.005	0.004	0.016	0.016	0.014	0.012	0.109	0.006	0.022	0.015	0.054	0.004	0.000	0.039	0.074	0.045	0.046
16	0.002	0.002	0.004	0.003	0.002	0.005	0.006	0.006	0.005	0.007	0.003	0.008	0.012	0.009	0.002	0.039	0.000	0.013	0.013	0.136
17	0.007	0.004	0.018	0.009	0.004	0.016	0.015	0.011	0.010	0.105	0.008	0.082	0.039	0.096	0.005	0.073	0.013	0.000	0.032	0.033
18	0.001	0.003	0.006	0.004	0.003	0.015	0.008	0.007	0.007	0.010	0.006	0.027	0.026	0.163	0.005	0.045	0.013	0.032	0.000	0.062
19	0.003	0.002	0.005	0.003	0.003	0.026	0.009	0.008	0.007	0.011	0.004	0.012	0.011	0.021	0.003	0.046	0.136	0.033	0.061	0.000

Notes: 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna, 18- Rajshahi; 20- Rangpur.

Table C.4 R_{ij} Values for Freight Movements between 20 Districts of Bangladesh

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0.000	0.308	0.620	0.560	0.108	0.161	0.015	0.031	0.062	0.050	0.012	0.116	0.030	0.042	0.018	0.052	0.021	0.065	0.083	0.077
1	0.231	0.000	0.237	0.257	0.054	2.529	0.024	0.047	0.063	0.070	0.017	0.018	0.015	0.020	0.016	0.019	0.013	0.023	0.018	0.015
2	0.616	0.237	0.000	1.484	0.753	0.936	0.052	0.155	0.134	0.230	0.032	0.313	0.043	0.116	0.028	0.090	0.051	0.306	0.099	0.269
3	0.565	0.257	1.484	0.000	0.050	0.315	0.028	0.066	0.103	0.209	0.024	0.253	0.013	0.029	0.022	0.048	0.056	0.035	0.084	0.806
4	0.108	0.054	0.763	0.050	0.000	0.071	0.062	0.025	0.032	0.018	0.020	0.091	0.023	0.086	0.018	0.022	0.018	0.049	0.104	0.025
5	0.161	3.161	0.940	0.312	0.071	0.000	0.063	0.245	0.876	1.199	0.011	0.345	0.084	0.104	0.039	0.157	0.053	0.214	0.161	0.226
6	0.015	0.024	0.052	0.028	0.062	0.063	0.000	0.038	0.049	0.032	1.213	0.399	0.386	0.631	0.396	0.173	0.059	0.027	0.020	0.086
7	0.031	0.047	0.155	0.066	0.025	0.245	0.038	0.000	1.610	3.330	0.024	0.030	0.019	0.041	0.022	0.062	0.030	0.052	0.039	0.040
8	0.062	0.063	0.134	0.103	0.032	0.881	0.049	1.610	0.000	1.376	0.030	0.031	0.052	0.041	0.027	0.015	0.030	0.556	0.055	0.040
9	0.050	0.070	0.230	0.209	0.018	1.212	0.032	3.352	1.385	0.000	0.032	0.037	0.030	0.052	0.028	0.084	0.038	1.594	0.088	0.050
10	0.012	0.017	0.032	0.024	0.020	0.011	1.213	0.024	0.030	0.032	0.000	0.147	0.027	0.168	8.466	0.075	0.035	0.113	0.083	0.046
11	0.117	0.018	0.313	0.253	0.091	0.349	0.404	0.030	0.031	0.037	0.147	0.000	2.640	1.428	0.412	0.090	0.158	0.080	0.154	0.140
12	0.030	0.015	0.050	0.013	0.023	0.085	0.386	0.019	0.052	0.030	0.027	2.621	0.000	0.537	0.095	0.287	0.097	0.234	0.186	0.627
13	0.042	0.020	0.116	0.029	0.086	0.104	0.631	0.041	0.041	0.052	0.168	1.418	0.537	0.000	0.129	1.111	0.597	2.239	0.048	0.498
14	0.018	0.016	0.028	0.022	0.018	0.039	0.396	0.022	0.027	0.028	8.466	0.412	0.095	0.129	0.000	0.063	0.031	0.091	0.069	0.040
15	0.052	0.019	0.090	0.048	0.022	0.157	0.173	0.062	0.015	0.084	0.075	0.087	0.285	1.106	0.063	0.000	0.178	0.196	0.714	0.196
16	0.021	0.013	0.051	0.056	0.018	0.053	0.059	0.030	0.030	0.038	0.035	0.154	0.096	0.588	0.031	0.176	0.000	0.177	0.259	0.387
17	0.066	0.023	0.306	0.035	0.049	0.218	0.027	0.052	0.562	1.604	0.113	0.078	0.238	2.268	0.091	0.197	0.182	0.000	0.203	0.192
18	0.083	0.018	0.099	0.084	0.104	0.161	0.020	0.039	0.055	0.088	0.083	0.149	0.186	0.047	0.069	0.714	0.263	0.203	0.000	0.292
19	0.078	0.015	0.269	0.806	0.025	0.228	0.086	0.040	0.030	0.050	0.046	0.140	0.634	0.513	0.040	0.196	0.394	0.191	0.304	0.000

Notes: 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna, 18- Rajshahi; 20- Rangpur.

Table C.5 Passenger Vehicle Trip Matrix, 1990 in PCU/day

0	294	264	1205	63	375	8	8	0	0	0	8	8	0	0	0	0	34	7	0
294	0	0	0	10	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0
264	0	0	0	131	983	7	0	7	7	0	7	7	0	0	0	0	34	13	0
1205	0	0	0	31	280	0	0	0	0	0	0	19	0	0	0	0	37	0	0
63	10	131	31	0	478	0	0	0	0	0	0	0	0	0	0	0	0	0	0
375	34	983	280	478	0	337	240	669	635	70	43	206	114	16	171	73	136	170	140
8	0	7	0	0	337	0	0	0	0	68	98	40	0	0	0	0	21	14	0
8	0	0	0	0	240	0	0	0	118	0	0	0	0	0	0	0	0	0	0
0	0	7	0	0	669	0	0	0	0	0	8	0	0	0	0	0	0	0	0
0	0	7	0	0	635	0	118	0	0	0	3	5	0	0	245	0	190	0	0
0	0	0	0	0	70	68	0	0	0	0	43	61	0	147	0	0	0	0	0
8	0	7	0	0	43	98	0	8	3	43	0	644	143	20	0	0	96	0	0
8	0	7	19	0	206	40	0	0	5	61	644	0	40	24	50	64	107	94	20
0	0	0	0	0	114	0	0	0	0	0	143	40	0	0	0	0	107	235	0
0	0	0	0	0	16	0	0	0	0	147	20	24	0	0	0	0	0	0	0
0	0	0	0	0	171	0	0	0	245	0	0	50	0	0	0	133	131	105	51
0	0	0	0	0	73	0	0	0	0	0	0	64	0	0	133	0	35	46	233
34	0	34	37	0	136	21	0	0	190	0	96	107	107	0	131	35	0	59	29
7	0	13	0	0	170	14	0	0	0	0	0	94	235	0	105	46	59	0	72
0	0	0	0	0	140	0	0	0	0	0	0	20	0	0	51	233	29	72	0

Note: Sums of trips of 13th column and 13th row are 1389 PCU/day.

Table C.6 Link Traffic Volume for the trip matrix in Table C.5.

Origin	Destination	Traffic volume(PCU/day)
0	1	337
0	20	2024
1	0	337
2	20	1186
2	21	1883
2	23	235
3	20	1571
4	23	712
5	21	2361
5	25	1574
5	28	1673
5	29	0
6	10	302
6	33	0
6	38	743
6	39	626
7	8	0
7	26	365
8	7	0
8	24	0
8	25	684
8	26	0
9	25	890
9	26	808
10	6	302
10	14	206
10	33	0
11	12	1389
11	39	1214
12	11	1389
13	36	930
13	39	657
14	10	206
15	19	662
15	34	628
15	35	552
16	19	583
17	36	897

Origin	Destination	Traffic Volume(PCU/day)
17	37	743
18	35	815
19	15	663
19	16	583
20	0	2024
20	2	1186
20	3	1571
21	2	1883
21	5	2361
21	22	477
22	21	477
22	23	477
22	24	0
23	2	235
23	4	712
23	22	477
24	8	0
24	22	0
25	5	1574
25	8	684
25	9	890
26	7	365
26	8	0
26	9	808
26	27	442
27	26	442
27	30	442
28	5	1673
28	31	929
28	32	743
29	5	0
29	33	0
30	27	442
30	34	442
31	28	929
31	37	929
32	28	743
32	38	743
33	6	0
33	10	0
33	29	0

Origin	Destination	Traffic Volume(PCU/day)
34	15	628
34	30	442
34	37	581
35	15	552
35	18	815
35	36	921
36	13	930
36	17	897
36	35	921
37	17	743
37	31	929
37	34	581
38	6	743
38	32	743
39	6	626
39	11	1214
39	13	657

APPENDIX-D

DATA FILES FOR THE JAMUNA BRIDGE

Table D.1 JAMUNA.BUS

(Bus trip matrix[a] for the old 20 districts[b] of Bangladesh considering Jamuna bridge)
Year: 1990

