Dynamic Interaction between Transportation Investment and Economic Development based on Stochastic Approach

By

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A Thesis submitted to the Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka - in partial fulfilment of the requirement of the degree of

Master of Science in Civil and Transportation Engineering

January 2008

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ACKNOWLEDGEMENT

At first, the author would like to express his wholehearted gratitude to the Almighty Allah for each and every achievement of his life. May Allah lead every individual to the way which is best suited for the particular individual.

The author becomes delighted to state that this study was supervised by Dr. Md. Jobair Bin Alam, Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka.

The author wishes to express his sincerest debt to Dr. Md. Jobair Bin Alam for his affectionate assistance, proper guidance, and enthusiastic encouragement. Throughout the whole study he has timely extended his experienced views and understanding of the problem for the successful completion of the research. The author is also very thankful to his employer, WSP International Management Consulting, for their insistent support throughout the study period especially during collection of data.

Lastly, the author would also like to admit the inspiration and unconditional support by his parents, his wife and all other family members.

ABSTRACT

Bangladesh has developed a huge road infrastructure at the cost of millions of dollars borrowed from development partners. Lack of policy strategy, inadequate planning and biased regional focus create investment inefficiency in transport sector of Bangladesh. During the last couple of decades transportation attracted more than twenty percent of national investment – most of which is concentrated in road sector. Hence, there exists a scope to examine the role of accessibility, provided by multimodal transportation facilities, in aggregate efficiency of production of different regions. This study establishes a methodological framework and analyses the impact of transportation infrastructure investment with regional economic efficiency of Bangladesh based on choice theoretic Stochastic Data Envelopment Model (SDEM) and compares the result with conventional Data Envelopment Analysis (DEA).

A common measure for relative efficiency is given by the ratio of the weighted sum of outputs and weighted sum of inputs. It is assumed that there exists a stochastic error term in the calculation of efficiency. Each DMU chooses its own production function as the function yields optimum output. Assuming the error term is IID Gumbel Distributed, the efficiency of the target unit in a set is obtained by solving by conventional logit model, which is non-linear in formulation. It is further simplified by using monotonic logarithmic transformation of the efficiency function and assuming Cob-Douglas type multiplicative form of the input and output functions. The parameters of the function are estimated using Maximum Likelihood method having the following Log-Likelihood function. BIOGEME Statistical package is used to estimate the multinomial logit model. Based on this framework, the time lag between transportation infrastructure investment and economic development is evaluated with an objective of assessing priorities in investment and decision making.

In the context of Bangladesh, the data for the 20 greater districts or region is analyzed using Choice theoretic SDEM considering each region as an individual production unit. To calculate the relative efficiencies of different regions, effective land area, civilian labour force, industrial asset and accessibility index (as measure of transportation infrastructure and system) are used as inputs and the total GDP is considered as output. The Accessibility Index has been calculated from the existing transportation network of the country.

Results in SDEM suggest that the proposed framework facilitates relaxation of the constraints although it enables incorporation of stochastic error to in assessing

production frontiers. All the parameters measured using SDEM are found statistically significant. Analyses show that many regions perform inefficiently and there exists imbalance in input factors of production as demonstrated by the value of exponents. It also shows that there are specific regions where production efficiency is severely constrained by lack of land and industrial capital. Analytic framework has been developed to capture time lag between transportation investment and its utilization in economic activities based on stochastic approach. The analysis reveals that the lag time ranges between 2-3 years for short term, 6-7 years for medium term and 16-17 years for long term in case of Bangladesh.

Assessment of factor demand functions demonstrate that price elasticity of accessibility is around -0.90. The analytical procedures for assessing elasticities and demand functions have significant implication on policy formulation and resource allocation at regional level.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AE	Allocative Efficiency
BBS	Bangladesh Bureau of Statistics
BCC	Banker, Charnes and Cooper
BDT	Bangladeshi Taka
BG	Broad Gauge
BIWTA	Bangladesh Inland Water Transport Authority
BIWTC	Bangladesh Inland Water Transport Corporation
BR	Bangladesh Railway
BRTA	Bangladesh Road Transport Authority
CCR	Charnes, Cooper and Rhodes
CE	Cost Efficiency
CES	Constant Elasticity of Substitution
CHT	Chittagong Hill Tracts
CRS	Constant Returns to Scale
DCC	Dhaka City Corporation
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DTCB	Dhaka Transport Coordination Board
DUTP	Dhaka Urban Transport Project
ECNEC	Executive Committee of National Economic Council
GCS	Geographic Coordinate System
GDP	Gross Domestic Product
GNI	Gross National Income
GNP	Gross National Product
HGV	Heavy Goods Vehicles
ICD	Inland Container Depots
IID	Identical and independently Distributed
IMTP	Integrated Multi-modal Transport Policy
IWT	Inland Water Transport
JMB	Jamuna Multipurpose Bridge
LCC	Lambert Conformal Conic
LGED	Local Government Engineering Department
MG	Meter Gauge
MT	Motorized Transport

MTA	Metropolitan Transport Authority
NCHRP	National Cooperative Highway Research Program
NGO	Non Government Organization
NLTP	National Land Transport Policy
NMT	Non Motorized Transport
NNI	Net National Income
NNP	Net National Product
NRSC	National Road Safety Council
OECD	Organization for Economic Cooperation and Development
PRS	Poverty Reduction Strategy
RADP	Revised Annual Development Programme
RHD	Roads and Highways Department
RMMS	Road Maintenance and Management System
RRMP	Rural Road Master Plan
SDEM	Stochastic Data Envelopment Model
SFA	Stochastic Frontier Analysis
TE	Technical Efficiency
TFP	Total Factor Productivity
TSC	Transport Sector Coordination
RRP	Railway Recovery Programme
UMTA	Unified Metropolitan Transport Authorities
VRS	Variable Returns to Scale

1. INTRODUCTION

1.1 General

The economic development requires adequate, effective transportation services, and this is considered as axiomatic. It is generally accepted that there exist for a given countries at specified stages of development, a theoretically optimum amount of transport capacity. Nonetheless, agreement on the determination of these capacities and their implied rate of investment is far from unanimous. Experts and policy makers alike recognize the importance of transport as an instrument of economic progress, but they lack the tools of making investment decisions that will serve economic development without allocating too large, or small, a share of national income to the transport sector. This probably is due as much to the failure of economists to study the role of transportation in contemporary economic development as it is to basic disparities in views. Few comprehensive analyses of normative transportation-development theory have been conducted to date.

Identification of the need and the effect of transportation infrastructure investment are particularly important when development resources are scarce, this is true especially in the context of a developing country and/or region. From the perspective of the decision makers it involves identification and assessment of the need for infrastructure development, accurate estimation of the need that allows for effective budgeting and financing of the projects, informed decisions while evaluating individual projects, and above all a balanced distribution of resource and efficiency through incentives for competition. All these aspects have generated considerable research interest in the analysis of investment needs and optimal allocation of resources. Usually economic performance is at the core of the investment decisions. Performance of invested resources is usually measured by an efficiency factor, which is the ratio between output and input factors of production. In the case of investment in infrastructure for development the output factors are usually expressed in different forms of aggregate production and the input factors include natural resources, land area, population, and accessibility.

Transportation is considered to be one of the most important infrastructure components influencing production. For this reason there exists considerable pressure for investment in the transportation sector. Transportation improvements affect both economic development and productivity. Pure economic development effects are usually regional in nature and result from improved access to labour pools or to larger markets (NCHRP, 1998). While considering the economic development of different regions of a country, transportation infrastructure and the overall system may play a significant role in removing regional economic disparities. Within the same country and under the same development policies, significant role for transportation implies that regions with better transportation infrastructure will have better access to the locations of input materials and markets and thus will be more productive, competitive and hence more successful than regions with inferior transportation accessibility (Vickerman *et al.*, 1995). Better accessibility and mobility also plays a significant role in human resource development of a region.

In the context of Bangladesh, examining the role of transportation investment in regional economic development of the country and comparing its effectiveness with other input parameters is very important. This is because of the fact that investment pattern and criteria under which resources are allocated among competing sectors and projects might have created investment bias towards already developed regions and resulted in economic inefficiency. This study is devoted to estimate efficiencies of 20 greater districts or regions, considered as Decision Making Units (DMU), of Bangladesh, then analyze effect of accessibility on the efficiencies of the DMU's, and finally recommend policies on the investment decision for each of the DMU's.

1.2 Present State of the Problem

Transport demand in Bangladesh has grown faster than the GDP growth of the country and doubled between 1974 and 1984 to 35 billion passenger kms (pkms). In 1996, it reached 72 billion pkms. Freight transport has also increased at a similar rate and reached 10 billion ton kms in 1996. However, the share of transport modes has not increased in the same proportion. The road sector carries the majority of passenger traffic, increasing from 54% in 1974 to 73% in 1996, mainly at the expense of rail. In the freight sector, transport by water is more dominant, although its demand has been slightly eroded from 37% in 1974 to 30% in 1996. In comparison, road transport increased to 63% in 1996, again mainly at the expense of rail transport. Thus, the faster expansion of the country's road network as well as the increase in road vehicles has led to the dominance of the road sector, although transport by water still remains substantial. Bangladesh has developed a huge road infrastructure at the cost of millions of dollars borrowed from development partners. Lack of policy strategy, inadequate planning and biased regional focus create investment inefficiency in the transport sector of Bangladesh. National investment policy appears to be inclined for more investment in the comparatively more developed regions under the pretext of higher aggregate production. On the other hand, investments in infrastructural development of less efficient regions seem to be more effective by providing higher rate of return. Hence, there exists scope to examine the role of accessibility, provided by multi-modal transportation facilities, in aggregate efficiency of production of different regions.

The study to determine more precise and dynamic relationship between transportation investments is particularly important for Bangladesh, because there exists severe disparity in the spatial distribution of infrastructure investment. In addition, it is observed that during the last couple of decades transportation attracted more than twenty percent of national investment - most of which is concentrated in road transportation sector. Although this investment has increased aggregate production in many areas, its relative effectiveness and marginal rate of return of the input factors requires further investigation.

1.3 Objectives of the Study

The preliminary aim of this study is to develop a tool for studying interrelationship between transportation and economic development. The specific objectives of the study can be summarized as follows:

- To develop a methodological framework to correlate transportation infrastructure with regional economic efficiency based on choice theoretic approach.
- To analyze the role of transport infrastructure in regional economic efficiency in Bangladesh based on choice theoretic stochastic Data Envelopment Model and compare the result with conventional Data Envelopment Approach.
- To establish methodology of endogenous and simultaneous identification of correspondence between current demands for increased investment in transportation infrastructure and lag period for the materialization of its effects.

1.4 Brief Outline of the Methodology

When the production function of the fully efficient firm is not known, e.g. while measuring efficiency of investment for a particular region, the efficient frontier must be estimated using the sample data on the basis of either Mathematical Programming Approach or Econometric Approach. The Econometric Approach attempts to determine the absolute economic efficiency of organizations against some imposed benchmark. Reasoning regarding the random errors observed in the economic approach has led to the development of Deterministic Frontier Approach assuming that all deviations from the estimated frontier represent inefficiency. On the other hand, the Stochastic Frontier Approach seeks to take the external factors into account when estimating the efficiency of the real world organizations. The Mathematical Programming Approach is nonparametric and non-stochastic in nature. Therefore, no accommodation is made for the types of bias resulting from environmental heterogeneity, external shocks, measurement error and omitted variables. Consequently, the entire deviation from the frontier is assessed as caused by inefficiency. The mathematical programming approach attempts to evaluate the efficiency of an organization relative to other organizations of the same industry. The most commonly used version of this approach is a linear programming method referred to as Data Envelopment Analysis (DEA). Efficiencies measured by conventional DEA are relative efficiencies rather than absolute efficiencies. Also the linear programming based DEA method is deterministic in nature. Considering the complexities and uncertainties in the relationship between transportation infrastructure and economic development, such a limitation imposes severe constraints in its applicability. DEA approach does not have any goodness of fit statistics and significance tests to examine the integrity of the analysis. To overcome these problems a new framework to assess efficiency of production units using choice theoretic approach is applied in this study. The analytical approach enables incorporation of stochastic error in assessing production frontiers as well as facilitates relaxation of the binding constraint discussed above through application of maximum likelihood method for calibration purpose.