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	55	65	240	5	95	1	1	0	0	0	1	1	0	0	0	0	13	2	0
1	55	0	0	0	2	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	65	0	0	0	26	221	1	0	1	1	0	1	1	0	0	0	0	10	3	0
3	240	0	0	0	8	70	0	0	0	0	0	0	4	0	0	0	0	10	0	0
4	5	2	26	8	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	95	7	221	70	60	0	40	23	109	90	22	10	65	30	4	49	34	13	56	58
6	1	0	1	0	0	40	0	0	0	0	20	27	11	0	0	0	0	5	3	0
7	1	0	0	0	0	23	0	0	0	24	0	0	0	0	0	0	0	0	0	0
8	0	0	1	0	0	109	0	0	0	0	0	1	0	0	0	0	0	0	0	0
9	0	0	1	0	0	90	0	24	0	0	0	0	1	0	0	0	0	0	0	0
10	0	0	0	0	0	22	20	0	0	0	0	12	18	0	45	0	0	0	0	0
11	1	0	1	0	0	10	27	0	1	0	12	0	130	25	4	0	0	6	0	0
12	1	0	1	4	0	65	11	0	0	1	18	130	0	8	6	15	20	15	13	4
13	0	0	0	0	0	30	0	0	0	0	0	25	8	0	0	0	0	15	10	0
14	0	0	0	0	0	4	0	0	0	0	45	4	6	0	0	0	0	0	0	0
15	0	0	0	0	0	49	0	0	0	0	0	0	15	0	0	0	40	30	14	10
16	0	0	0	0	0	34	0	0	0	0	0	0	20	0	0	40	0	10	10	30
17	13	0	10	10	0	13	5	0	0	0	0	6	15	15	0	30	10	0	7	4
18	2	0	3	0	0	56	3	0	0	0	0	0	13	10	0	14	10	7	0	3
19	0	0	0	0	0	58	0	0	0	0	0	0	4	0	0	10	30	4	3	0

a. Generated traffic for the Jamuna bridge included (ref. Chapter 7).

b. 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Table D.2 JAMUNA.MBS

(Minibus trip matrix[a] for old 20 districts[b] of Bangladesh considering Jamuna bridge)
Year: 1990

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	31	13	85	15	10	1	1	0	0	0	1	1	0	0	0	0	1	1	0
1	31	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	13	0	0	0	1	65	1	0	1	1	0	1	1	0	0	0	0	1	1	0
3	85	0	0	0	1	20	0	0	0	0	0	0	2	0	0	0	0	2	0	0
4	15	1	1	1	0	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	10	3	65	20	95	0	55	53	80	90	1	1	1	1	1	47	4	25	30	13
6	1	0	1	0	0	55	0	0	0	0	1	1	1	0	0	0	0	1	1	0
7	1	0	0	0	0	53	0	0	0	11	0	0	0	0	0	0	0	0	0	0
8	0	0	1	0	0	80	0	0	0	0	0	1	0	0	0	0	0	0	0	0
9	0	0	1	0	0	90	0	11	0	0	0	1	0	0	0	45	0	30	0	0
10	0	0	0	0	0	1	1	0	0	0	0	1	1	0	3	0	0	0	0	0
11	1	0	1	0	0	1	1	0	1	1	1	0	58	14	2	0	0	25	0	0
12	1	0	1	2	0	1	1	0	0	0	1	58	0	2	1	1	1	20	10	2
13	0	0	0	0	0	1	0	0	0	0	0	14	2	0	0	0	0	20	60	0
14	0	0	0	0	0	1	0	0	0	0	3	2	1	0	0	0	0	0	0	0
15	0	0	0	0	0	47	0	0	0	45	0	0	1	0	0	0	3	10	5	1
16	0	0	0	0	0	4	0	0	0	0	0	0	1	0	0	3	0	1	5	35
17	1	0	1	2	0	25	1	0	0	30	0	25	20	20	0	10	1	0	12	4
18	1	0	1	0	0	30	1	0	0	0	0	0	10	60	0	5	5	12	0	20
19	0	0	0	0	0	13	0	0	0	0	0	0	2	0	0	1	35	4	20	0

a. Generated traffic for the Jamuna bridge included (ref. Chapter 7).

b. 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Table D.3 JAMUNA.LMV

(Light vehicle trip matrix[a] for 20 districts[b] of Bangladesh considering Jamuna bridge)
Year: 1990

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	36	30	230	3	60	2	2	0	0	0	2	2	0	0	0	0	1	1	0
1	36	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	30	0	0	0	50	125	1	0	1	1	0	1	1	0	0	0	0	1	1	0
3	230	0	0	0	4	10	0	0	0	0	0	0	1	0	0	0	0	1	0	0
4	3	1	50	4	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	60	4	125	10	13	0	52	12	102	95	1	10	8	21	1	52	5	22	15	27
6	2	0	1	0	0	52	0	0	0	0	5	14	4	0	0	0	0	3	2	0
7	2	0	0	0	0	12	0	0	0	13	0	0	0	0	0	0	0	0	0	0
8	0	0	1	0	0	102	0	0	0	0	0	2	0	0	0	0	0	0	0	0
9	0	0	1	0	0	95	0	13	0	0	0	0	2	0	0	50	0	10	0	0
10	0	0	0	0	0	1	5	0	0	0	0	4	4	0	3	0	0	0	0	0
11	2	0	1	0	0	10	14	0	2	0	4	0	80	26	2	0	0	3	0	0
12	2	0	1	1	0	8	4	0	0	2	4	80	0	10	3	2	1	2	25	2
13	0	0	0	0	0	21	0	0	0	0	0	26	10	0	0	0	0	2	25	0
14	0	0	0	0	0	1	0	0	0	0	3	2	3	0	0	0	0	0	0	0
15	0	0	0	0	0	52	0	0	0	50	0	0	2	0	0	0	4	11	48	18
16	0	0	0	0	0	5	0	0	0	0	0	0	1	0	0	4	0	2	1	38
17	1	0	1	1	0	22	3	0	0	10	0	3	2	2	0	11	2	0	2	5
18	1	0	1	0	0	15	2	0	0	0	0	0	25	25	0	48	1	2	0	3
19	0	0	0	0	0	27	0	0	0	0	0	0	2	0	0	18	38	5	3	0

a. Generated traffic for the Jamuna bridge-included (ref. Chapter 7).

b. 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Table D.4 **JAMUNA.TRK**

(Truck trip matrix[a] for old 20 districts[b] of Bangladesh considering Jamuna bridge)

Year: 1990

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0	0	2	125	198	89	535	7	7	34	16	6	45	31	17	0	32	19	25	40	20
1	2	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	125	0	0	0	26	129	0	0	3	3	0	5	2	2	0	2	2	4	2	3
3	198	0	0	0	3	75	1	1	4	5	0	7	1	1	0	2	4	0	3	1
4	89	0	26	3	0	40	5	1	3	1	0	6	4	6	0	2	3	4	9	1
5	535	14	129	75	40	0	20	38	328	263	4	91	60	29	0	81	39	59	63	47
6	7	0	0	1	5	20	0	0	0	1	60	15	39	25	0	0	0	0	0	0
7	7	0	0	1	1	38	0	0	0	50	0	0	1	0	0	0	0	0	0	0
8	34	0	3	4	3	328	0	0	0	50	0	0	6	0	0	1	0	21	3	1
9	16	0	3	5	1	263	1	50	50	0	0	0	2	0	0	0	0	30	3	0
10	6	0	0	0	0	4	60	0	0	0	0	6	3	0	24	0	0	0	0	0
11	45	0	5	7	6	91	15	0	0	0	6	0	217	46	1	4	12	3	6	3
12	31	0	2	1	4	60	39	1	6	2	3	217	0	47	0	35	20	24	20	35
13	17	0	2	1	6	29	25	0	0	0	0	46	47	0	0	53	48	90	2	11
14	0	0	0	0	0	0	0	0	0	0	24	1	0	0	0	0	0	0	0	0
15	32	0	2	2	2	81	0	0	1	0	0	4	35	53	0	0	20	11	42	6
16	19	0	2	4	3	39	0	0	0	0	0	12	20	48	0	20	0	17	26	20
17	25	0	4	0	4	59	0	0	21	30	0	3	24	90	0	11	17	0	10	5
18	40	0	2	3	9	63	0	0	3	3	0	6	20	2	0	42	26	10	0	8
19	20	0	3	1	1	47	0	0	1	0	0	3	35	11	0	6	20	5	8	0

a. Generated traffic for the Jamuna bridge included (ref. Chapter 7).

b. 0- Chittagong; 1- Ctg. Hill Tracts; 2- Comilla; 3- Noakhali; 4- Sylhet; 5- Dhaka; 6- Faridpur; 7- Jamalpur; 8- Mymensingh; 9- Tangail; 10- Barisal; 11- Jessore; 12- Khulna; 13- Kushtia; 14- Patuakhali; 15- Bogra; 16- Dinajpur; 17- Pabna; 18- Rajshahi; 19- Rangpur.

Table D.5 JAMNET_P.DAT[a]

(Network description for Passenger vehicles considering Jamuna bridge)

```
108
16 19 81 5934 35.47
19 15 114 5934 45.00
15 35 72 5934 38.92
15 34 60 5934 46.75
18 35 49 5934 39.73
35 42 17 5934 40.80
36 42 17 5934 40.80
30 34 20 5934 21.82
34 37 55 5934 50.00
17 36 26 5934 33.91
17 37 47 5934 42.73
31 37 6 5934 51.43
13 36 32 5934 21.82
13 39 52 5934 43.33
6 39 83 5934 37.16
6 38 20 5934 41.38
32 38 10 5934 50.00
11 39 45 5934 39.13
11 12 61 5934 37.35
6 33 52 5934 26.22
6 10 144 5934 26.42
10 33 132 5934 24.91
10 14 40 5934 17.14
27 30 1 4154 0.31
28 31 1 5934 0.20
28 32 1 5934 0.37
29 33 1 3560 0.20
26 27 22 5934 25.38
26 41 17 5934 48.57
41 40 8 5934 48.00
40 30 6 5934 30.00
40 34 16 5934 48.00
34 42 60 5934 37.50
5 28 88 5934 36.16
5 29 40 5934 16.00
5 25 34 5934 26.84
5 21 14 5934 17.87
8 25 88 5934 43.64
9 25 64 5934 30.97
9 26 15 5934 30.00
8 26 82 5934 30.37
7 26 79 5934 37.03
7 8 91 5934 29.35
8 24 69 5934 27.97
```

a. See notes.

Table D.5 Continued....

22	24	57	5934	36.52
21	22	79	5934	37.92
2	21	83	5934	30.18
22	23	14	5934	14.74
4	23	171	5934	40.23
2	23	86	5934	38.80
2	20	54	5934	40.50
0	20	107	5934	41.96
3	20	42	5934	30.36
0	1	76	5934	32.81
19	16	81	5934	35.47
15	19	114	5934	45.00
35	15	72	5934	38.92
34	15	60	5934	46.75
35	18	49	5934	39.73
42	35	17	5934	40.80
42	36	17	5934	40.80
34	30	20	5934	21.82
37	34	55	5934	50.00
36	17	26	5934	33.91
37	17	47	5934	42.73
37	31	6	5934	51.43
36	13	32	5934	21.82
39	13	52	5934	43.33
39	6	83	5934	37.16
38	6	20	5934	41.38
38	32	10	5934	50.00
39	11	45	5934	39.13
12	11	61	5934	37.35
33	6	52	5934	26.22
10	6	144	5934	26.42
33	10	132	5934	24.91
14	10	40	5934	17.14
30	27	1	4154	0.31
31	28	1	5934	0.20
32	28	1	5934	0.37
33	29	1	3560	0.20
27	26	22	5934	25.38
41	26	17	5934	48.57
40	41	8	5934	48.00
30	40	6	5934	30.00
34	40	16	5934	48.00
42	34	60	5934	37.50
28	5	88	5934	36.16
29	5	40	5934	16.00
25	5	34	5934	26.84
21	5	14	5934	17.87
25	8	88	5934	43.64
25	9	64	5934	30.97
26	9	15	5934	30.00
26	8	82	5934	30.37

Table D.5 Continued...

26	7	79	5934	37.03
8	7	91	5934	29.35
24	8	69	5934	27.97
24	22	57	5934	36.52
22	21	79	5934	37.92
21	2	83	5934	30.18
23	22	14	5934	14.74
23	4	171	5934	40.23
23	2	86	5934	38.80
20	2	54	5934	40.50
20	0	107	5934	41.96
20	3	42	5934	30.36
1	0	76	5934	32.81

Notes: Each row (except first row) of Table D.5 contains five elements. The elements are 'from node', 'to node', 'link length (km)', 'link capacity (PCU/day)' and ' link average speed (km/h)'.
First row contains number of data items i.e. number of rows.

Table D.6 **JAMNET_F.DAT**[a]

(Network description for freight movements considering Jamuna bridge)

```
108
16 19 81 5676 18.00
19 15 114 5676 18.00
15 35 72 5676 18.00
15 34 60 5676 18.00
18 35 49 5676 18.00
35 42 17 5676 18.00
36 42 17 5676 18.00
30 34 20 5676 18.00
34 37 55 5676 18.00
17 36 26 5676 18.00
17 37 47 5676 18.00
31 37 6 5676 18.00
13 36 32 5676 18.00
13 39 52 5676 18.00
6 39 83 5676 18.00
6 38 20 5676 18.00
32 38 10 5676 18.00
11 39 45 5676 18.00
11 12 61 5676 18.00
6 33 52 5676 18.00
6 10 144 5676 18.00
10 33 132 5676 18.00
10 14 40 5676 18.00
27 30 1 3975 0.015
28 31 1 5676 0.015
28 32 1 5676 18.00
29 33 1 3410 0.01
26 27 22 5676 18.00
26 41 17 5676 18.00
41 40 8 5676 18.00
40 30 6 5676 18.00
40 34 16 5676 18.00
34 42 60 5676 18.00
5 28 88 5676 18.00
5 29 40 5676 18.00
5 25 34 5676 18.00
5 21 14 5676 18.00
8 25 88 5676 18.00
9 25 64 5676 18.00
9 26 15 5676 18.00
8 26 82 5676 18.00
7 26 79 5676 18.00
7 8 91 5676 18.00
8 24 69 5676 18.00
```

---

a. See notes.

Table D.6 Continued...

22	24	57	5676	18.00
21	22	79	5676	18.00
2	21	83	5676	18.00
22	23	14	5676	18.00
4	23	171	5676	18.00
2	23	86	5676	18.00
2	20	54	5676	18.00
0	20	107	5676	18.00
3	20	42	5676	18.00
0	1	76	5676	18.00
19	16	81	5676	18.00
15	19	114	5676	18.00
35	15	72	5676	18.00
34	15	60	5676	18.00
35	18	49	5676	18.00
42	35	17	5676	18.00
42	36	17	5676	18.00
34	30	20	5676	18.00
37	34	55	5676	18.00
36	17	26	5676	18.00
37	17	47	5676	18.00
37	31	6	5676	18.00
36	13	32	5676	18.00
39	13	52	5676	18.00
39	6	83	5676	18.00
38	6	20	5676	18.00
38	32	10	5676	18.00
39	11	45	5676	18.00
12	11	61	5676	18.00
33	6	52	5676	18.00
10	6	144	5676	18.00
33	10	132	5676	18.00
14	10	40	5676	18.00
30	27	1	3975	0.015
31	28	1	5676	0.015
32	28	1	5676	18.00
33	29	1	3410	0.01
27	26	22	5676	18.00
41	26	17	5676	18.00
40	41	8	5676	18.00
30	40	6	5676	18.00
34	40	16	5676	18.00
42	34	60	5676	18.00
28	5	88	5676	18.00
29	5	40	5676	18.00
25	5	34	5676	18.00
21	5	14	5676	18.00
25	8	88	5676	18.00
25	9	64	5676	18.00
26	9	15	5676	18.00
26	8	82	5676	18.00

Table D.6 Continued...

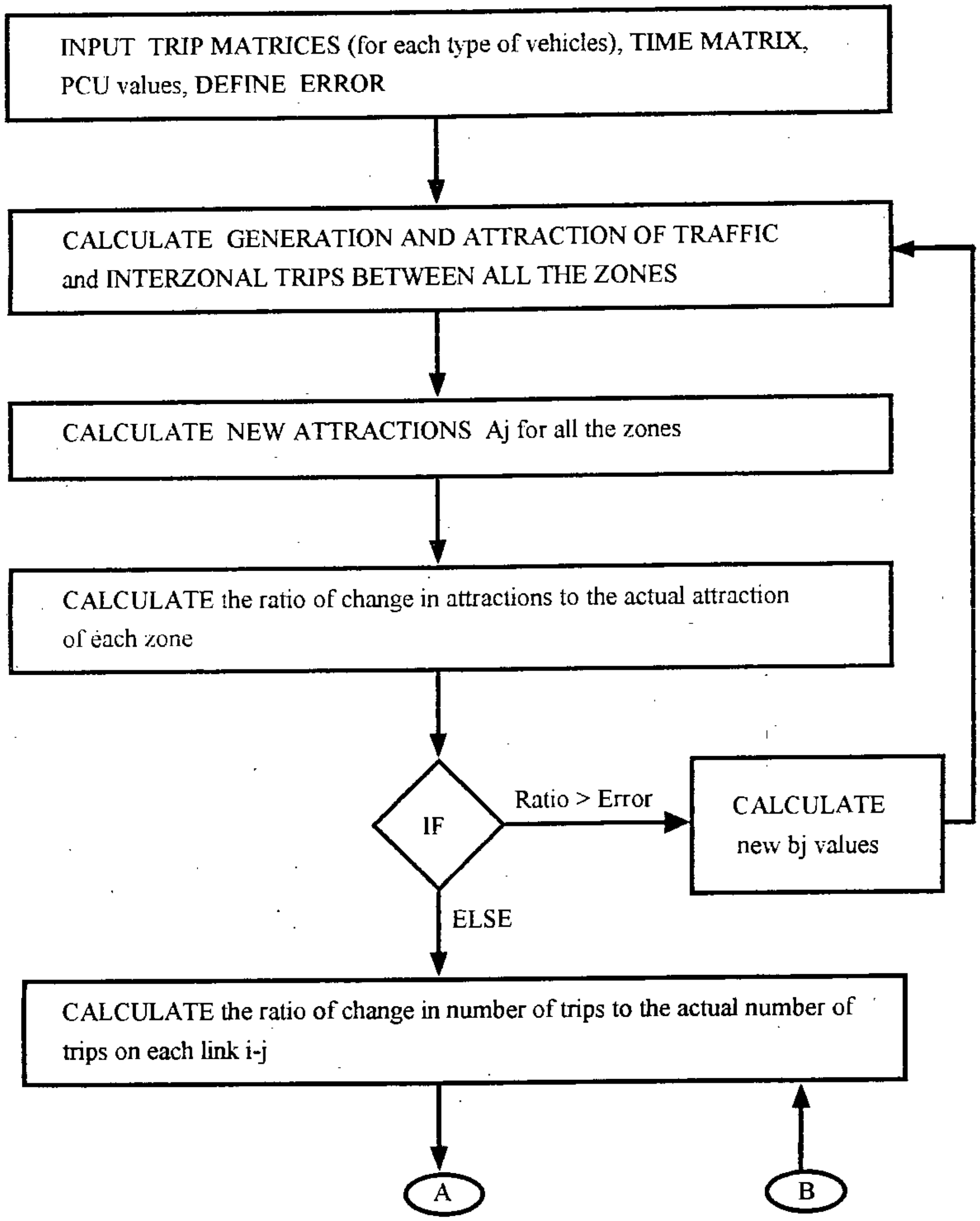
26	7	79	5676	18.00
8	7	91	5676	18.00
24	8	69	5676	18.00
24	22	57	5676	18.00
22	21	79	5676	18.00
21	2	83	5676	18.00
23	22	14	5676	18.00
23	4	171	5676	18.00
23	2	86	5676	18.00
20	2	54	5676	18.00
20	0	107	5676	18.00
20	3	42	5676	18.00
1	0	76	5676	18.00