A common measure for relative efficiency is given by the ratio of the weighted sum of outputs and weighted sum of inputs. It is assumed that there exists a stochastic error term in the calculation of efficiency. Each DMU chooses its own production function as the function yields optimum output. Assuming the error term is IID Gumbel Distributed, the efficiency of the target unit in a set can be obtained by solving by conventional logit model, which is non-linear in formulation. It can further be simplified by using monotonic logarithmic transformation of the efficiency function and assuming Cob-Douglas type multiplicative form of the input and output functions. The parameters of the function can be estimated using Maximum Likelihood method having the following Log-Likelihood function. BIOGEME Statistical package can be used to estimate conventional multinomial logit model. Based on this approach (choice theoretic SDEM), the time lag between transportation infrastructure investment and economic development has been evaluated with an objective of assessing priorities in investment and decision making.

In the context of Bangladesh, the data for the 20 greater districts or region is analyzed using Choice theoretic SDEM considering each district as an individual production unit. Each region is assumed to be an individual production unit, utilizing its land, labour and capital to produce output. To calculate the relative efficiencies of different regions, effective land area, civilian labour force, industrial asset and accessibility index (as measure of transportation infrastructure and system) have been used as inputs and the total GDP has been considered as output. The Accessibility Index has been calculated from the existing transportation network of the country.

1.5 Scope of the Study

Although Aschauer (1990, 1993) and Vickerman *et al.* (1995) discussed the role of transportation on aggregate production, those studies did not explicitly examine issues like relative efficiencies and imbalance in input factors. The spatial variation of input resources and observed distribution of outputs provide a potential context for analyzing economic efficiency through the application of Data Envelopment Analysis.

During the analysis in this study, the weights of the inputs and outputs together with the relative efficiency may explain the role of the inputs, specifically the role of transportation in the economy of the zones. It may be possible to know, with the existing transportation infrastructure and system, which districts are producing efficiently and in which districts the lack of transportation infrastructure is acting as a barrier in further efficient utilization of the existing natural and other resources. The research may also give the target outputs for efficient economic activity for the lagging regions / districts of the country.

A set of policy recommendations may also be the outcome of the research. The recommendations could cover such areas as the requirement of transportation infrastructure or enhancement of transportation services at different regions, the requirement of other infrastructures at different regions, which sector of the regional economy need to be emphasized in future, etc. By identifying and measuring the role of transportation in regional economic efficiency, the analysis may assist in assessing the requirement of regional investment in transportation sector among various competing sectors demanding resources and setting priority within transportation sector. Thus the research might as well form the basis of an integrated national transportation plan for the country.

1.6 Organization of the Thesis

The thesis consists of six chapters.

The second chapter discusses the correlation between transportation investment and regional development. It also discusses the transport infrastructure and macroeconomic framework of Bangladesh.

The third chapter discusses the analytical framework of the study. Stochastic Data Envelopment Analysis approach is discussed in details in this chapter.

The forth chapters presents the overview of the transport sector of Bangladesh with up to date information, facts and figures.

The fifth chapter discusses the details of data collection and the analysis of the results.

The sixth and last chapter of the study contains the concluding remarks on the findings of the study. It also focuses on the implementation of the results of the study. In addition, the chapter provides directives for future research on the topic.

A flow chart showing the organization of the thesis is presented in

Chapter 1 : Introduction

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Chapter 2 : Literature Review

- Relationship among economic development, economic growth and transportation investment
- Data Envelopment Analysis (DEA)
- Stochastic Frontier Analysis (SFA)
- Stochastic Data Envelopment Analysis (SDEA)
- Studies that used DEA, SFA and SDEA
- Selection of Proper Method

↓

Chapter 3 : Study Design and Methodology

- DEA Model to Measure Efficiency and Lagging Effect of Accessibility
- Analytical Approach : Stochastic Data Envelopment Model
  - Framework for Measuring Efficiency
  - Framework for Dynamic Analysis
  - Framework for Policy Implication

↓

Chapter 4 : Transport Sector Overview of Bangladesh

- Transport Sector Policy
- Transportation Network and Service
- Transportation Investment Scenario
- Transport Sector Performance and Micro-Model Split

↓

Chapter 5 : Data Collection and Analysis

- Data Collection
- Data Analysis and Results

↓

Chapter 6 : Conclusions

- Findings of the Study
- Recommendation for Further Study

Figure 1.1: Organization of the Study

2. LITERATURE REVIEW

2.1 Introduction

This chapter covers a review of literature on methodology to assess impacts of infrastructure investment in an economic system with special emphasis on investment in transport sector and its relationship with economic growth. Literature survey of relevant researches and studies has been conducted and some of them are abstracted in this chapter. Review of literatures reveals that the research on the relationship between transportation investment and economic development has been a classical research issue for the last two decades. But only a limited number of studies have been performed in Bangladesh regarding the issue.

2.2 Basic Concepts of Economic Development and Growth

Economic development is the development of economic wealth of countries or regions for the well-being of their inhabitants. That legal and institutional adjustment is made to give incentives for innovation and for investments so as to develop an efficient production and distribution system for goods and services. Economic development is a sustainable increase in living standards that implies increased per capita income, better education and health as well as environmental protection. According to and Vaughan and Bearse (1981), Development is a qualitative change, which entails changes in the structure of the economy, including innovations in institutions, behaviour, and technology. And growth is a quantitative change in the scale of the economy - in terms of investment, output, consumption, and income.

Long-term economic welfare or economic development results from sustainable economic growth. Economic growth refers to the growth of output of a regional or a national economy. Economic growth occurs as result of accumulation of factors of production and improvements of resource utilization or increases in factor productivity.

To address the question as to what determines growth rate of output over a long period of time, there are two complementary approaches: Growth Theory and Growth Accounting. Growth theory models the interaction among factor supplies, productivity growth, savings and investment in the process of growth. Growth Accounting attempts to quantify the contribution of different determinants of output growth. Both of these approaches draw on a common analytical framework – Production Function.

2.2.1 Production function

Production function expresses that maximum output of a technologically determined production process is a mathematical function of input factors of production. Considering the set of all technically feasible combinations of output and inputs, only the combinations encompassing a maximum output for a specified set of inputs would constitute the production function. Alternatively, a production function can be defined as the specification of minimum input requirements needed to produce designated quantities of output, given available technology. Relationship of output to inputs is non-monetary, that is, a production function relates physical inputs to physical outputs, and prices and costs are not considered. Primary purpose of production function is to address allocative efficiency in use of factor inputs in production and resulting distribution of income to those factors.

2.2.2 Production function as mathematical equation

There are several ways of specifying production function.

In a general mathematical form, a production function can be expressed as:

$$Q = f(X_1, X_2, X_3, \ldots, X_n)$$

where: Q = quantity of output, $X_1, X_2, X_3, \ldots, X_n$ = factor inputs (such as capital, labour, land or raw materials). This general form does not encompass joint production, that is a production process, which has multiple co-products or outputs.

One way of specifying a production function is simply as a table of discrete outputs and input combinations, and not as a formula or equation at all. Using an equation usually implies continual variation of output with minute variation in inputs, which is simply not realistic. Fixed ratios of factors, as in case of labourers and their tools, might imply that only discrete input combinations, and therefore, discrete maximum outputs, are of practical interest.

One formulation is as a linear function:

$$Q = a + bX_1 + cX_2 + dX_3, \ldots$$

where $a, b, c,$ and d are parameters that are determined empirically.

Another is as a Cobb-Douglas production function (multiplicative). Other forms include constant elasticity of substitution production function (CES) which is a generalized form of Cobb-Douglas function, and the quadratic production function which is a specific type of additive function. The best form of equation to use and the values of parameters (*a,b,c,* and *d*) vary from company to company and industry to industry. In a short run production function at least one of the *X*'s (inputs) is fixed. In the long run all factor inputs are variable at discretion of management.

2.2.3 Cobb-Douglas production function

In economics, Cobb-Douglas functional form of production functions is widely used to represent relationship of an output to inputs. It was proposed by Knut Wicksell (1851-1926), and tested against statistical evidence by Paul Douglas and Charles Cobb in 1928 (Coelli *et al.*, 1998).

For production, the function is

$$Y = A * L^{\alpha} K^{\beta},$$

where: Y = output, L = labour input, K = capital input
A, α and β are constants determined by technology.

If $\alpha + \beta = 1$, the production function has constant returns to scale (if L and K are each increased by 20%, Y increases by 20%). If $\alpha + \beta < 1$, returns to scale are decreasing, and if $\alpha + \beta > 1$, returns to scale are increasing. Assuming perfect competition, α and β can be shown to be labour and capital's share of output.

2.3 Transportation Investment and Economic Development Context

The term "economic development" is often not defined consistently, and there are several viewpoints of economic development with regards to transportation investment that influence how infrastructure projects are developed and evaluated. Economic development can be seen as the outcome of a process such that the level of economic activity in an area (which may be a neighbourhood, city, region, state, or even an entire country) is enhanced on a continuing rather than a temporary basis. While economic development occurs spontaneously, it is the work of economic developers to create policies as well as private and public initiatives that stimulate development when it is desirable, to provide more jobs, wealth, tax base, and quality of life.

The broad definition of economic development entails an increase in total output in a given geographic area. This increase can be due to a greater quantity of production inputs within the area, such as the supply of labour, the amount of capital available, improvements in technology, the level or quality of materials, or some combination of these factors. This definition takes economic structure as given and focuses on short-term changes in the economy, sometimes referred to as "economic growth" (Malizia, 1986). Another facet of economic development emerges from improvements in the productivity with which society uses these inputs. In essence, a more efficient use of the inputs of production enables a firm or a region to become or remain competitive through technological and structural economic change (NCHRP, 1998). Transportation improvements have the potential for affecting both economic growth and productivity. Economic growth effects are usually regional in nature; they result from improved access to labour pools, larger markets, and suppliers. Because productivity improvements occur within the production process (e.g., the implementation of "just-in-time" manufacturing and distribution methods), it is harder to trace their impacts at a local or regional scale. Economic development initiatives, including those using transportation investment strategies, can be used to "jump-start" economic activity in a lagging region or to enhance opportunity in a more economically successful region. Transportation investment based on an "economic needs" analysis focuses on assisting regions in fulfilling their developmental potential. A "user benefits"-based analysis, on the other hand, emphasizes the measurement of cost savings resulting from improvements in transportation efficiency (which are translated into economic benefits) and generally points to projects that maximize economic benefits, regardless of the relative economic need of the region. User benefits, however, may also be evaluated, as part of a process to analyze alternatives within a transportation investment strategy designed to address economic needs.

Depending on the desired outcome, transportation investment as a tool in economic development may emphasize or combine the following two approaches:

2.3.1 Transportation investment as a regional growth catalyst

A consideration for transportation investment projects, at times, may include an evaluation of whether a region or an area within a region lags in key economic development indicators. This involves the identification and quantification of economic development needs that can be addressed and rectified through a transportation investment. Well-focused transportation improvements and initiatives, coordinated with efforts to attract new businesses or encourage the expansion of existing businesses and develop job opportunities, can form a catalyst for regional economic growth. For example, the introduction of a four-lane roadway may induce businesses to expand or relocate in a region that otherwise may not have been considered. A new or improved transportation facility may not completely remedy economic deficiencies on its own, but is a tool that can be leveraged to promote or enhance economic development in a region. Although transportation investment is used as a tool to revive the economic competitiveness of lagging regions, it is not clear whether these types of investments always represent the optimum approach for addressing economic deficiencies. Often, the primary impediment to regional economic development is not transportation, but labor force availability and quality. If the existing transportation infrastructure is not limiting a region from meeting its developmental potential, then investments in this region may simply redistribute benefits from other areas where improvements are needed to either unleash the potential of a constrained market or to provide more reliable access to (or within) an economic hinterland.

2.3.2 Effect of transportation investment for increasing efficiency

In general, transportation investments are most effective as an economic development tool when they remove impediments (related to such performance factors as speed, reliability, and safety) that are constraining a market. These performance factors can be translated into economic costs reflected by a worsening in transportation performance that, ideally, will be mitigated by a well-selected transportation project. The improved safety, connectivity, reliability, or speed stemming from transportation investments are measured and categorized as user benefits. Beyond improved facility performance, transportation investments also generate economic impacts by increasing the catchment area for businesses to reach labour, suppliers, and markets, allowing companies to increase sales and employment. Ultimately, user benefits and expanded catchment areas resulting from transportation investment may contribute to higher productivity and increased income levels in a region. A systematic approach is required to gauge the relative merits of transportation projects based on an analysis of user benefits and expanded catchment areas. The identification and measurement of these benefits forms the foundation for developing economic analyses that can be used to prioritize transportation investment options that will in turn generate the greatest regional economic development benefits relative to project costs.

Many traditional analyses monetize user benefits to form a basis for an economic or cost-benefit analysis. User benefits enumerate improvements in transportation performance while an economic development analysis demonstrates how a transportation project may dynamically change the economic capacity of a region. The following two definitions further clarify what constitutes economic development impacts and a broader economic analysis:

Economic development impacts relate specifically to development of the economy of an area and the flow of dollars or number of jobs in that economy. Economic development impacts resulting from a transportation project are a gauge of how well the project increases economic activity measured by such concepts as increases in production, value-added, wages, jobs, and per capita income.

Economic analysis, in contrast, can encompass any elements of benefit and cost to society. It can include the impacts on transportation system users, on the environment, and on quality of life, as well as economic development or business related impacts. A key component of an economic analysis is the identification and enumeration of user benefits resulting from a transportation project (NCHRP, 2000).

2.3.3 Input and output of an economic system

To understand the effect of transportation investment on economic growth, one has to understand inputs and outputs of an economic system. Productivity growth and its relationship with regional economic development are also important in this regard.

Input resources in an economic system distinguish among such factors of production as:

Land or Natural resources are naturally occurring goods such as soil and minerals that are used in the creation of products. They include land used for farming or for supporting houses, factories, roads, and energy sources, non-energy sources.

Labour consists of the human effort used in production which also includes technical and marketing expertise. It is most crucial to an advanced industrial economy.

Accessibility is the measurement of easiness regarding transportation from one place to another. Accessibility provides the means of agglomeration of input products to produce the output. It is measured in terms of time, cost, and safety issues of transportation network.

Capital goods – human-made goods (or means of production) which are used in the production of other goods. These include machinery, tools and buildings. In a general sense, the payment for capital may take the form of interest or dividends.

Measures of national income and output of an economic system is to estimate the value of goods and services produced in an economy. They use a system of national accounts or national accounting first developed during the 1940s. Some of the more common measures are Gross National Product (GNP), Gross Domestic Product (GDP), Gross National Income (GNI), Net National Product (NNP), and Net National Income (NNI).

There are various ways of calculating these numbers. The expenditure approach determines aggregate demand, or Gross National Expenditure, by summing consumption, investment, government expenditure and net exports. The income approach and the closely related output approach sum wages, rents, interest, profits, non-income charges, and net foreign factor income earned. The three methods must yield the same result because total expenditures on goods and services (GNE) must by definition equal the value of goods and services produced (GNP) which must equal total income paid to the factors that produced the goods and services (GNI).

A region's gross domestic product, or GDP, is one of the ways of measuring the size of its economy. The GDP of a country is defined as the total market value of all final goods and services produced within a country in a given period of time (usually a calendar year). It is also considered the sum of value added at every stage of production (the intermediate stages) of all final goods and services produced within a country in a given period of time. The most common approach to measuring and understanding GDP is the expenditure method:

$$GDP = consumption + investment + (government\ spending) + (exports - imports)$$

The difference between GDP and GNP is that, GDP covers goods and services within the border of the country, whereas GNP covers goods and services produced by labour and capital supplied by citizens of the country within the border or living in a foreign country. In this study, GDP is considered as the yardstick of out put function of the economic system.

2.4 Research on the Link between Transportation Investment and Economic Development

The literature review covers various research studies on the link between transportation investment and economic development. Largely because of the work by Aschauer (1989), academics have undertaken numerous studies that explore the relationship between transportation investment and economic performance. Economic performance can be measured by output, value-added (GDP), productivity and employment (e.g., Demetriades and Mamuneas, 2000). Some studies have explored the impact of infrastructure investment on technical efficiency that enters production function (e.g., Delorme, Thompson, and Warren, 1999).

According to Bell and McGuire (1997), a major finding from studies up to early 1994 is that "a positive statistically significant but small effect of public capital on output has been confirmed by many." As pointed out in the report, however, structural changes in relation to infrastructure investment have received insufficient attention in the literature. These changes include "differentiated economic linkage between specific industry and specific type of infrastructure," the role of investment flows in examining "the derived demand for public infrastructure by private sector," and "the relationship between infrastructure types" (Bell and McGuire 1997, p. 9-10). The review indicates that research on the question of the relative productivity of different types of public infrastructure, which have been constrained by data limitations, requires data by infrastructure type or mode of transportation.

The subsequent literature review by NCHRP (1998) focused on evaluating merits and limitations of techniques used in studies linking transportation investment and economic performance. This review divides existing studies into macro- and microanalysis, with former employing mainly production function and cost function methods and the latter cost-benefit analysis and case studies. In an attempt to find impact of investment on productivity, macroanalysis methods compare national trends in economic activity with levels of total public infrastructure investment. The microanalysis methods, by focusing on the economic effects of a particular project, provide insights into how the private sector reacts to changes in transportation. The review points out that both methods lack "a solid understanding of the mechanisms by which transportation investment influence structural changes in a developed economy" (NCHRP 1998, p. 26).

A recent synthesis of practices for assessing economic development impacts from transportation investments (NCHRP, 2000) covers studies by both academia and practitioners up to early 2000. The synthesis, aimed at providing sub-national (local, regional, and state) planners with analytical tools, defines the economic impact by using regional rather than national indicators (e.g., using gross regional product rather than gross domestic product). It pointed out that the evaluation of economic impact of public investment in transportation infrastructure has to date "focused primarily on highway spending," implying the need to broaden the study to cover more transportation modes.

Among all the studies of economic impact of transportation investment, Nadiri and Mamunees (1996) appeared to be the most influential. The study used data on public highway capital, which was developed by Apogee Research, Inc., based on Federal Highway Administration capital outlay data. One of the findings is that the economic impact of highway capital at national level differs from that at industry level and varies by industry. The study also overlooked the welfare benefits of highway capital to consumers that are "likely to be significant" (Eno, 1999).

Among other recent studies, Chandra and Thompson (2000) found that highways not only have "a differential impact across industries" but also "affect the spatial allocation of economic activity." Demetriades and Mamuneas (2000), using an inter-temporal optimization framework, found that in all 12 OECD countries, the magnitude of positive economic effect of public capital changes over time depending on the under-investment gap in infrastructure, which was wider during the 1970s and 1980s but narrowed down significantly by the early 1990s. Everaert and Heylen (2001), using single-equation co-integration analysis based on annual data, found a strong positive relationship with causality running from public capital (including roads, buildings, educational facilities, etc.) to multifactor productivity in Belgium for the period of 1953 to1996.

In summary, the above literature review tells us that past studies were mostly focused on the economic impact of government transportation investment. Most of the studies were concentrated on impacts of highway capital. Little attention has been paid to business transportation investment, its economic impact, and its interaction with government investment; and other modes. Finally, few studies raise the issue of how economic development impacts transportation investment. That is how economic development (e.g., economic growth and industrial restructuring) stimulates transportation investment in terms of both growing demand and increased funding sources for transportation services.

2.5 Methods for Assessing Impacts of Transport Sector Investment

A variety of factors can lead to economic development, including improvements in transportation system efficiency in serving users, increases in business productivity (and output) facilitated by transportation improvements, and improvements in other environmental and quality of life factors, which may affect business growth, property values and economic well-being. As a result, economic development has broader economic impacts. Weisbrod and Grovak (2001) examine and contrast alternative types of economic impact analysis. These are:

(1) System efficiency (user benefit) analysis: System efficiency is the traditional measure of benefit for transportation investment projects. It measures benefits in terms of the improvement in travel time, travel expense and safety for travellers, all expressed in terms of a money value. The advantage of this type of analysis is that it is straightforward. The disadvantage is that it values only direct benefits to users. The incremental values of any additional benefits to users as well as non-users (e.g., environmental benefits, inter-modal linkages, logistic opportunities etc.) are typically not accounted for.

(2) Macro-economic simulation modelling: Regional macro-economic simulation models can be used to estimate economic impact of transportation projects as a consequence of cost savings and other productivity benefits. This approach measures impacts in terms of effects on employment, income and value added (gross domestic product). It has the advantage that it can reflect economic benefits to non-users, although it also ignores other types of benefits, which do not affect flows of money.

(3) Productivity analysis: Productivity research examines how transportation investments affect business productivity, and hence generate income. Impacts can be measured in terms of net business costs, business output, productivity (cost/output ratio) or implied value of (willingness to pay for) additional transportation spending benefits. Unlike the other analytic approaches, this approach in its current form does not make use of project-level transportation network analysis. Rather, it builds upon aggregate-level data to calibrate cost models or production models to identify typical levels of

business performance gains associated with transportation investment. This approach is most useful to help inform policy-level decision-makers regarding the allocation of public funds to transportation improvements.

(4) Strategic planning (scenario) analysis: A fundamental aspect of economic development strategies is the determination of the most appropriate strategies given an assessment of current and potential future scenarios. In theory, strategic factors can all be considered in the framework of a benefit-cost analysis that considers the net present value of all possible future alternative scenarios. Scenario analysis is not an alternative method for measuring impacts, in that it still relies on previously discussed macro-economic modelling methods to represent the job, income and output impacts of transportation improvements. In that sense, all of the limitations and distortions inherent in measuring economic impacts through economic models remain. However, it does provide an opportunity for identification of external contingencies and competitive strategy factors that may not otherwise be explicitly recognized. Most important, it can be a useful way of identifying upside possibilities and downside risks affecting the economic impacts of projects, and that can be useful for decision-making. Thus, this type of approach is sometimes referred to as "risk analysis" or "risk/benefit" analysis.

(5) Social welfare analysis: Social welfare measures attempt to reflect the value of all impacts of transportation projects - including user impacts, non-user impacts, environmental impacts and social impacts. This type of analysis has the advantage that in its full application, distortions present in other benefit measurement approaches (including under-counts and biases) can theoretically all be corrected. Negative externality impacts may be considered to be "disbenefits" (i.e., negative factors that reduce benefits) or "hidden costs". Either way, care must be taken to avoid double-counting of benefits and costs, as some externality impacts may ultimately be reflected in economic measures through changes in property values or population and business attraction to an area. In theory, this approach can lead decision-makers to a more complete analysis of net project costs and benefits. In practice, its usefulness is limited by lack of consensus on the appropriate valuation of non-economic effects.

Vickerman (1991), Bruinsma and Rietveld (1994) addressed twofold subdivided approaches which are in common use in empirical research to trace impact of new infrastructure on spatial patterns of economic activities. First, there is a subdivision between models and non-model approaches. Second, there is a subdivision based on the spatial level of aggregation of the data input.

The main difference between aggregate and disaggregate approaches is that the former use a measure of total infrastructure within the region concerned as the input measure, disaggregate approaches consider only transportation infrastructure and use accessibility as the measure of transportation.

Models based on aggregate data: This type of models is mainly used by transport engineers, urban planners and economists. Integrated transport-land use models for example can be considered as an extension of the well known urban transport models where a feedback is formulated from the transport system on employment and population growth in the various zones (Webster *et al.*, 1988).

Another example is the production function approach, which are applied to estimate the impact of an improvement of a certain type of transport infrastructure on the productivity of labour and capital. Improvement of transport infrastructure in a region may lead to an increase in the productivity of private production factors. This may lead to an expansion and/or relocation of those production factors in and between regions. This effect is analyzed by location models. In those models the impact of transport infrastructure is analyzed together with other factors that may influence the location of firms like the price of labour, investment subsidies, sectoral structure, accessibility of markets etc. The main target in a location model is to explain the changes in private investments and/or employment by those location factors (Evers *et al.*, 1987).

Models based on disaggregate data: Revealed and stated preference approaches are most common for studying the impact of transport infrastructure on spatial patterns of economic activities with models using data on a disaggregate level. These approaches may be applied at different spatial levels. Both approaches are based on individual utility functions. In the case of revealed preference models the utility function is estimated with data concerning choice behaviour in actual situations. In case of stated preference models the data concern preferred behaviour of respondents who made a choice in a laboratory situation (Kroes and Sheldon, 1988).

Other approaches based on aggregate data: The quasi-experimental approach is an example of a non-model approach based on aggregate data. In this approach the development in a region is analyzed after an improvement of the infrastructure. This development is compared with the development in the region before the improvement and/or with a group of reference regions. The choice of appropriate reference regions is vital for the quality of this approach (Isserman, 1990).