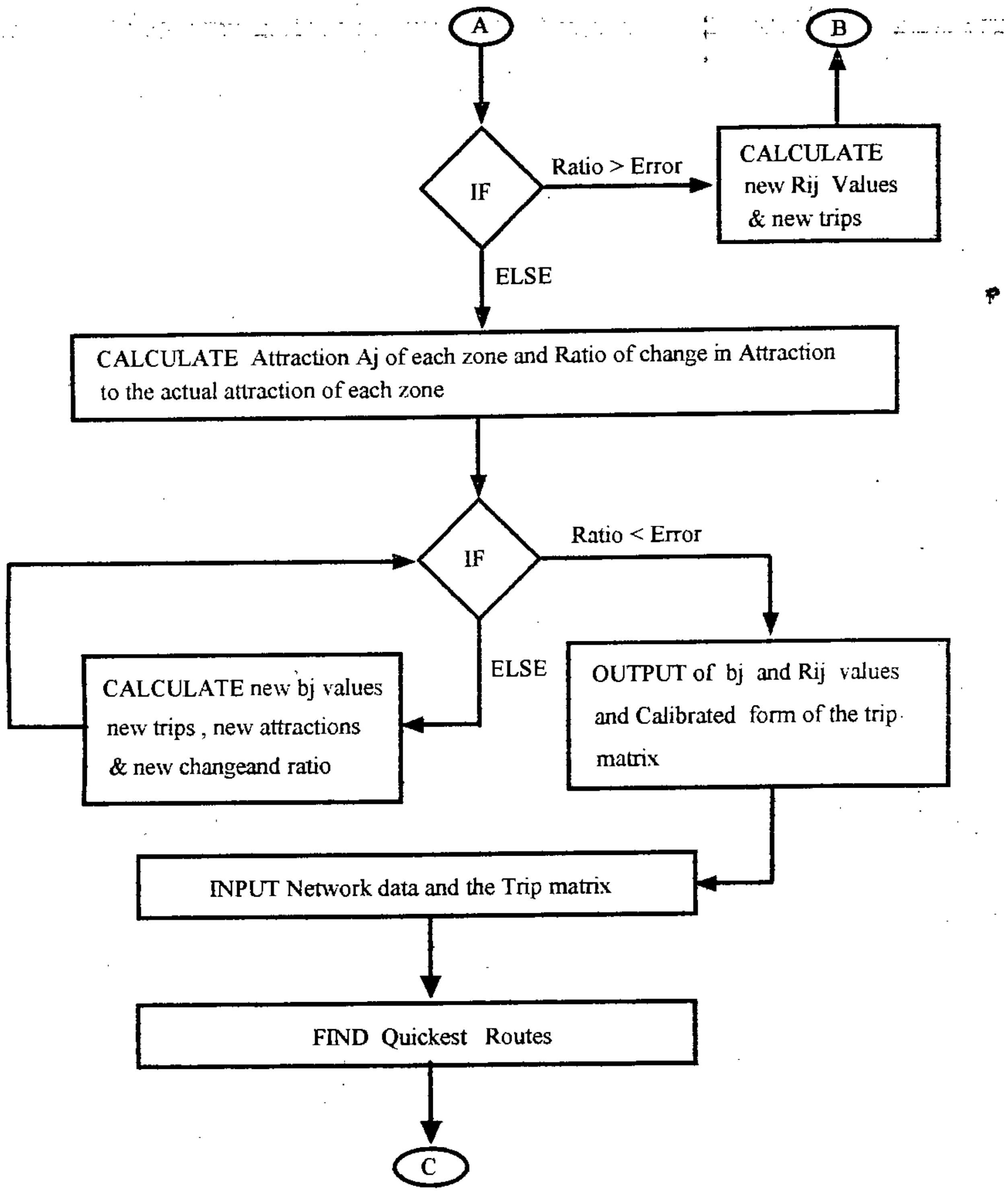
Notes: Each row (except first row) of Table D.5 contains five elements. The elements are 'from node', 'to node', 'link length (km)', 'link capacity (PCU/day)' and ' link average speed (km/h)'.
First row contains number of data items i.e. number of rows.

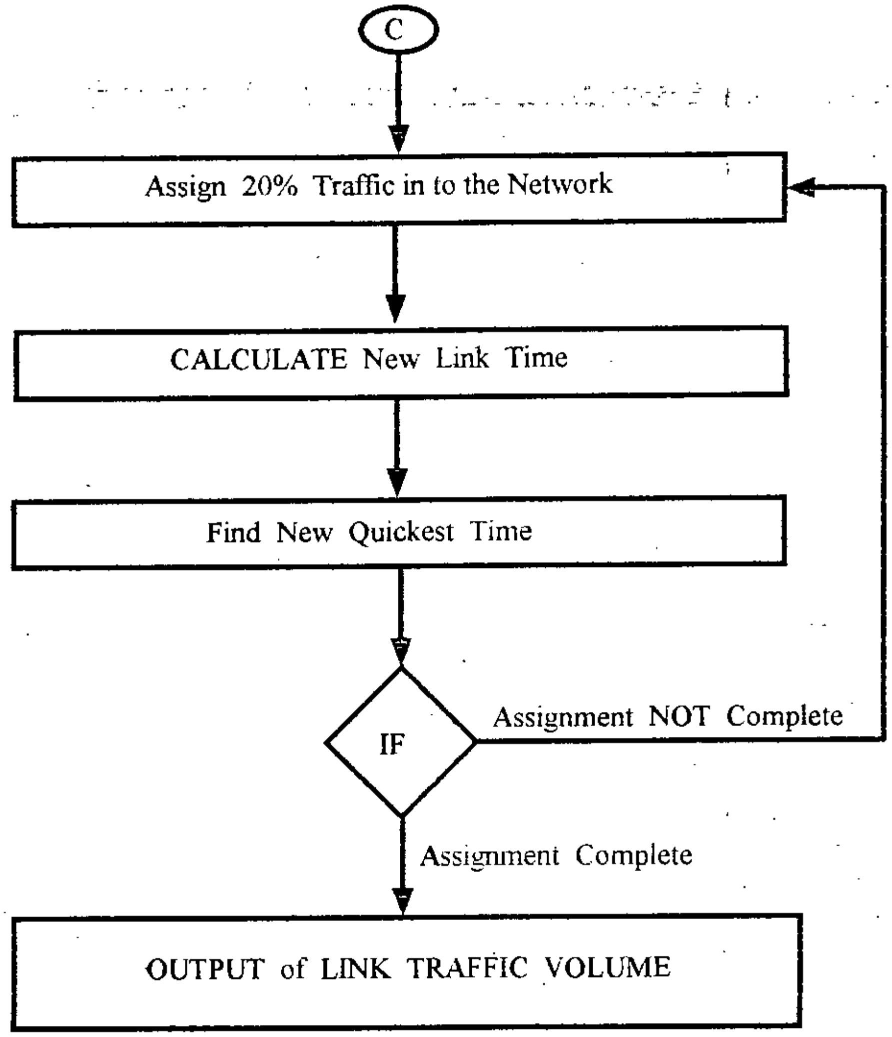
APPENDIX-E

FLOW CHART, CALIBRATION TECHNIQUE & LISTING OF THE COMPUTER PROGRAM

FLOW CHART


INPUT TRIP MATRICES (for each type of vehicles), TIME MATRIX, PCU values, DEFINE ERROR
CALCULATE GENERATION AND ATTRACTION OF TRAFFIC and INTERZONAL TRIPS BETWEEN ALL THE ZONES
CALCULATE NEW ATTRACTIONS Aj for all the zones
CALCULATE the ratio of change in attractions to the actual attraction of each zone
IF
Ratio > Error
CALCULATE new bj values
ELSE
CALCULATE the ratio of change in number of trips to the actual number of trips on each link i-j
A
B