Other approaches based on disaggregate data: One of the non-model approaches that concerns surveys among entrepreneurs are usually ignored in model type studies. This method differs among others in theoretical background, type of data used, spatial level of analysis and dependent variable (productivity versus employment). It is therefore not surprising that these approaches sometimes lead to rather different outcomes (Offner, 1992).

Other than these types of studies researchers also used Production Frontier approach to examine the relationship among public capital (that includes infrastructure capital) and economic performance both at the regional and country level. There are essentially four major methods (Coelli *et al.*, 1998):

- Least-squares econometric production models,
- Total Factor Productivity (TFP) indices,
- Data Envelopment Analysis (DEA), and
- Stochastic Frontier Analysis (SFA).

The first two methods are most often applied to aggregate time-series data and provide measures of technical change and/or TFP. Both of these methods assume all firms are technically efficient. Latter two methods, on the other hand, are most often applied to data on a sample of firms (at one point in time) and provide measures of relative efficiency among those firms. Hence these two methods do not assume that all firms are technically efficient. Also DEA and stochastic frontiers can be used to measure both technical change and efficiency change, if panel data are available.

2.6 Production Frontier Approach

Performance of invested resources is usually measured by efficiency factor, which is the ratio between output and input factors of production. By estimating the best-practice production function the Production Frontier Approach calculates technical efficiency as the distance between the production frontier and the observed output.

2.6.1 Efficiency concepts

Farrell (1957) provided the impetus for developing the literature on empirical estimation of technical, allocative and economic efficiency. His work led to a better understanding of the concept of the efficiency. He proposed that the efficiency of a firm consisted of these components: technical, allocative and economic efficiencies. Technical efficiency is defined as the ability to produce a given level of output with a minimum quantity of inputs under certain technology. Allocative efficiency refers to the ability to choose optimum input levels for given factor prices. Economic or total cost efficiency is the product of technical and allocative efficiencies. An economically efficient input-output combination would be on both the frontier function and the expansion path.

Farrell (1957) illustrated his ideas using a simple example involving firms that use two inputs (x_1 and x_2) to produce a single output y such that the production function is $y=f(x_1, x_2)$, under the assumption constant return to scale. Knowledge of the unit isoquant of fully efficient firms, represented by SS′ in Figure 2.1, permits the measurement of technical efficiency. If a given firm uses quantities of inputs, defined by the point P, to produce a unit of output, the technical inefficiency of that firm could be represented by the distance QP, which is the amount by which all inputs could be propositionally reduced without a reduction of output. This is usually expressed in percentage terms by the ratio QP/OP, which represents the percentage by which all inputs needed to be reduced to achieve technically efficient production. The technical efficiency (*TE*) of a firm is most commonly measured by the ratio *TE* = OQ/OP, which is equal to one minus QP/OP. It takes a value between zero and one, and, hence, provides an indicator of the degree of technical efficiency of the firm. A value of one implies that the form is fully technically efficient. For example, the point Q is technically efficient because it lies on the efficient isoquant.

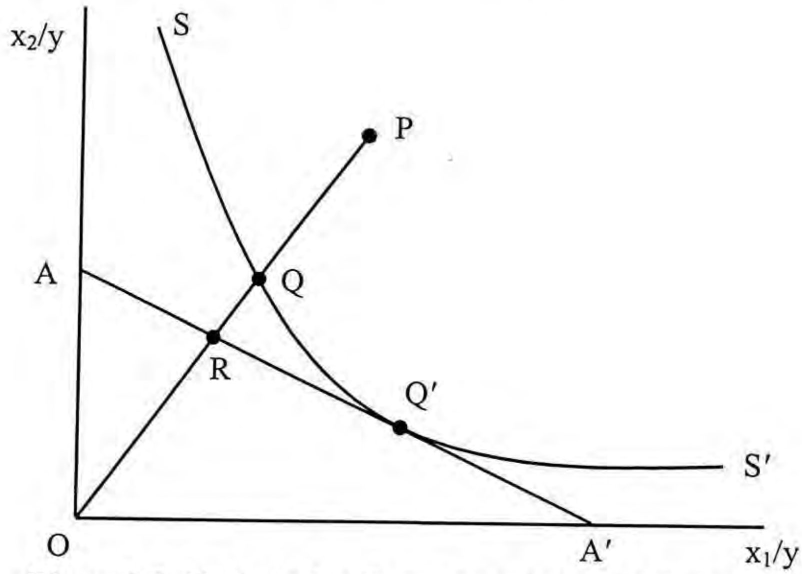


Figure 2.1: Technical, Allocative and Total Efficiency

The input-oriented measure of technical efficiency of a firm can be expressed in terms of input-distance function d_i(x, y) as: $TE = 1/\ d_i(x, y)$. The firm under consideration is technically efficient if it is on the frontier, in which case *TE* = 1 and d_i(x, y) is also equal to 1.

In the presence of input price information, it would be possible to measure the cost efficiency of the firm under consideration. Let w represent the vector of input prices and let x^P represent the observed vector of inputs used associated with point P. Let x and x' represent the input vector associated with the technically efficient point Q and the cost-minimising input vector at Q' respectively.

Then cost efficiency of the firm is defined as the ratio of input costs associated with input vectors, x and x*, associated with points, P and Q' Thus

$$CE = \frac{w'x'}{w'x^P} = OR/OP$$

If the input price ratio, represented by the slope of the isocost line, AA' in Figure 2.1, is also known, then allocative efficiency and technical efficiency measures can be calculated using the isocost line, These are given by

$$AE = \frac{w'x'}{w'x} = OR/OQ$$

$$TE = \frac{w'x}{w'x^P} = OQ/OP$$

These equations follows from the observation that the distance RQ represents the reduction in production costs that would occur if production were to occur at the allocatively (and technically) efficient point Q', instead of at the technically efficient, but allocatively inefficient, point Q.

Given the measure of technical efficiency, the total *overall cost efficiency (CE)* can be expressed as a product of technical and allocative efficiency measures:

$$TE \times AE = (OQ/OP) \times (OR/OQ) = OR/OP = CE$$

The cost reduction achievable is the distance RP that could be obtained by moving from point P (the observed point) to point Q' (the cost minimizing point).

2.6.2 Techniques of efficiency measurement

The above graphical illustration of efficiency measures assume that the production technology is known. In practice, this is not the case, and the efficient isoquant or frontier must be estimated from the sample data. Farrell (1957) suggests using either of the following methods:

- *Mathematical Programming Approach* - a nonparametric piecewise-linear convex isoquant to be constructed so that no observed point should lie to the left or below it.
- *Parametric or Econometric approach* - a parametric function such as the Cobb-Douglas form, fitted to the data so that no observed point should lie to the left or below it.

Mathematical programming approach can be categorized according to the type of data available (cross section or panel), and according to the type of variables available (quantities only, or quantities and prices). With quantities only, technical efficiency can be calculated, while with quantities and prices economic efficiency can be calculated and decomposed into its technical and allocative components, just as in the econometric approach. The two approaches differ in many ways, but the essential differences, and the sources of the advantages of one approach or the other, boil down to two characteristics.

1. The econometric approach is stochastic, and so attempts to distinguish the effects of noise from the effects of inefficiency. The programming approach is nonstochastic, and lumps noise and inefficiency together and calls the combination inefficiency.

2. The econometric approach is parametric, and confounds the effects of misspecification of functional form (of both technology and inefficiency) with inefficiency. The programming approach is nonparametric and less prone to this type of specification error.

The two principal methods that have been used are data envelopment analysis (DEA) and stochastic frontier analysis (SFA), which involve mathematical programming and econometric methods, respectively.

SFA is an alternative method for frontier estimation that assumes a given functional form for the relationship between inputs and an output. When the functional form is specified then the unknown parameters of the function need to be estimated using econometric techniques. These requirements make SFA more computationally demanding than DEA. Coelli *et al.* (1998) cited some econometric methods for estimating economic relationships.

Production, cost and profit functions express one output as a function of inputs, while a variable cost function expresses cost as a function of input prices and outputs. Common functional forms include linear, Cobb-Douglas, normalized quadratic, translog etc. Other than this method, single equation estimation using ordinary least square estimation and maximum likelihood estimation, imposing equality and inequality constraints, hypothesis testing, Bayesian approach, simulation methods for drawing independent variables and Markov Chain Monte Carlo Methods are also in practice.

It is possible to estimate the important economic characteristics of a production technology using production, cost or profit function models. The empirical literature (Coelli *et at.*, 1998) contains a wide variety of models, each underpinned by important assumptions concerning functional form and the distribution of random errors. Under fairly weak assumptions it is usually possible and appropriate to estimate models using the method of least squares. Slightly stronger distributional assumptions allow estimating the unknown parameters using maximum likelihood or Bayesian techniques. Maximum likelihood estimators are popular because they have desirable large sample properties. Bayesian estimation is becoming increasingly popular, not least because it allows obtaining exact finite-sample results concerning nonlinear functions of the parameters.

2.7 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a Linear Programming methodology to measure the efficiency of multiple Decision Making Units (DMUs) when the production process presents a structure of multiple inputs and outputs. DEA is a fractional programming model that can include multiple outputs and inputs without recourse to a priori weights (as in index number approaches) and without requiring explicit specification of functional relations between inputs and outputs (as in regression approaches). It computes a scalar measure of efficiency and determines efficient levels of inputs and outputs for the organizations under evaluation. DEA was first introduced in the literature in 1978 (Charnes *et al.*, 1978).

Following an illustrative example may be helpful to understand the results of DEA. Assume that a system of five production units (or decision making units) is B, C, D, E and F. Each of these units uses two inputs x_1 and x_2 in different proportions to produce a single output y. The illustration is given in Figure 2.2.

Production units B, C and D are the best performing units of the set of five lying on the efficient frontier AA′. The technical efficiency (TE) of B, C and D are 1. Neither of E or F is technically efficient (efficiency < 1).

Efficiency (TE) of E = OE′/OE
Efficiency (TE) of F = OF′/OF

E′ and F′ are on the efficiency frontier. The ratio OE′/OE and OF′/OF are the ratios by which the inputs of E and F could be reduced without decreasing the output, indicated by points E′ and F′ respectively.

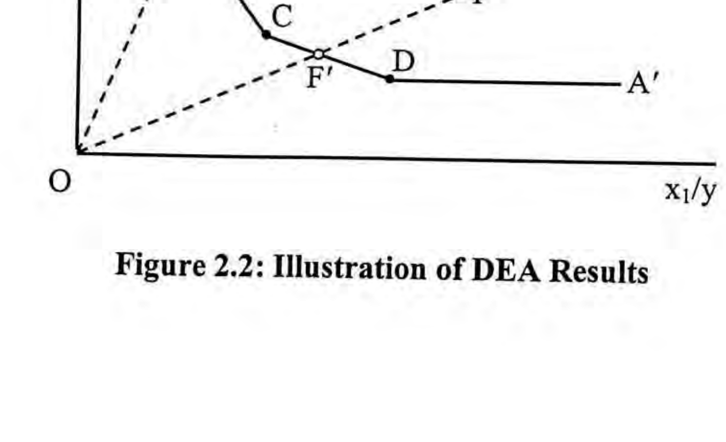


Figure 2.2: Illustration of DEA Results

The efficient point for F is F′, which lies between points C and D. Therefore, C and D are the peers of unit F. But for E the only peer is B. Again, the efficient point E′ could be moved to point B, thereby reducing the ratio x_2/y without affecting the ratio x_1/y. This ability to reduce one input without affecting another input (when on the efficient frontier) is referred to as slack. The distance BE′ is the measure of this slack. When an infinitely large number of production units are used to construct the frontier the smooth curve of the frontier may eliminate the observed slack. Thus slack is to an extent a result of the calculation performed more than necessary attributes of the real world (Hollas, Macleod and Stansell, 2002).

Thus, clearly, DEA measures the relative technical efficiency of the production units under consideration.