A
B
IF
Ratio > Error
CALCULATE
new Rij Values
& new trips
ELSE
CALCULATE Attraction Aj of each zone and Ratio of change in Attraction
to the actual attraction of each zone
IF
Ratio < Error
ELSE
CALCULATE new bj values
new trips , new attractions
& new changeand ratio
OUTPUT of bj and Rij values
and Calibrated form of the trip
matrix
INPUT Network data and the Trip matrix
FIND Quickest Routes
C


C
Assign 20% Traffic in to the Network
CALCULATE New Link Time
Find New Quickest Time
IF
Assignment NOT Complete
Assignment Complete
OUTPUT of LINK TRAFFIC VOLUME

Calibration of Gravity Model

Let us consider a hypothetical 4 zone city, 2 zones of which are strictly residential and the other 2 of which are strictly commercial (shopping). The present (base year) interzonal trip matrix and time matrix are as follows:

Trip matrix

	1	2	3	4
1	0	0	200	300
2	0	0	100	500
3	0	0	0	0
4	0	0	0	0

Time matrix

	1	2	3	4
1	0	8	5	10
2	20	0	10	5
3	5	10	0	20
4	10	5	20	0

So,

$$P_1=T_{11}+T_{12}+T_{13}+T_{14}=0+0+200+300=500$$
$$P_2=T_{21}+T_{22}+T_{23}+T_{24}=0+0+100+500=600$$
$$P_3=T_{31}+T_{32}+T_{33}+T_{34}=0+0+0+0=0$$
$$P_4=T_{41}+T_{42}+T_{43}+T_{44}=0+0+0+0=0$$

$$A_1=T_{11}+T_{21}+T_{31}+T_{41}=0+0+0+0=0$$
$$A_2=T_{12}+T_{22}+T_{32}+T_{42}=0+0+0+0=0$$
$$A_3=T_{13}+T_{23}+T_{33}+T_{43}=200+100+0+0=300$$
$$A_4=T_{14}+T_{24}+T_{34}+T_{44}=300+500+0+0=800$$

Now using Gravity model,

$$T_{13}=500\left[\frac{300(\frac{1}{5^2})}{300(\frac{1}{5^2})+800(\frac{1}{10^2})}\right] = 300 \quad trips$$

$$T_{14}=500\left[\frac{800(\frac{1}{10^2})}{300(\frac{1}{5^2})+800(\frac{1}{10^2})}\right] = 200 \quad trips$$

$$T_{23} = 600\left[\frac{300(\frac{1}{10^2})}{300(\frac{1}{10^2})+800(\frac{1}{5^2})}\right] = 51 \quad trips$$

$$T_{24} = 600\left[\frac{800(\frac{1}{5^2})}{300(\frac{1}{10^2})+800(\frac{1}{5^2})}\right] = 549 \quad trips$$

and $T_{11}=T_{12}=T_{21}=T_{22}=T_{31}=T_{32}=T_{33}=T_{34}=T_{41}=T_{42}=T_{43}=T_{44}=0$ trips since either corresponding P_i or $A_j = 0$. Let us define ERROR as 0.03. Comparing attractions we get, $A_3=T_{13}+T_{23} = 300+51= 351$ and $A_4=T_{14}+T_{24} = 200+549= 759$. So at this point,

Error for zone 3 = (351- 300)/300=0.17 > 0.03 and
Error for zone 4 = (800-749)/800=0.06 > 0.03.

and also,

T_{13}=300 trips > 200, T_{14}=200 trips < 300, T_{23}=51 trips < 100 and T_{24}=549 trips > 500.

Considering these values, it becomes obvious that the gravity model is not very reliable in reproducing present trip distribution in this example. The present feeling as to the cause of the two types of discrepancies brought out above is that: (1) the A_j's are not absolute measures of the attraction of trips to a zone, but instead are relative measures which could have different absolute magnitudes, and (2) travel time alone is not sufficient to give an indication of the 'friction' on travel caused by distance, so the R_{ij}'s, which supposedly represent the influence of 'friction', are only approximated by a term such as $1/t_{ij}^2$. [Dickey, 1975]

These two explanations necessitates the act for making changes in the A_j's and R_{ij}'s. The A_j's are changed first, then the R_{ij}'s, and this sequence is followed several times. Each separate use of gravity model with a new set of A_j's or R_{ij}'s is called an iteration. To start, let us modify the A_j's by using the equation given in Chapter 5 as follows:

$b_3^{(1)} = 300/(300+51) = 0.857$
$b_4^{(1)} = 800/(200+549) = 1.068$

Therefore,

$$T_{13}^{(1)} = 500\left[\frac{300(0.857)(\frac{1}{5^2})}{300(0.857)(\frac{1}{5^2})+800(1.068)(\frac{1}{10^2})}\right] = 273$$

and, through similar calculations, $T_{14}^{(1)}=227$, $T_{23}^{(1)}=42$, and $T_{24}^{(1)}=558$, with all other T_{ij}'s, as before, equal to 0. Consequently, in comparing A_j we get, $A_3=273+42=315$ and $A_4=227+558=785$ and the errors are

error for zone 3 = (315-300)/300 =0.05 and

error for zone 4 = (800-785)/800 =0.02, one of which is greater than the acceptable error 0.03. So another iteration will be required. The new correction coefficients, $b_j^{(2)}$, are as follows:

$b_3^{(2)} = 0.857 \ (300)/315 = 0.816$
$b_4^{(2)} = 1.068 \ (800)/785 = 1.088$

Using the gravity model, we find that, $T_{13}^{(2)}=265$, $T_{14}^{(2)}=235$, $T_{23}^{(2)}=39$, and $T_{24}^{(2)}=561$ which yield

$A_3=265+39=304$
$A_4=235+561=796$ and the errors are

error for zone 3 = (304-300)/300=0.01
error for zone 4 = (800-796)/800=0.005, both of which are less than the

acceptable limit of error (=0.03). So the modifications on A_j's can be stopped and the next step is to make changes on R_{ij}'s to match the trip frequency. At this stage, the interzonal trips are

T_{13} = 265 (actual value is 200)
T_{14} = 235 (actual value is 300)
T_{23} = 39 (actual value is 100)
T_{24} = 561 (actual value is 500)

So the modified R_{ij} values are:

$R_{13} = (1/52)(200/265) = 0.0302$

$R_{14} = (1/102)(300/235) = 0.0128$

$R_{23} = (1/102)(100/39) = 0.0256$

$R_{24} = (1/52)(500/561) = 0.0356$

Substituting these R_{ij} values and b_j values after 2nd iteration into the gravity model, we get

$T_{13} = 199$

$T_{14} = 301$

$T_{23} = 101$

$T_{24} = 499$

So, error on link 1-3 = (200-199)/200 = 0.005 < 0.03

error on link 1-4 = (301-300)/300 = 0.003 < 0.03

error on link 2-3 = (101-100)/100 = 0.01 < 0.03

error on link 2-4 = (500-499)/500 = 0.002 < 0.03

The attractions are,

$A_3 = 199+101 = 300$

$A_4 12 = 301+499 = 800$, both of which are exactly equal to the actual attraction of zones 3 and 4.

So, the final form of the gravity model after calibration appears as

$$T_{ij} = P_i \frac{A_j b_j R_{ij}}{\sum_{j=1}^{n} A_j b_j R_{ij}}$$

where b_j values are:

$b_1 = 0$, $b_2 = 0$, $b_3 = 0.816$, $b_4 = 1.088$

and R_{ij} values are:

$R_{13} = 0.0302$. $R_{14} = 0.0128$, $R_{23} = 0.0256$ and $R_{24} = 0.0356$.