A common measure for relative efficiency is :

$$Efficiency = \frac{Weighted \quad sum \quad of \quad Outputs}{Weighted \quad sum \quad of \quad Inputs}$$

Introducing the usual notation this can be written as:

$$Efficiency \ of \ unit \ j = \frac{u_1 y_{1j} + u_2 y_{2j} + ... + u_r y_{rj}}{v_1 x_{1j} + v_2 x_{2j} + ... + v_i x_{ij}} \leq 1 \qquad ......(2.7.1)$$

Where, u_r = weight of output *r*

y_{rj} = amount of output *r* from unit *j*

v_i = weight of input *i*

x_{ij} = amount of input *i* from unit *j*

Efficiency is usually constrained to the range [0,1]. It is assumed that under a given production process each Decision Making Unit (DMU) will optimize its efficiency under the constraint of availability of input factors. Consequently, for a known input-output volume equation (2.7.1) becomes as optimization problem. Here the solution produces weights, which are most favourable to unit *j* and provides a measure of efficiency.

(a) Charnes, Cooper, Rhodes (CCR) version:

Following the concept of relative efficiency, Charnes, Cooper and Rhodes (1978) proposed a model that had an input orientation and assumed constant returns to scale (CRS).

Model 1: Maximize: $h_o = \dfrac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}}$;

Subject to,

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \qquad j = 1, 2, 3, \ldots\ldots\ldots, n$$

$$\frac{u_r}{\sum_{i=1}^{m} v_i x_{io}} > \varepsilon \qquad r = 1, 2, 3, \ldots\ldots\ldots, s$$

$$\frac{v_r}{\sum_{i=1}^{m} v_i x_{io}} > \varepsilon \qquad i = 1, 2, 3, \ldots\ldots\ldots, m$$

$$\varepsilon > 0$$

Where,
y_{rj} = Amount of output r produced by DMU j
x_{ij} = Amount of input i produced by DMU j
u_j = Endogenous weight of output r
v_i = Endogenous weight of input i

The model is designed to evaluate the relative performance of any decision making unit designated as DMU_o based on the observed performances of $j = 1,2,3,\ldots\ldots,n$ DMUs.

The $(y_{rj}, x_{ij}) > 0$ in the model are constants representing observed amounts of the r^{th} output and the i^{th} input of the j^{th} DMU, where $j = 1,2,3,\ldots\ldots,n$ number of DMUs in a set to convert inputs into outputs. Number of outputs, $r = 1,2,3,\ldots\ldots,s$. Number of inputs, $i = 1,2,3,\ldots\ldots,m$. $\varepsilon > 0$ represents a non-Archimedean constant, which is smaller than any positive valued real number.

The model described above is in fraction linear form. To solve the model it is necessary to convert it into simple linear form so that the methods of linear programming can be applied. In the objective function it can be observed that while maximizing a fraction or ratio it is the relative magnitudes of the numerator and denominator that are of interest rather that their individual values. It is thus possible to achieve the same effect by setting the denominator equal to a constant maximizing the denominator. The resulting linear programming model is shown below:

Model 2: Maximize: $h_o = \sum_{r=1}^{s} u_r y_{ro}$;

Subject to,

$$\sum_{i=1}^{m} v_i x_{io} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0,$$

$$v_i, u_r \geq \varepsilon > 0, \forall r, i$$

The efficiency of the target unit in a set can be obtained by solving *Model 2*. The program is run n times in identifying the relative efficiency scores of all the DMUs. The solution to this LP provides a measure of the relative efficiency of the target unit and the weights leading to that efficiency. These weights are the most favourable ones from the point of view of the target unit. To obtain the efficiencies of the entire set of units it is necessary to solve a linear program focusing on each unit in turn. In solving each linear program the solution technique will attempt to make the efficiency of the target unit as large as possible. This search procedure will terminate when either the efficiency of the target unit or the efficiency of one or more other units hits the upper limit of 1. Thus for an inefficient unit at least one other unit will be efficient with the target unit's set of weights. These efficient units are known as the peer group for the inefficient unit. It is sometimes useful to scale the data on the peer units so that a better comparison of the inefficient unit with the peer units can be made. Input data of the peer units are to be scaled in such a way so that each peer unit may use no more of an input than the inefficient unit. The solution to the DEA model thus provides a relative efficiency measure for each unit in the set, a subset of peer units for each inefficient unit, and a set of targets for each inefficient unit.

The dual of the linear program, presented above in Model 2, provides useful information and knowledge regarding the mechanism of efficiency estimation and significance of the parameters. It also involves fewer constraints than the primal and hence generally preferred to solve. The dual is shown below in *Model 3*:

Model 3: $\quad Min_{\ \theta,\lambda}\ \theta_o;$

Subject to, $\quad -y_{ro}+\sum_{j=1}^{n} y_{rj}\lambda_j \geq 0$

$$\theta x_{io}-\sum_{j=1}^{n} x_{ij}\lambda_j \geq 0,$$

θ is unrestricted sign.

Here θ provides efficiency score of the o^{th} unit. Each of the constraints of *Model 3* is associated with either the inputs or the outputs. Using the principle of complementary slackness, from the results of *Model 2* and *Model 3* the following sets of identities can be obtained at optimum solution, which imply that, the values of the weight factors u_r, and v_i provide the shadow prices for the relevant output and input respectively. The identities demonstrate that values of the weight factors provide the effect of marginal change in constraint boundary on the value of DMUs' efficiency.

$$u_r(-y_{ro}+\sum_j y_{rj}\lambda_j)=0$$

$$v_i(\theta x_{io}-\sum_j x_{ij}\lambda_j)=0$$

This method is applied in this study to measure the relative economic efficiency of different regions (districts) of Bangladesh (and to examine the significance of transportation infrastructure with respect to other production factors in achieving the efficiency level) and to compare the results with stochastic approach using the same production factors.

(b) Banker, Charnes and Cooper (BCC) version:

Subsequent papers have considered alternative sets of assumptions, such as Fare, Grosskopf and Logan (1983) and Banker, Charnes and Cooper (1984), in which variable returns to scale (VRS) models are proposed.

Model 4: Maximize: $h_o = \sum_{r=1}^{s} u_r y_{ro} - u_o$;

Subject to, $\sum_{i=1}^{m} v_i x_{io} = 1$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_o \leq 0,$$

$$v_i, u_r \geq \varepsilon > 0, \forall r, i$$

As formulated here the BCC model allows variable returns to scale and measures only technical efficiency for each DMU. This implies that, for a DMU to be considered as CCR efficient, it must be both scale and technically efficient. For a DMU to be considered BCC efficient, it only needs to be technically efficient.

2.8 Stochastic Frontier Analysis (SFA)

The above programming solution does not take account of the sort of statistical errors, e.g. errors of measurement, which are considered in the usual least squares method of regression. This was pointed out by Timmer (1971), who provided a simple method to deal with these errors introducing probabilistic approach to the deterministic frontier used by Aigner and Chu (1968). Based on this assumption Aigner, Lovell, and Schmidt (1977), abbreviated as ALS and a month earlier Meeusen and van den Broeck (1977), abbreviated as MB, independently proposed the stochastic production frontier models. Both these papers are very similar and appeared shortly before a third SFA paper by Battese and Corra (1977).

These three original SFA models shared the composed error structure mentioned previously, and each was developed in a production frontier context. The model can be expressed as:

$$y_{it} = f(x_{it}; \beta_t) \cdot exp(v_{it} - u_{it}) \quad \text{............} \quad (2.8.1)$$

Where, all production units are indexed with subscript i (=1, 2, 3,...,n) and the observation time periods or years are indexed with subscript t (= 1, 2, 3, ...,k), and,

- y_{it} = Production level or scalar output;
- $f(\bullet)$ = Production technology representing function;
- x_{it} = A vector of input quantities for the i[th] production unit in the t[th] time period.
- β_t = A vector of unknown technology parameters in the t[th] time period
- v_{it} = A symmetric random error term, independently and identically distributed as $N^+(\mu,\sigma_V^2)$, intended to capture the effects of statistical noise.
- u_{it} = A non-negative random error term ($u \geq 0$), independently and identically distributed as $N^+(\mu,\sigma_U^2)$. This term is intended to capture the effects of technical inefficiency.

MB assigned an exponential distribution to u_{it}, Battese and Corra (1977) assigned a half-normal distribution to u_{it}, and ALS considered both distributions to u_{it}. Parameters to be estimated include β_t, σ_V^2, and a variance parameter σ_V^2. Either distributional assumption on u_{it} implies that the composed error $(v_{it} - u_{it})$ is negatively skewed, and statistical efficiency requires that the model be estimated by maximum likelihood.

If we assume that $f(x_{it};\beta_t)$ takes the log-linear Cobb-Douglas form, then the stochastic production frontier model given in the equation (2.8.1) can be written as:

$$\ln y_{it} = \beta_0 + \sum_n \beta_n \ln x_{nit} + v_{it} - u_{it} \qquad \text{............ (2.8.2)}$$

These features of the stochastic frontier model can be illustrated graphically. To do so it is convenient to restrict attention to production units that produce the output u_i using only one input, x_i.

$$\ln y_t = \beta_0 + \beta_1 \ln x_i + v_i - u_i \qquad \text{............ (2.8.3)}$$

or, $$y_t = \exp\,(\beta_0 + \beta_1 \ln x_i + v_i - u_i)$$

or, $$y_t = \underbrace{\exp\,(\beta_0 + \beta_1 \ln x_i)}_{\substack{\text{deterministic}\\ \text{component}}} \times \underbrace{\exp(v_i)}_{\text{noise}} \times \underbrace{\exp(u_i)}_{\text{inefficiency}}$$

Such a frontier is depicted in Figure 2.3 where the inputs and outputs of two production units, A and B, and the deterministic component of the frontier model has been drawn to reflect the existence of diminishing returns to scale. Values of the input are measured along the horizontal axis and outputs are measured on the vertical axis. Unit A uses the input level x_A to produce the output y_A, while unit B uses the input level x_B to produce the output y_B (these observed values are indicated by the points marked with ×). If there were no inefficiency effects (i.e., if $u_A = 0$ and $u_B = 0$) then the frontier outputs would be

$$y_A^* \equiv \exp\,(\beta_0 + \beta_1 \ln x_A + v_A) \text{ and } y_B^* \equiv \exp\,(\beta_0 + \beta_1 \ln x_B + v_B)$$

for units A and B respectively. These frontier values are indicated by the points marked with (⊗) in Figure 2.3. It is clear that the frontier output for unit A lies above the deterministic part of the production frontier only because the noise effect is positive (i.e., $v_A > 0$), while the frontier output for unit B lies below the deterministic part of the frontier because the noise effect is negative (i.e., $v_B < 0$). It can also be seen that the observed output of unit A lies below the deterministic part of the frontier because the sum of the noise and inefficiency effects is negative (i.e., $v_{it} - u_{it} > 0$).

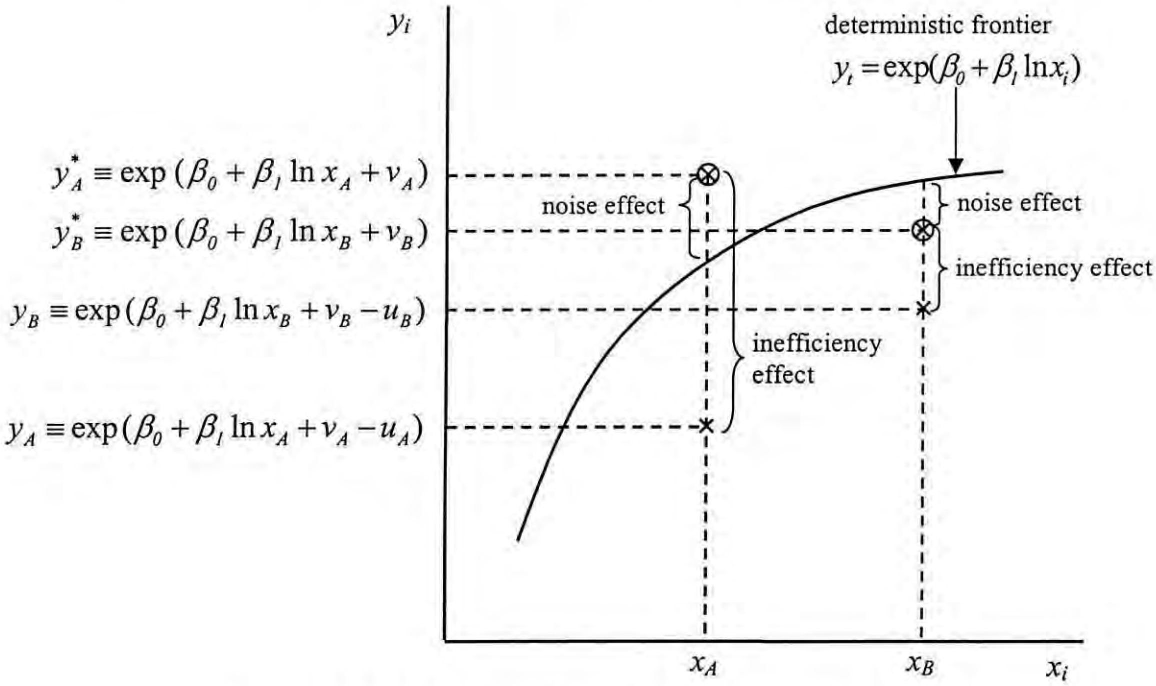


Figure 2.3: The Stochastic Production Frontier

These features of the frontier model (equation 2.8.3) generalise to the case where production units use several inputs. Specifically, (unobserved) frontier outputs tend to be evenly distributed above and below the deterministic part of the frontier. However, observed outputs tend to lie below the deterministic part of the frontier. Indeed, they can only lie above the deterministic part of the frontier when the noise effect is positive and larger than the inefficiency effect (i.e., $y_i^* > \exp(x_t;\beta)$ iff $\varepsilon_i \equiv v_{it} - u_{it} > 0$).

Much of stochastic frontier analysis is directed towards the prediction of the inefficiency effects. The most common output-oriented measure of technical efficiency is the ratio of observed output to the corresponding stochastic frontier output:

$$TE_i = \frac{y_i}{\exp(x_i\beta + v_i)} = \frac{\exp(x_i\beta + v_i - u_i)}{\exp(x_i\beta + v_i)} = \exp(-u_i) \qquad \text{....... (2.8.4)}$$

This measure of technical efficiency takes a value between zero and one. It measures the output of the i^{th} unit relative to the output that could be produced by a fully efficient unit using the same input vector. Clearly the first step in predicting the technical efficiency, TE_i, is to estimate the parameters of the stochastic production frontier model (equation 2.8.1).

2.9 Stochastic Data Envelopment Analysis (SDEA)

The dilemma of the efficiency evaluation approach choice depends on the trade off between the minimal specification that favours DEA and the handling of stochastic error in measuring DMU efficiency that favours SFA. To compete with SFA in error handling, the stochastic data envelopment analysis (SDEA) approach was developed by considering the value of inputs and outputs as random variables in the SDEA model specification.

Following sections introduce the generalized stochastic CCR model, which is related to the possible presence of increasing, decreasing and constant returns to scale. This is different from the deterministic case. It is also shown that variable returns to scale in the generalized stochastic BCC model depend not only on the value of the additional variable but also on other variables.

(a) Stochastic Efficiency in CCR model:

Introducing the following version of a probability model to adapt the usual definitions of "DEA efficiency" to a Chance Constrained Programming context (Cooper *et al.*, 1996),

$$\text{Maximize:} \quad \Pr\left\{\frac{\sum_{r=1}^{s} u_r \tilde{y}_{ro}}{\sum_{i=1}^{m} v_i \tilde{x}_{io}} \geq 1\right\} \qquad \text{............ (2.9.1)}$$

$$\text{Subject to,} \quad Pr\left\{\frac{\sum_{r=1}^{s} u_r \tilde{y}_{rj}}{\sum_{i=1}^{m} v_i \tilde{x}_{ij}} \geq 1\right\} \geq 1 - \alpha_j\ , \qquad j = 1, 2, 3, \ldots\ldots\ldots, n$$

$$u_r, v_i \geq 0 \qquad \forall r, i.$$

Here, Pr means "Probability" and the symbol "~" is used to identify the inputs and outputs as random variables with a known joint probability distribution. The, $v_i > 0$ are the virtual multipliers (= weights) to be determined by solving the above problem. This model evidently builds upon the CCR model of DEA, with the ratio in the objective representing output and input values for DMU_O, the DMU to be evaluated, which is also included in the $j = 1, 2, 3, \ldots\ldots\ldots, n$ DMUs with output-to-input ratios represented as chance constraints.

Evidently, the constraints in equation (2.9.1) are satisfied by choosing $u_r = 0$, and $v_i > 0$ for all r and i. Hence, for continuous distributions, it can be written as:

$$\Pr\left\{\frac{\sum_{r=1}^{s} u_r^* \tilde{y}_{ro}}{\sum_{i=1}^{m} v_i^* \tilde{x}_{io}} \leq 1\right\} + \Pr\left\{\frac{\sum_{r=1}^{s} u_r^* \tilde{y}_{ro}}{\sum_{i=1}^{m} v_i^* \tilde{x}_{io}} \geq 1\right\} = 1$$

$$\Pr\left\{\frac{\sum_{r=1}^{s} u_r^* \tilde{y}_{ro}}{\sum_{i=1}^{m} v_i^* \tilde{x}_{io}} \leq 1\right\} = 1 - \alpha^* \geq 1 - \alpha_0,$$

$$u_r, v_i \geq 0 \qquad \forall r, i.$$

Here, * refers to an optimal value, so α^* is the probability of achieving a value of at least unity with this choice of weights and $1-\alpha^*$ is therefore the probability of failing to achieve this value. To see how these formulations may be used, we must have $\alpha_0 \geq \alpha^*$, since $1-\alpha_0$ is prescribed in the constraint for $j=0$ as the chance allowed for characterizing the $\tilde{y}_{ro}, \tilde{x}_{io}$ values as inefficient. In chance constrained programming methodology the term $1-\alpha_0$ is interpreted as the modeller's confidence level and α_0 is interpreted as the modeller's risk (a predetermined number between 0 and 1). The risk equals the probability measure of the extent to which specific conditions are violated. More formally, introducing the following stochasticized definition of efficiency:

Definition. *DMU_O is "stochastic efficient" if and only if* $\alpha^* = \alpha_0$

This opens a variety of new directions for research and potential uses of DEA. Before indicating some of these possibilities, however, replacing equation (2.9.1) with the following:

$$\text{Maximize:} \quad \Pr\left\{\frac{\sum_{r=1}^{s} u_r \tilde{y}_{ro}}{\sum_{i=1}^{m} v_i \tilde{x}_{io}} \geq 1\right\} \qquad \text{............ (2.9.2)}$$

$$\text{Subject to,} \quad Pr\left\{\frac{\sum_{r=1}^{s} u_r \tilde{y}_{rj}}{\sum_{i=1}^{m} v_i \tilde{x}_{ij}} \leq 1\right\} + Pr\left\{\frac{\sum_{r=1}^{s} u_r \tilde{y}_{rj}}{\sum_{i=1}^{m} v_i \tilde{x}_{ij}} \geq 1\right\} \geq 1, \quad j = 1, 2, 3, ..., n$$

$$u_r, v_i \geq 0 \qquad \forall r, i.$$

This simpler model makes it easier to see what is involved in uses of these chance constraints programming of DEA formulations.

(b) Stochastic Efficiency in BCC model:

Following the previous notation convention (Cooper *et al.*, 1996), $\tilde{x}_j = (\tilde{x}_{1j}, ..., \tilde{x}_{mj})^T$ and $\tilde{y}_j = (\tilde{y}_{1j}, ..., \tilde{y}_{sj})^T$ to represent ($m \times 1$) and ($s \times 1$) random input and output vectors, respectively, and $x_j = (x_{1j}, ..., x_{mj})^T$ and $y_j = (y_{1j}, ..., y_{sj})^T$ stand for the corresponding vectors of expected values of input and output for each DMU$_j$, $j = 1, 2, 3, ..., n$. The superscript T represents transpose. Let us consider all input and output components to be jointly normally distributed in the following chance constrained version of a stochastic DEA model in BCC version:

$$\text{Maximize:} \quad \phi \qquad \text{............ (2.9.3)}$$

$$\text{Subject to,} \quad \Pr\left\{\sum_{j=1}^{n} \tilde{y}_{rj}\lambda_j \geq \phi\, \tilde{y}_{ro}\right\} \geq 1 - \alpha, \qquad r = 1, 2, 3, ..., s$$

$$\Pr\left\{\sum_{j=1}^{n} \tilde{x}_{ij}\lambda_j \leq \phi\, \tilde{x}_{io}\right\} \geq 1 - \alpha, \qquad i = 1, 2, 3, ..., m$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 1, \qquad j = 1, 2, 3, ..., n$$

Here, ϕ is otherwise unconstrained and λ_j represents the structural variables.

Definition. *DMU$_O$ is "stochastic efficient" if and only if the following two conditions are both satisfied:*

(i) $\phi^* = 1$;

(ii) Slack values are all zero for all optimal solutions.

The $\widetilde{x}_{ij} = \widetilde{x}_{io}, \widetilde{y}_{rj} = \widetilde{y}_{ro}$ values for DMU_O appear on the left as well as on the right inside the braces of equation (2.9.3). Hence, we can always get a solution with $\phi = 1$, $\lambda_o = 1$ and $\forall \lambda_j = 0$ $(j \neq 0)$ with all slacks zero. However, this solution need not be maximal. It follows that a maximum with $\phi^* > 1$ in equation (2.9.3) for any sample of j = *1, 2, 3, ..., n* observations means that the DMU_0 being evaluated is not efficient because, to the specified level of probability defined by α, all outputs of DMU_0 can be increased to $\phi^* \widetilde{y}_{ro} > \widetilde{y}_{ro}$, r = *1, 2, 3, ..., s* without violating the output constraints by using a convex combination of other DMUs which will also satisfy $\sum_{j=1}^{n} \widetilde{x}_{ij}\lambda_j \le \phi \widetilde{x}_{io}$, i = *1, 2, 3, ..., m*. The stochastic model in equation (2.9.3) is evidently a generalization of the BCC model in 2.7 (Model 4).

2.10 Studies that used DEA, SFA and SDEA

As Charnes, Cooper, Lewin and Seiford (1994) explain in their introduction, the story of data envelopment analysis begun with Edwardo Rhodes's dissertation, which was the basis for the later published paper by Charnes *et al.* (1978). In his dissertation, E. Rhodes used the production efficiency concept by Farrell (1957) to analyze the educational program for disadvantaged students in the USA. Rhodes compared the performance of students from schools participating and not participating in the program. The performance was recorded in terms of inputs and outputs, e.g., "increased self-esteem" (measured by psychological tests) as output and "time spent by mother reading with child" as input. The subsequent work on efficiency evaluation of multiple inputs and outputs technology led to Charnes *et al.* (1978), where the CCR model for DEA was formulated.

The introduced CCR model is derived for the technology with constant returns to scale. This fact is reflected in the shape of the production possibility frontier when the frontier is formed by a single ray. The efficient DMU is an element of the production possibility frontier set up by frontier ray. To handle the variable returns to scale, introduced by Farrell and Fieldhouse (1962) in to the SFA framework, the CCR model was extended by Banker, Charnes and Cooper (1984). Since the BCC model's frontier is a piecewise linear set, Banker *et al.* (1984) defined weak efficiency (a weakly efficient DMU has nonzero slacks) and efficiency (an efficient DMU has zero slacks). Further, only the efficient DMUs are elements of the estimated production possibility set frontier in the framework of the BCC model. As many applications suggest, two capabilities that make DEA a powerful tool are the capability of handling multiple inputs-outputs models and that the production function form is not required. The efficiency scores in various industries are examined e.g. in air transportation Land, Lovell and Thore (1993), fishing

Walden and Kirkley (2000), banking Ŝevĉoviĉ, Halicka' and Brunovsky' (2001), Byrnes and Valdmanis (1989) where 123 US hospitals were covered and Halme and Korhonen (1999) examines dental care units. A bibliography (1978-2001) of Data Envelopment Analysis (DEA) containing 2,152 DEA applications in various fields can be found in the RUTCOR Research Report, RRR 01-02, January 2002 (Tavares, 2002). DEA found its way to transportation analysis in a variety of assessments and it has been used in benchmarking of railways (Tsamboulas and Frangos, 2003), aviation and airport performance assessments (Humphreys and Francis, 2002, Saffarzadeh and Bahramian, 2002), and public transportation systems evaluations (Karlaftis, 2000).

The expanding number of papers devoted to DEA helped to identify the limitations of the DEA approach. An analyst should keep these limitations in mind when choosing whether or not to use DEA. DEA is good at estimating the "relative" efficiency of a DMU but not in "absolute" efficiency estimation. In other words, DEA reveals how well DMU is doing compared to other DMU but not compared to a "theoretical maximum". This is the result of the analyst's limitation in knowledge of the true production function.