/* LISTING OF COMPUTER PROGRAM*/

```
#include <stdio.h>
#include <conio.h>
#include <math.h>
#include <stdlib.h>

#define ERROR 0.01
#define ZONE 20
#define TRUE 1
#define FALSE 0
#define MAX_ITERATION 100
#define NO 43
typedef int boolean;

char network[20],filename[20],growth_file[20],file[20];
char tp[20],cal_tp[20],bb[20],ff[20];

int n=20;
int trip[ZONE+1][ZONE+1],    new_trip[ZONE+1][ZONE+1],
production[ZONE+1],    attraction[ZONE+1];
int new_attraction[ZONE+1],trip_exist[ZONE+1][ZONE+1];
int projected_new_attraction[ZONE+1],projected_production[ZONE+1],
   projected_attraction[ZONE+1];
int projected_trip[ZONE+1][ZONE+1];
float b[ZONE+1],  f[ZONE+1][ZONE+1],    time[ZONE+1][ZONE+1];
float b_projected[ZONE+1],f_reg[ZONE+1][ZONE+1];
int cost[ZONE+1][ZONE+1];
int pnn[NO],lc[NO][NO],qr[NO];
float lv[NO][NO],od[NO][NO];
float pnnt[NO],lt[NO][NO],lt0[NO][NO],ll[NO][NO],ls[NO][NO];
int node=43;
int i,j,k,nn;
float qrt;

FILE *projected_trip_file;

void get_input_of_trips();
void calculate_attractions();
void calculate_productions();
void get_input_of_times();
void get_input_of_cost();
void calculate_new_trips();
void calculate_new_attractions();
boolean attraction_change_is_acceptable();
boolean trip_change_is_acceptable();
void calculate_b_factors();
void calculate_f_factors();
```

```
void get_output_of_b_factors();
void get_output_of_f_factors();
void get_output_of_new_trips();
void calculate_projected_b_factors();
void calculate_projected_trips();
void calculate_projected_new_attractions();
void get_output_of_projected_trips();
void regression_time();
void regression_cost();
void prediction_of_trips();
boolean  projected_attraction_change_is_acceptable();
void get_output_of_f_reg();
void correlation();
void get_input_of_projected_attraction();
void get_input_of_projected_production();
void ROUTE(void);
void Q_ROUTE(void);
void N_EQU(void);
void OUT_P(void);
void L_TIME(void);
void INPUT(void);
void QR_FIND(void);
void NET_EQ(void);

main()
{
 int i,j,x,choice,okay=FALSE,outer_loop_count,inner_loop_count;
 int select,answer,like;
 float bu,m,l,t;
 char bus[20],minibus[20],light[20],tk[20];
 char pcu_pass[20],pcu_truck[20];
 int bs[21][21],  mbus[21][21],lmv[21][21],trk[21][21];
 int pcup[21][21],pcut[21][21];
FILE *bus_file,*minibus_file,*truck_file,*lmv_file,*pcup_file,
   *pcut_file;
FILE *old_f_file;
 clrscr();
 gotoxy(15,4);
 printf("\aTRANSPORT  MODELLING  FOR  PREDICTION  OF
FLOW_PATTERN\n");
 printf("    AND  VOLUME  OF  TRAFFIC  ON  THE  NATIONAL
HIGHWAY\n");
 printf("     NETWORK  OF BANGLADESH\n");
 printf("\n\n\n\n\n     Developed  by:\n");
 printf("           Tanweer  Hasan.\n");
 printf("           Roll#  9012102P\n");
 printf("           Session:  1988-'89\n");
 printf("\n\n\n          Under  the  supervision  of:\n");
```

```
 printf("\n          Dr. Alamgir  Mujibul  Hoque.\n");
 printf("           Professor,  Dept. of Civil Engg.\n");
 printf("           BUET, Dhaka.\n");
 printf("\n\n         Press  any KEY  to continue...");getch();
 clrscr();
 printf("\a\n<<   Conversion   of   Traffic   into   PCU   (passenger   car
equivalents)>>");
 printf("\n\nINPUT  FILE (BUS)? ");
 scanf("%s",bus);
 printf("\nINPUT  FILE (MINIBUS)?");
 scanf("%s",minibus);
 printf("\nINPUT  FILE (LIGHT  VEHICLE)?  ");
 scanf("%s",light);
 printf("\nINPUT  FILE (TRUCK)?  ");
 scanf("%s",tk);
 printf("\n\nThe  PCU Values  are:");
 printf("\nFor  Bus ? ");
 scanf("%f",&bu);
 printf("\nFor  Minibus  ? ");
 scanf("%f",&m);
 printf("\nFor  Light  Vehicles  ? ");
 scanf("%f",&l);
 printf("\nFor  Truck  ? ");
 scanf("%f",&t);
 printf("\n\aOUTPUT   FILE (passenger  vehicle  in PCU)? ");
 scanf("%s",pcu_pass);
 printf("\n\aOUTPUT   FILE (truck  in PCU) ? ");
 scanf("%s",pcu_truck);
 bus_file=fopen(bus,"r");
 minibus_file=fopen(minibus,"r");
 lmv_file=fopen(light,"r");
 truck_file=fopen(tk,"r");
 pcup_file=fopen(pcu_pass,"w");
 pcut_file=fopen(pcu_truck,"w");
 for(i=1;i<=n;++i)
   for(j=1;j<=n;++j){
     fscanf(bus_file,"%d",&bs[i][j]);
     fscanf(minibus_file,"%d",&mbus[i][j]);
     fscanf(lmv_file,"%d",&lmv[i][j]);
     fscanf(truck_file,"%d",&trk[i][j]);
     }
for(i=1;i<=n;++i)
for(j=1;j<=n;++j){
 pcup[i][j]=(int)(bs[i][j]*bu+mbus[i][j]*m+lmv[i][j]*l);
 pcut[i][j]=(int)(trk[i][j]*t);
}
 for(i=1;i<=n;++i){
    fprintf(pcup_file,"\n");
```

```
        for(j=1;j<=n;++j){
            fprintf(pcup_file," %5d",pcup[i][j]);
      }
  }
   for(i=1;i<=n;++i){
     fprintf(pcut_file,"\n");
       for(j=1;j<=n;++j){
               fprintf(pcut_file," %5d",pcut[i][j]);
  }
      }
  fcloseall();
   for(i=1;i<=n;++i)    production[i]=0.0;
   for(i=1;i<=n;++i)    attraction[i]=0.0;
   for(i=1;i<=n;++i)    new_attraction[i]=0.0;
   clrscr();
   printf("\aCALIBRATION    OF TRIP MATRIX  BEGINS....");
   printf("\n1.  Passenger  vehicle");
   printf("\n2.  Truck\n");
   printf("\n==   SELECT  ?  ");
   select=getche();
   switch(select){
   case '1':
   printf("\n\n\nINPUT   FILE (TRIP  MATRIX)?  ");
   scanf("%s",tp);
   printf("\nOUTPUT   FILE (CALIBRATED  TRIP MATRIX)  ?");
   scanf("%s",cal_tp);
   printf("\nOUTPUT   FILE ('b' factors for passenger  vehicle)?  ");
   scanf("%s",bb);
   printf("\nOUTPUT   FILE ('f' factors  for passenger  vehicle)?  ");
   scanf("%s",ff);
   get_input_of_trips();
   calculate_attractions();
   calculate_productions();
   get_input_of_times();
/********initializations      of factors***************************/
    for(i=1;i<=n;++i)
    for(j=1;j<=n;++j)if   (time[i][j])   {
  f[i][j]  = 1.0/(time[i][j]*time[i][j]);
  }
  for(i=1;i<=n;++i)    b[i]=1.0;
  for(i=1;i<=n;++i)    b_projected[i]=1.0;
/*******************************************************/
printf("\n\n\a                   CALIBRATION   IS GOING  ON...");
  outer_loop_count=0;
  while(outer_loop_count++     < MAX_ITERATION)   {
    inner_loop_count=0;
    while(inner_loop_count++     < MAX_ITERATION)   {
       calculate_new_trips();
```

```
        calculate_new_attractions();
        if(attraction_change_is_acceptable())      {
        break;
        }
     else {
        calculate_b_factors();
        okay=FALSE;
     }
    }
    if(okay) break;
    inner_loop_count=0;
    while(inner_loop_count++    < MAX_ITERATION)   {
      if(trip_change_is_acceptable())     {
   okay=TRUE;
   break;
      }
      else {
         calculate_f_factors();
   calculate_new_trips();
      }
    }
    if(inner_loop_count    == MAX_ITERATION)   okay=TRUE;
   }
   clrscr();
   get_output_of_b_factors();
   get_output_of_f_factors();
   get_output_of_new_trips();
   regression_time();
   correlation();
   get_output_of_f_reg();
   printf("\nProjection   of trips  before  traffic  assignment(y/n)?    ");
   choice=toupper(getche());
   switch(choice){
   case 'Y':
label12:
prediction_of_trips();
while(1)  {
     calculate_projected_trips();
     calculate_projected_new_attractions();
     if(projected_attraction_change_is_acceptable())        {
     break;
    }
     else {
        calculate_projected_b_factors();
    }
    }
   get_output_of_projected_trips();
   printf("\a\nWould   you like  to continue  projection(y/n)   ? ");
```

```
 answer=toupper(getche());
 switch(answer){
  case 'Y':
  goto label12;
  break ;
  case 'N':
  break;
  }
 case 'N':
break;
 }
 break;
 case '2':
 printf("\n\nINPUT  FILE (TRIP MATRIX)? ");
 scanf("%s",tp);
 printf("\nOUTPUT  FILE (CALIBRATED  TRIP MATRIX) ?");
 scanf("%s",cal_tp);
 printf("\nOUTPUT  FILE ('b' factors for trucks)? ");
 scanf("%s",bb);
 printf("\nOUTPUT  FILE ('f' factors for trucks)? ");
 scanf("%s",ff);
 projected_trip_file=fopen("proj_trp.dat","w");
 get_input_of_trips();
 calculate_attractions();
 calculate_productions();
 get_input_of_cost();