Since DEA is an extreme point technique, noise (even symmetrical noise with zero mean) such as measurement error can cause significant problems because the solution to optimization problems is sensitive to changes in data. As a consequence of this, theoretical attempts to incorporate these errors were made. SDEA applications are based on the theoretical paper by Land *et al.* (1993), where the authors used their new models to examine the efficiency of the same schooling program for disabled scholars as in Charnes *et al.* (1978). In Land *et al.* (1993), the authors offered the prospect of stochastic data envelopment analysis and constructed their own model (the LLT model). They introduced the stochastic component to DEA and derived the LLT model as a chance constrained version of BCC output oriented model in envelopment form. Further, Land *et al.* (1993) transformed these problems to their deterministic non-linear equivalents, which allowed them to determine the efficient DMUs.

Olesen and Petersen (1995) presented a different approach to incorporating the stochastic component into DEA. Olesen and Petersen (1995) assumed that the inefficiency of DMU can be decomposed into true inefficiency and disturbance term and derived the OP model from the multiplier formulation of the BCC model. The approaches of Land *et al.* (1993) and Olesen and Petersen (1995) to SDEA are compared by Olesen (2002) and the weaknesses of both approaches are identified. The LLT model is criticized because it does not account for all the correlations that can occur in disturbances. Olesen (2002) criticizes the OP model proposed by Olesen and Petersen (1995) because the OP model ignores correlation between DMUs and the related weakness of the OP model is omission of the fact that a convex combination of two DMUs has a lower variance than the DMUs themselves, except for the case where the input output i.d. vectors are perfectly correlated. Straightforward remedy for the OP model is to take the union of confidence regions for any linear combination of the stochastic vectors themselves rather than using a piecewise linear envelopment of the confidence regions. Olesen (2002) implemented this idea and derived the combined chance constrained model in his paper.

The theoretical paper by Huang and Li (1994.) sketches stochastic models with the possibility of variations in inputs and outputs and introduced stochastic efficiency dominance. Huang and Li (1994) defined the efficiency measure of a DMU via joint probabilistic comparisons of inputs and outputs with other DMUs which can be evaluated by solving a chance constrained programming problem. By utilizing the theory of chance constrained programming, deterministic equivalents are obtained for both situations of multivariate symmetric random disturbances and a single random factor in production relationships. Li (1998) obtained a linear deterministic equivalent via programming theory under the assumption of the single random factor and the stochastic supporting hyperplane is use to analyze the returns to scale. In the following sections, I will derive oriented form of models derived Li (1998) and I will use the efficiency dominance principle to obtain chance constrained equivalents to one stage oriented DEA models.

The papers by Gstach (1998) and Simar (2003) show that there are research directions in which the future developments on DEA and SDEA may be driven. Gstach (1998) proposes using DEA to estimate a pseudo frontier (nonparametric shape estimation) and then apply a maximum likelihood-technique to the DEA-estimated efficiencies to estimate the scalar value by which this pseudo-frontier must be shifted downward to get the true production frontier (location estimation). Simar (2003) proposes, for cases where noise to signal ratio is low, the bootstrapping method for improving the performance of the deterministic DEA frontier estimation.

Mortimer (2002) in his comparative study of SFA and DEA literature summarizes the results from SFA and DEA studies to identify the amount of correlation between scores in SFA and DEA comparative studies. Mortimer (2002) calls for more studies that will compare efficiency scores correlation across production efficiency approaches.

The present studies show strong correlation (e.g. Ferro-Luzzi, Ramirez, Flückiger and Vassiliev (2003) or very low correlation (e.g. Lan and Lin (1998), Wadud and White (2000)) of obtained efficiency rankings.

The major problems associated with solving the DEA models are the analysis of a large set of DMUs and the solutions with zero elements. The analysis of a large data set leads to large size optimization problems that can be costly to solve. The solutions with zero elements cause problems when these solutions are interpreted as inputs and outputs shadow prices. Gonzales-Lima, Tapia and Thrall (1996) present the primal-dual interior points computational methods as the methods that significantly improve the reliability of solution in comparison to simplex methods. The interior-points methods maximize the product of the positive components among solutions, which means that the number of zero components of the optimal solution is minimized. Due to this solution's property it is easier to interpret the DEA models results. Therefore, as the part of the theoretical work the interior point method solver is constructed.

2.11 Selection of Proper Method

Intuitively interesting production frontier approaches has gained considerable attention in recent years. Stochastic frontier approach is more attractive to transportation system analysts and planners due to its econometric implications and ability to deal with uncertainty. But researchers are still skeptical about its capabilities because of its dependency on parametric assumptions, analytical complexities during calibration, specification constraints and ability to handle multiple outputs. On the contrary, the data envelopment approach possesses the capability to overcome these limitation of SFA particularly specification and number of outputs. It is applied in wide range of operations management decision making as summarized by Burgess and Wilson (1986) for health sector, Cullinane *et al.* (2005) for supply chain logistics and, Kirkwood and Nahm (2005) for banking sector efficiency analysis. Recently, DEA methodology has been applied by Alam *et al.* (2004 and 2005) to assess the dynamic relationship between transportation investment and economic development. Despite broad applications the approach suffers from a few limitations as outlined below.

- Inability to deal with stochastic data: The linear programming based DEA method is deterministic in nature. Considering the complexities and uncertainties in the relationship between transportation infrastructure and economic development, such a limitation imposes severe constraints in its applicability. Although in the past few years research works by Banker (1983), Land *et al.* (1993), Olesen and Petersen (1994), Cooper *et al.* (2002) and, Ruggiero (2003) present alternative frameworks for incorporation of stochastic characteristics in DEA construction (e.g., chance constraint SDEA), these approaches have not become widely operational due to analytical and computational complexities.

- In DEA approach there exists a binding constraint regarding the upper limit of efficiency to be less than 1. Analytically the constraint binds the feasibility zone and enables the system to reach finite feasible solution. In the field of research in transportation economics the constraint imply that the output should not exceed input, which seems to be counter intuitive.

- Conventional DEA approach does not have any goodness of fit statistics and significance tests to examine the integrity of the analysis.
- In DEA approach efficiency of the target Decision Making Unit (DMU) relies on the composition of peer group. Measured efficiency and the weight factors may vary when the target DMU changes and thereby comparison of measured efficiencies may be difficult.

To overcome these problems a new framework to assess efficiency of production units using choice theoretic approach is presented in this study. The analytical approach enables incorporation of stochastic error in assessing production frontiers as well as facilitates relaxation of the constraints discussed above. The research is concerned with analyzing the dynamic interaction between accessibility and economy in Bangladesh using pooled data of land, labour, capital and accessibility for the period of 25 years between 1980 and 2005.

2.12 Summary

In this chapter, the relation between transportation investment and economic development based on previous studies has been summarized. Brief description of the methods of assessing impact of transportation on economic growth has also been described in this chapter. Different techniques of production frontier analysis have been evaluated based on a comprehensive literature search. Finally, an attempt to make a justification of a new approach has been presented. Theoretical framework of this new approach has been illustrated in the following chapter.

3. STUDY DESIGN AND METHODOLOGY

3.1 Introduction

Assessing regional production process and its interaction with productions factors is one of the most challenging research topics in transportation and regional planning. Issues of particular interest include assessment of production function and variations in regional production efficiency. Core aspects underlying the analysis comprise variables to incorporate and methodology to pursue.

In the context of performance evaluation efficiency is a key concept and possesses practical significance for resource allocation among competing entities. Efficiency and demand of input parameters are two determining factors influencing decision-making process. This chapter presents a theoretical framework to measure efficiency and demand for production factors simultaneously based on stochastic extension of Data Envelopment Analysis (DEA). It incorporates Cobb-Douglas type production function and choice theoretic approach in DEA structural formulation.

One of the most intriguing matters in the mechanism(s) of the relationship(s) between transportation investments and economic development is the time lag between the two events. This is partially due to the complexity of dynamic influence of transportation investments that materializes through direct and indirect benefits, which include short term effects such as the creation of employment and increase of market for local goods and services and longer term effects like the establishment of industries for utilization of local goods and services. Assessment of time lag between investment and its return affects evaluation of the benefits of investment which, in turn, has significant implications on decision making process. Based on choice theoretic approach, a framework for capturing this dynamic relationship between transportation investment and economic development has been examined in this research. A comparative analysis of the same using conventional linear programming based DEA has also been conducted in this study. Design of the study is summarized in Figure 3.1 in a flow diagram.

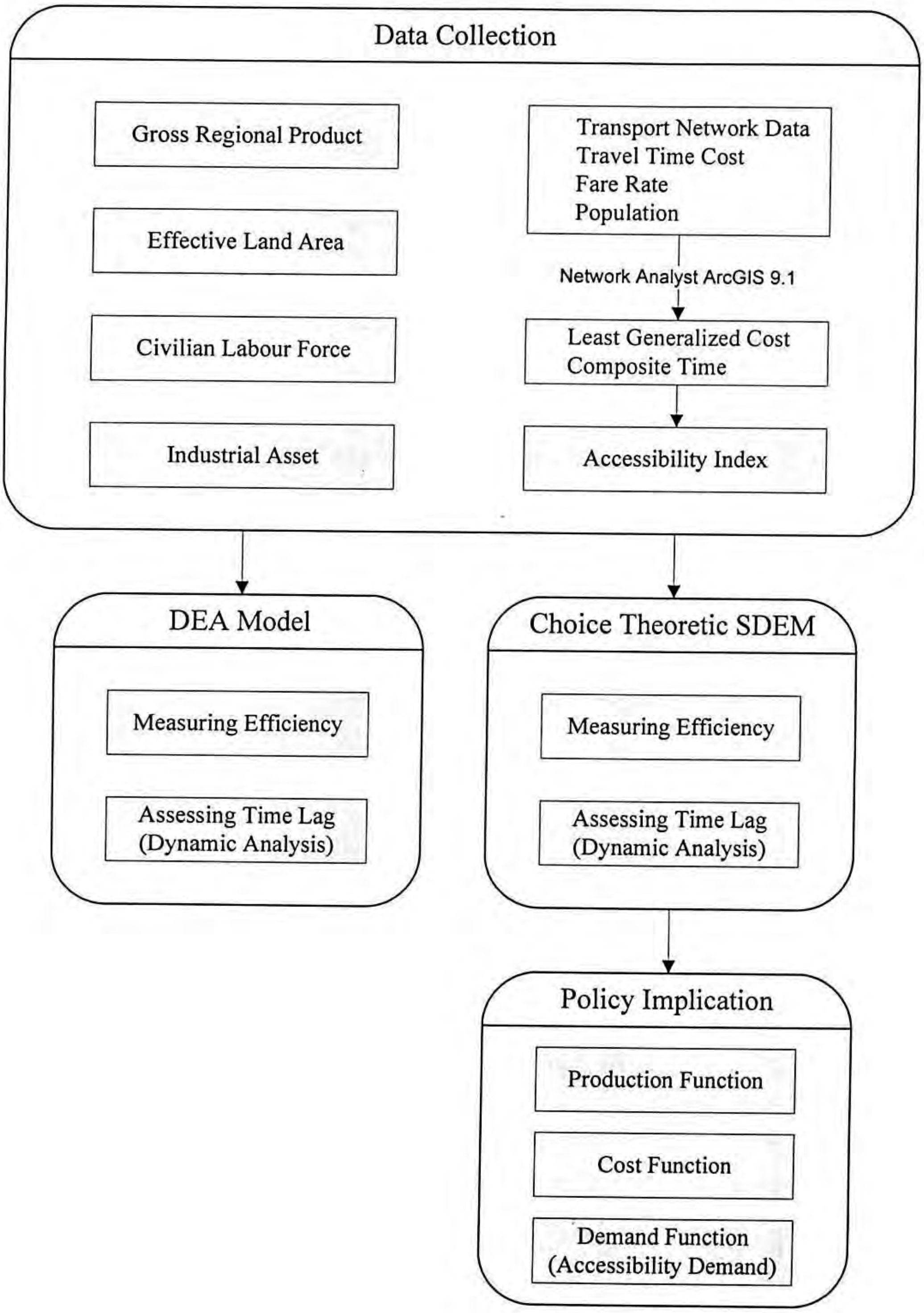


Figure 3.1: Design of the Study

3.2 Measurement of Regional Efficiency

Firm performance is conventionally judged utilising the concept of economic efficiency, which is generally assumed to be made up of two components technical efficiency and allocative efficiency. The former is defined as the capacity and willingness of an economic unit to produce the maximum possible output from a given bundle of inputs and a technology. The latter concept is defined as the ability and willingness of an economic unit to equate its specific marginal value product with its marginal cost. Quantification of these measures is useful in three ways. One, as measures per se, they facilitate comparisons across similar economic units, i.e. they indicate relative efficiency. Second, where measurement reveals variations in efficiencies among economic units, further analysis can be undertaken to identify the factors causing such variations. Third, such analyses bear policy implications for the improvement of efficiencies. The concept of technical efficiency is central to measuring the firm performance. The measurement of technical efficiency has proved difficult and complex, and the literature provides a range of methodologies. Literature Review section (Chapter 2) of this thesis provides overview of various methodologies for measuring technical efficiency and offers a comparison between established methods of measurements.