/***********initializations    of factors  *****************/
  for(i=1;i<=n;++i)
  for(j=1;j<=n;++j)if  (cost[i][j])  {
f[i][j]  =  1.0/((float)cost[i][j]/1000.0*(float)cost[i][j]/1000.0);
 }
  old_f_file=fopen("old_f.dat","w");
  for(i=1;i<=n;++i){
  fprintf(old_f_file,"\n");
  for(j=1;j<=n;++j){
  fprintf(old_f_file,"%5.4f",f[i][j]);
  }
 }
fclose(old_f_file);
 for(i=1;i<=n;++i)  b[i]=1.0;
 for(i=1;i<=n;++i)  b_projected[i]=1.0;
/*********************************************************
**/  printf("\n\n\a          CALIBRATION  IS GOING ON...");
 outer_loop_count=0;
 while(outer_loop_count++   < MAX_ITERATION)  {
  inner_loop_count=0;
  while(inner_loop_count++   < MAX_ITERATION)  {
    calculate_new_trips();
```

```
        calculate_new_attractions();
        if(attraction_change_is_acceptable())       {
        break;
        }
    else {
        calculate_b_factors();
        okay=FALSE;
    }
     }
     if(okay)  break;
     inner_loop_count=0;
     while(inner_loop_count++     < MAX_ITERATION)   {
        if(trip_change_is_acceptable())      {
    okay=TRUE;
    break;
        }
        else  {
           calculate_f_factors();
    calculate_new_trips();
        }
     }
     if(inner_loop_count    == MAX_ITERATION)   okay=TRUE;
    }
    clrscr();
    get_output_of_b_factors();
    get_output_of_f_factors();
    get_output_of_new_trips();
    regression_cost();
    correlation();
    get_output_of_f_reg();
    printf("\nProjection   of trips  before  traffic  assignment(y/n)?   ");
    choice=toupper(getche());
    switch(choice){
    case 'Y':
label10:
        prediction_of_trips();
    while(1)  {
       calculate_projected_trips();
       calculate_projected_new_attractions();
       if(projected_attraction_change_is_acceptable())        {
      break;
      }
       else  {
     calculate_projected_b_factors();
     }
      }
    get_output_of_projected_trips();
    printf("\aWould   you like  to continue  projection(y/n)   ? ");
```

```
  answer=toupper(getche());
  switch(answer){
   case 'Y':
   goto label10;
   break;
   case 'N':
   break;
   }
  case 'N':
break;
  }
 }
printf("\n\n\a===   TRAFFIC  ASSIGNMENT  BEGINS >> ");
label11:
printf("\n\nNETWORK   DATA FILE ? ");
scanf("%s",network);
printf("\n\aTRIP  MATRIX TO BE ASSIGNED  ?");
scanf("%s",filename);
printf("\n\aPress   any KEY to continue...");getch();
  NET_EQ();
printf("\nWould  you like to continue  traffic assignments(y/n)?   ");
  like=toupper(getche());
  switch(like){
   case 'Y':
goto label11;
   break;
   case 'N':
   break;
   }
  fcloseall();
}
/*****************************************************/
void get_input_of_trips()
{
  int i,j;
  FILE *old_trip_file;
 if((old_trip_file=fopen(tp,"r"))==NULL)
printf("can  not open  %s\n",tp);
  for(i=1;i<=n;++i)
     for(j=1;j<=n;++j)    {
  fscanf(old_trip_file,"%d",&trip[i][j]);
  }
fcloseall();
}
/*****************************************************/
void get_input_of_times()
{
  int i,j;
```

```
  FILE  *time_file;
  time_file=fopen("time.dat","r");
  for(i=1;i<=n;++i)
      for(j=1;j<=n;++j)
  fscanf(time_file," %f",&time[i][j]);
  fcloseall();
}

void get_input_of_cost()
{
int i,j;
FILE *cost_file;

cost_file=fopen("cost.dat","r");
for(i=1;i<=n;++i)
  for(j=1;j<=n;++j)
     fscanf(cost_file," %d",&cost[i][j]);

fcloseall();
}
/*****************************************************/
void calculate_attractions()
{
int i,j;
  for(i=1;i<=n;++i){
     attraction[i]=0;
 for(j=1;j<=n;++j)
   attraction[i]+=trip[j][i];
  /* printf("attraction[%d]=%d",i,attraction[i]);getch();*/
}
}
/*****************************************************/
void calculate_productions()
{
 int i,j;
 for(i=1;i<=n;++i){
   production[i]=0;
     for(j=1;j<=n;++j)
  production[i]+=trip[i][j];
  }
}
/*****************************************************/
void calculate_new_trips()
{
 int i,j;
 for(i=1;i<=n;++i)
     for(j=1;j<=n;++j)if(trip[i][j])      {
 int m;
```

```
  float sum_afk=0.0;
  for(m=1;m<=n;++m)   if(trip[i][m])
  sum_afk += (float)(attraction[m])*b[m]*f[i][m];
  new_trip[i][j]=(int)((float)production[i]*(float)attraction[j]*
              b[j]*f[i][j]/sum_afk    + 0.5);
  }
}


void calculate_new_attractions()
{
 int i,j;
 for(i=1;i<=n;++i)   {
    new_attraction[i]=0;
    for(j=1;j<=n;++j)if(trip[j][i])
    new_attraction[i]   +=new_trip[j][i];
 }
}
/****************************************************/
boolean  attraction_change_is_acceptable()
{
 int i;
 float change;
 for(i=1;i<=n;++i)   if(attraction[i]   && new_attraction[i])   {
    change=(float)abs(attraction[i]-new_attraction[i])/
          (float)attraction[i];
    if(change  > ERROR)return   FALSE;
 }
 return  TRUE;
}
/****************************************************/
boolean  trip_change_is_acceptable()
{
 int i,j;
 float change;
 for(i=1;i<=n;++i)
    for(j=1;j<=n;++j)if(trip[i][j]     && new_trip[i][j])   {
    change  = (float)(abs(trip[i][j]-new_trip[i][j]))/
           (float)trip[i][j];
    if(change  > ERROR) return FALSE;
 }
 return TRUE;
}
/****************************************************/
void calculate_b_factors()
{
 int j;
 for(j=1;j<=n;++j)   if( (int)new_attraction[j])    {
```

```
      b[j] *=(float)attraction[j]/(float)new_attraction[j];
      }
  }

  /*****************************************************/
  void calculate_f_factors()
  {
   int i,j;
   for(i=1;i<=n;++i){
      for(j=1;j<=n;++j)if(trip[i][j]     && new_trip[i][j]){
       f[i][j] *=(float)trip[i][j]/(float)new_trip[i][j];
   }
   }
  }
  /*****************************************************/
  void get_output_of_b_factors()
  {
   int i;
   FILE *b_factor_file;
   b_factor_file=fopen(bb,"w");
   fprintf(b_factor_file,"             CALCULATED  b FACTORS\n\n");
   for(i=1;i<=n;++i)   fprintf(b_factor_file,"%f\n",b[i]);
  fcloseall();
  }
  /*****************************************************/
  void get_output_of_f_factors()
  {
   int i,j;
   FILE *f_factor_file;
   f_factor_file=fopen(ff,"w");
   fprintf(f_factor_file,"             CALCULATED  f FACTORS\n\n");
   for(i=1;i<=n;++i)   {
      fprintf(f_factor_file,"\n");
      for(j=1;j<=n;++j)   {
   fprintf(f_factor_file,"%4.3f     ",f[i][j]);
      }
   }
   fcloseall();
  }
  /** *****************************************************/
  void get_output_of_new_trips()
  {
   int i,j;
   FILE *new_trip_file;
   new_trip_file=fopen(cal_tp,"w");
   for(i=1;i<=n;++i)   {
      fprintf(new_trip_file,"\n");
      for(j=1;j<=n;++j)   {
```

```
 fprintf(new_trip_file,"%5d",new_trip[i][j]);
     }
 }
 fcloseall();
}
/*****************************************************/
void regression_time()
{
  int i,j;
 double  power_of_t;
 double  sum_of_log_time=0.0;
 double  sum_of_log_f=0.0;
   for(i=1;i<=n;++i)
     for(j=1;j<=n;++j)   if(trip[i][j]   && f[i][j])  {
 sum_of_log_time+=log(time[i][j]);
 sum_of_log_f+=log(f[i][j]);
 }
 power_of_t=  sum_of_log_f/sum_of_log_time;
 gotoxy(20,4);
 printf("\aCALIBRATION    OF TRIP MATRIX  SUCCESSFUL..\n");
 printf("\npower   of t  =%6.4lf",power_of_t);
 printf("\nThe   Regression   equation   is:  f  =  t**(%lf)",power_of_t);
 printf("\n                where,  travel  time  (t)  is  in  Hours.");
 printf("\n\nStatistical     measures   are:\n");
 printf("--------------------");
 for(i=1;i<=n;++i)
    for(j=1;j<=n;++j)    if(f[i][j])
 f_reg[i][j]=pow(time[i][j],power_of_t);
}
/** *****************************************************/
void regression_cost()
{
 int i,j;
 double  power_of_c;
 double  sum_of_log_cost=0.0;
 double  sum_of_log_f=0.0;
   for(i=1;i<=n;++i)
     for(j=1;j<=n;++j)   if(trip[i][j]   &&  f[i][j])  {
 sum_of_log_cost+=(double)log(cost[i][j]/1000.0);
 sum_of_log_f+=(double)log(f[i][j]);
 }
 power_of_c=  sum_of_log_f/sum_of_log_cost;
 gotoxy(20,4);
 printf("\aCALIBRATION    OF TRIP MATRIX  SUCCESSFUL..\n");
 printf("\npower   of cost  =%6.4lf",power_of_c);
 printf("\nThe    Regression    equation    is:  f  =
cost**(%lf)",power_of_c);
 printf("\n   where,  travel  cost is in  Taka  (in  thousand)");
```

```
  printf("\n\nStatistical    measures  are:\n");
  printf("-------------------");
  for(i=1;i<=n;++i)
     for(j=1;j<=n;++j)   if(f[i][j])

f_reg[i][j]=pow(cost[i][j]/1000.0,power_of_c);
}
/** *********************************************************** /
void correlation()
{
int i,j;
int tag=0;
double  sum_of_deviation_of_f=0.0;
double  sum_of_deviation_of_f_reg=0.0;
double  f_mean;
double  sum_of_f=0.0;
double  coefficient_of_determination;
double  coefficient_of_correlation;
for(i=1;i<=n;++i)
  for(j=1;j<=n;++j)   if(f[i][j])  {
      sum_of_f+=f[i][j];
  tag+=1;
      }
f_mean=sum_of_f/(double)tag;
for(i=1;i<=n;++i)
  for(j=1;j<=n;++j)   if(f[i][j])  {
    sum_of_deviation_of_f+=pow((f[i][j]-f_mean),2);
    sum_of_deviation_of_f_reg+=pow((f_reg[i][j]-f_mean),2);
    }
coefficient_of_determination=sum_of_deviation_of_f_reg/sum_of_deviation
_of_f;
printf("\n\ncoefficient   of determination   (R^2)  =%3.2lf",
coefficient_of_determination);
coefficient_of_correlation=pow(coefficient_of_determination,0.5);
printf("\ncoefficient_of_correlation       (R)  =%3.2lf",
coefficient_of_correlation);getch();
}
/****************************************************** /
void get_output_of_f_reg()
{
 int i,j;
 FILE *f_regression_file;
 f_regression_file=fopen("f_reg.dat","w");
 fprintf(f_regression_file,"f    FACTORS  AFTER  REGRESSION\n\n");
 for(i=1;i<=n;++i){
    fprintf(f_regression_file,"\n");
 for(j=1;j<=n;++j){
   fprintf(f_regression_file," %4.3f",f_reg[i][j]);
```

```
  }
 }
 fcloseall();
 }
/**************************************************/
void prediction_of_trips()
{
 int i;
 int year;
 float growth_rate[20];
 FILE *tgr_file;
 printf("\n\n\n              PREDICTION  OF FUTURE  FLOW-PATTERNS");
 printf("\n            /********************************/\n");
 printf("INPUT  FILE OF TRAFFIC  GROWTH  RATE ?");
 scanf("%s",growth_file);
 tgr_file=fopen(growth_file,"r");
 for(i=1;i<=n;++i)
   fscanf(tgr_file,"%f\n",&growth_rate[i]);
 printf("\nLength   of projection   (years)  = ");
 scanf("%d",  &year);
 for(i=1;i<=n;++i)   {
production[i]=(int)(production[i]*pow((1+(int)(growth_rate[i]+0.5)/100.0),
year)+0.5);
   attraction[i]=(int)(attraction[i]*pow((1+(int)(growth_rate[i]+
  0.5)/100.0),year)+0.5);
   }
fcloseall();
}
/**************************************************/
void calculate_projected_trips()
{
 int i,j;
 for(i=1;i<=n;++i)
    for(j=1;j<=n;++j)   if(trip[i][j])   {
 int m;
 double  sum_abfk=0.0;
 for(m=1;m<=n;++m)   if(trip[i][m])
 sum_abfk+=attraction[m]*f[i][m]*b_projected[m];
 trip[i][j]=(int)((float)production[i]*(float)attraction[j]*
b_projected[j]*f[i][j]/sum_abfk+0.5);
    }
}
/**************************************************/
void calculate_projected_new_attractions()
{
 int i,j;
 for(i=1;i<=n;++i)   {
   projected_new_attraction[i]=0;
```

```
   for(j=1;j<=n;++j)  if(trip[j][i])  {
   projected_new_attraction[i]+=trip[j][i];
   }
  }
}
/****************************************************/
boolean projected_attraction_change_is_acceptable()
{
 int i;
 float change;
 for(i=1;i<=n;++i)  if(attraction[i]  && projected_new_attraction[i])    {
   change=(float)abs(attraction[i]-projected_new_attraction[i])/
(float)attraction[i];
   if(change>ERROR)  return FALSE;
   }
   return TRUE;
}
/****************************************************/
void get_output_of_projected_trips()
{
 FILE *projected_trip_file;
 int i,j;
 printf("\n\aOUTPUT  FILE FOR PROJECTED  TRIPS ?");
 scanf("%s",file);
projected_trip_file=fopen(file,"w");
 for(i=1;i<=n;++i)  {
   fprintf(projected_trip_file,"\n");
   for(j=1;j<=n;++j)  {
     fprintf(projected_trip_file,"%5d",trip[i][j]);
     }
   }
   fcloseall();
}
/****************************************************/
void calculate_projected_b_factors()
{
 int j;
 for(j=1;j<=n;++j)  if(projected_new_attraction[j])
   b_projected[j]*=(float)attraction[j]/(float)projected_new_attraction[j];
}
/****************************************************/
       /*PROGRAM  FOR TRAFFIC  ASSIGNMENT*/
/****************************************************/
/*subroutine  quick route find */
/*********************************/
void ROUTE()
{
int i1,j1;
```

```
float  time,ctime,stime;
stime=node*10000.0;
pnn[i]=0;
pnnt[i]=0.0;
label1:
ctime=0.0;
for(i1=0;i1<node;i1++){
if(pnnt[i1]>9999.9)continue;
for(j1=0;j1<node;j1++){
if(lc[i1][j1]!=0){time=pnnt[i1]+lt[i1][j1];
  if(time<pnnt[j1]){pnn[j1]=i1;
    pnnt[j1]=time;}
}
 }
 }
for(j1=0;j1<node;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;
qrt=pnnt[k];
j1=0;
qr[j1]=k;
for(j1=1;j1<node;j1++){
i1=qr[j1-1];
if(pnn[i1]==i){
                qr[j1]=i;
     break;
      }
else
{
            qr[j1]=pnn[i1];
           }
}
nn=j1;
return;
}
/****************************************/
/*Network  Equilibrium*/
/****************************************/
void NET_EQ()
```

```
{
clrscr();
gotoxy(22,12);
printf("TRAFFIC   ASSIGNMENT   IS GOING  ON..");
INPUT();
N_EQU();
OUT_P();
return;
}
/**********************************/
/*Network  Equilibrium*/
/**********************************/
void N_EQU()
{
int i3,i4,o,d;
for(i3=1;i3<6;i3++){
   for(i=0;i<node;i++){
for(k=0;k<node;k++){
if(od[i][k]  !=0){
for(d=0;d<node;d++){
pnnt[d]=10000.0;
pnn[d]=0;
}
 ROUTE();
 for(i4=nn;i4>0;i4--){
   o=qr[i4];
   d=qr[i4-1];
   lv[o][d]=lv[o][d]+od[i][k]*0.2;
   }
     }
}
  }
   L_TIME();
}
return;
}
/**********************************************/
void L_TIME()
{
float x;
int o,d;
for(o=0;o<node;o++){
for(d=0;d<node;d++){
   if(ll[o][d]>0.1){
   x=lv[o][d]/lc[o][d];
   x=pow(x,4.0);
   lt[o][d]=lt0[o][d]*(1+0.15*x);
   }
```

```
}
}
return;
}
/***************************************************/
void OUT_P(void)
{
int o,d;
char d_out[20],t_out[20];
FILE *fpo1,*fpo2;
clrscr();
printf("\a     << ASSIGNMENT  OF TRIP MATRIX SUCCESSFUL  >>\n");
printf("\n    OUTPUT FILE (DIRECTIONAL  TRAFFIC VOLUME) ? ");
scanf("%s",d_out);
printf("\n    OUTPUT FILE (TOTAL TRAFFIC VOLUME) ?");
scanf("%s",t_out);
if((fpo1=fopen(d_out,"w"))==NULL)
  printf("cannot  open %s\n",d_out) ;
if((fpo2=fopen(t_out,"w"))==NULL)
  printf("cannot  open %s\n",t_out);
fprintf(fpo1,"                Link Volume & Link Travel Time\n");
fprintf (fpo1,"Origin--Destination-----Traffic     volume------Travel   Time\n");
for(o=0;o<node;o++){
for(d=0;d<node;d++){
  if(lc[o][d]>0){
fprintf(fpo1,"%3d-----%4d--------%10d---------%10.3f\n",o,d,(int)lv[o][d],lt[
o][d]);}
 }
  }
 fprintf(fpo2,"         Link Traffic Volume\n");
 fprintf(fpo2,"Origin--Destination------------Traffic        Volume\n\n");
 for(o=0;o<node;o++)   {
   for(d=o+1;d<node;d++)   {
    if(lc[o][d]>0)  {
     lv[o][d]+=lv[d][o];
     fprintf(fpo2,"%3d------%4d-------------%10d\n",o,d,(int)lv[o][d]);
     }
   }
 }
 fcloseall();
 return;
 }
 /**********************************************/
 void INPUT()
 {
 int o,d,nd;
 FILE *assigned_file,  *fp1;
 fp1=fopen(network,"r");
```

```
for(o=0;o<node;o++){
for(d=0;d<node;d++){
ll[o][d]=0.0;
od[o][d]=0.0;
lc[o][d]=0;
ls[o][d]=0.0;
lv[o][d]=0.0;
}
  }
fscanf(fp1,"%d\n",&nd);
for(o=0;o<nd;o++){
    fscanf(fp1,"%d %d",&i,&j);
    fscanf(fp1,"%f %d %f\n",&ll[i][j],&lc[i][j],&ls[i][j]);
}
assigned_file=fopen(filename,"r");
for(o=0;o<n;o++)
   for(d=0;d<n;d++){
   fscanf(assigned_file,"%f",&od[o][d]);
   }
for(i=0;i<node;i++){
for(j=0;j<node;j++){
   if(ll[i][j]>0.1)     lt0[i][j]=ll[i][j]/ls[i][j]*0.87*60.0;
       }
}
L_TIME();fcloseall();return;
}
```