Following sections describe the evolution of interest in measuring technical efficiency and formulation of input and output variable, based on which the efficiency model have been developed for this study.

The usual measure of efficiency is :

$$Efficiency = \frac{Output}{Input}$$

Here, in this study:

$$Efficiency = \frac{f(GDP)}{f(Land,\ Labour,\ Capital,\ Accessibility)}$$

3.2.1 Output variables

Output variable considered in the analysis includes Gross Domestic Product (GDP) in current market price of each region (greater district). Information regarding regional contribution to GDP is obtained from the national economic census. For the purpose of analysis in conventional DEA model, all the data are normalized with respect to maximum value of corresponding variable. For the analysis of choice theoretic approach actual value of the variables are used.

3.2.2 Input variables

Input variables are (i) Effective land utilization, (ii) Civilian labour force, (iii) Industrial capital in million taka, and (iv) Accessibility Index of each of the 20 regions of each of the 25 years. Each districts Population data for each year also used for Accessibility Index calculation.

Effective land area: Effective land area of each district expressed as square km includes agricultural land in terms of crop intensity i.e. single cropped, double cropped and triple cropped, forestland, mining areas, water bodies, industrial areas, settlements and other institution areas.

Civilian labour force: This variable represent the number of economically active population aged 10 years and older by each district.

Industrial Capital: Industrial capitals, consisting of direct costs and indirect costs are expressed in million Bangladeshi Taka, represents each region's manufacturing industrial capital.

Accessibility Index: In this research Accessibility index for each region of the country is used as an input instead of using transportation infrastructure stock. It is an indicator of both existing transportation infrastructure and service of each region. As described in next section, required data for accessibility index calculation are (i) shortest inter-district travel distance for all three modes (ii) respective travel time (iii) fare rates (iv) value of travel time and, (v) population percentage of each region.

All of these data are collected from the yearly publications of Statistical Year Books of Bangladesh published by the Bangladesh Bureau of Statistics. The Transportation Network data is collected from various maps showing the transportation network published by the Roads and Highways Department.

3.2.3 Accessibility index calculation

Accessibility index for each region of the country is used as an input instead of using the transportation infrastructure capital for three reasons: a) to represent effects of transport services; b) to account effects of regional distribution; and c) to reflect network connectivity.

The first is based on the realization that building more infrastructures may not solve the problem of an overall transportation constraint. In a densely populated country or region, building more roads or rail tracks would require more land, which will be subtracted from the existing land that is needed for agriculture, industrial and residential purposes. Therefore, from the land use perspective often transportation service improvements are more desirable. Using accessibility index as input we capture both the infrastructure and the service effects. Multimodal transportation systems consisting of improved infrastructure and efficient service will create more flexibility, more capacity, higher speed, better quality and above all, time and cost savings - all of which will be reflected in production cost in a region.

In Bangladesh, there exist many roads in a region, but these roads are not connected with the inter-regional or national highway system. The highway or the roadway is discontinuous because of the absence of a bridge over a river crossing the highway or the roadway. As a result the huge investment in construction fails to produce the desired effect in terms of reduction in travel time and/or travel cost. In this case inclusion of highway stock as an input variable may not appropriate, rather Accessibility index may be the appropriate input variable. Another advantage of accessibility is that it can be defined to reflect both within-region changes and changes outside the region (Vickerman *et al.*, 1995).

Neimeier (1997) summarized existing measures of accessibility that range from measurement of transportation stock in a region to accessibility measure based on random utility models. Kim and Shin (2002) based their study on the road capital stock of each region, mentioned that neglecting network interdependencies and spillover effect(s) might have caused underestimation of the role of the transportation system in their study. Considering the facts stated above and the availability of information to this study, accessibility (A_i) is measured as a composite impedance (t_{ij}) function given by equation (3.2.1), as shown below, incorporating all the alternative modes and zones, which basically comes from Ortúzar and Willumsen (2001).

$$t_{ij} = \frac{-1}{\lambda_{ij}} \ln \sum_{m} P_{ijm} \exp(-\lambda_{ij}\, t_{ijm})$$
$$A_i = \sum_{i} E_j \exp(-\mu\, t_{ij}) \qquad \text{............ (3.2.1)}$$

Here, λ_{ij} and μ are scale factors, which depend on the unit of measurement of travel impedance. t_{ijm} is the travel impedance for the m-th mode between zones i and j. Although usually λ_{ij} is considered to vary with the value of travel impedance, in the analysis it is assumed to be constant. E_j is a measure of attraction of zone j, here substituted by the product of population percentage of the origin and destination zones. P_{ijm} is the probability of choosing mode m from zone i to zone j, and can be formulated as:

$$P_{ijm} = \frac{\exp(-\lambda_{ij}\, t_{ijm})}{\sum_{m} \exp(-\lambda_{ij}\, t_{ijm})} \qquad \text{............ (3.2.2)}$$

The travel impedance between two zones is estimated by using Network Analyst tool of ArcGIS 9.1 on GIS layers of roads, rail and waterway network of Bangladesh. The tool estimates the optimal path between each origin-destination pair and provides information regarding travel time and travel length. The method is applied for all the alternative modes. Travel impedances for each mode and origin-destination pairs are measured in the form of generalized cost of travel using travel time, length, average travel cost per unit length and value of time (equation 3.2.3). The travel impedance t_{ijm} is calculated using the following expression (Ortúzar and Willumsen, 2001):

$$t_{ijm} = a_1 T_{ij} + a_2 F_{ij} \qquad \text{............ (3.2.3)}$$

where, T_{ij} is the in-vehicle travel time, F_{ij} is the fare charged to travel from *i* to *j*, a_1 is the value of travel time or more precisely the value of in vehicle travel time, and a_2 is the weight attached to the fare.

Accessibility of zone *i* (A_i) is defined as the population weighted sum of negative exponential of aggregate travel impedance of the available modes for all the destination zones as shown in equation (3.2.1, 3.2.2 and 3.2.3) above.

3.3 DEA Model to Measure Efficiency

The linear programming formulation of the Charnes, Cooper and Rhodes (1978) DEA model, often called as CCR version of DEA model (Section 2.7) is used in calculation the relative technical efficiencies of the 20 greater districts (regions) of Bangladesh.

In the model, total GDP is considered as output. Thus, for a district the relative efficiency can be defined mathematically as follows:

$$Efficiency\ of\ j\text{-}th\ region = \frac{u_{j1} GDP_j}{v_{j1} Land_j + v_{j2} Lab_j + v_{j3}\, Cap_j + v_{j4} Acc_j}$$

Where,
- u_{rj} = weight of output *r* of region *j*
- v_{ij} = weight of input *i* of region *j*
- GDP_j = GDP of region *j*
- $Land_j$ = effective land area of region *j*
- Lab_j = labour force of region *j*
- Cap_j = industrial capital of region *j*
- Acc_j = accessibility index of region *j*

for 20 districts, $j = 1, 2, 3, \ldots, 20$
for 1 output, $r = 1$
for 4 inputs, $i = 1, 2, 3, 4$

In DEA model, maximizing the observed efficiency (Section 2.7, Model 1):

$$\text{Maximize,}\quad h_o = \frac{u_{o1}GDP_o}{v_{o1}Land_o + v_{o2}Lab_j + v_{o3}\,Cap_o + v_{o4}Acc_o}$$

$$\text{Subject to,}\quad \frac{u_{j1}GDP_j}{v_{j1}Land_j + v_{j2}Lab_j + v_{j3}\,Cap_j + v_{j4}Acc_j} \leq 1$$

Where,

GDP_j = GDP of region j

$Land_j$ = effective land area of region j

Lab_j = labour force of region j

Cap_j = industrial capital of region j

Acc_j = accessibility index of region j

for 20 regions, $j = 1, 2, 3, \ldots\ldots\ldots\ldots, 20$ (except the o-th region)

and also subject to, $v_j \geq \varepsilon > 0,\ u_j \geq \varepsilon > 0.$

However, as the above-mentioned model is mathematically intractable if addressed directly, the linear program is defined by constraining denominator to be equal to unity. The resulting programming model is shown below:

$$\text{Maximize,}\quad h_o = u_{o1}GDP_o \qquad \ldots\ldots\ldots\ldots (3.3.1)$$

$$\text{Subject to,}\quad v_{o1}Land_o + v_{o2}Lab_o + v_{o3}\,Cap_o + v_{o4}Acc_o = 1$$

$$u_{j1}GDP_j - v_{j1}Land_j + v_{j2}Lab_j + v_{j3}\,Cap_j + v_{j4}Acc_j \leq 0$$

$$v_j \geq \varepsilon > 0,\ u_j \geq \varepsilon > 0.$$

The above linear programming based DEA framework provides the relative efficiencies of 20 regions of Bangladesh without incorporation of dynamic effect of transportation investment.

3.4 Lagging Effect of Accessibility

Improvement of accessibility has both short-term and long-term effects. For example the improved accessibility level of a certain time point will continue to work as a production input beyond that certain time point. But with the gradual increase in other production factors over time the effect of accessibility improvement may diminishes and thereby requiring a higher level of accessibility commensurate to the level of other production factors. Therefore, usually there exists a time lag between the accessibility improvement and the full utilization of that improvement.

In order to determine the lagging effect of accessibility improvement the Almon Polynomial Lag Model (Almon, 1965) as described in Econometrics by Maddala (1977), is used in this study. The general form of the Almon model with finite lag length λ can be expressed as

$$Y_t = \sum_{j=0}^{\lambda} \beta_j X_{t-j} + \varepsilon_t \qquad t = 1, 2, \ldots\ldots, T.$$

where the pattern of the β_j's is described by the p-th order polynomial

$$\beta_j = \sum_{k=0}^{p} \alpha_k (j)^k \qquad j = 0, 1, 2, \ldots\ldots, \lambda.$$

X_t is non-stochastic and $\varepsilon_t \sim (0, \sigma^2)$ *for all t.*

Considering the lagging effects, basic structure of DEA optimization function in this study can be formulated as follows.

$$\text{Maximize:} \quad h_O = \frac{u_1 y_{1(t)}}{v_1 x_{1(t)} + v_2 x_{2(t)} + v_3 x_{3(t)} + \sum_{i=0}^{k} \beta_i x_{4(t-i)}}$$

Subject to all constraints in Model 1 (Section 2.7)

The inputs x_1, x_2, *and* x_3 are the inputs that results in direct output. The effect of input x_4 spreads over a period of time. This implies that the current value of output y depends not just on $x_{4(t)}$ but also on some past values of $x_{4(t)}$. In this analysis, the input variable x_1 is land utilization (*Land*), x_2 is labour force (*Lab*), x_3 is industrial capital (*Cap*) and x_4 is accessibility index (*Acc*). The output variable y_1 is GDP.

For the empirical purpose it is assumed that β will have a quadratic polynomial lag characteristics (second degree) and follows a functional form as described below:

$$\beta_i = \alpha_0 + \alpha_1 i - \alpha_2 i^2 \qquad \ldots\ldots\ldots\ldots \ (3.4.1)$$

Here i is period of lag ($0 \le i \le k$) and α's are estimable parameters. The negative sign of the last parameter provides a convex shape of the lag effect, which is intuitively correct. As we are using linear programming we cannot get a negative sign as the output of endogenous estimation. So an exogenous negative sign is proposed.

Consequently, the coefficients of accessibility in equation (3.4.1) can be expressed as

$$\sum_{i=0}^{k} \beta_i Acc_{t-i} = \sum_{i=0}^{k} (\alpha_0 + \alpha_1 i - \alpha_2 i^2) Acc_{t-i}$$

$$= \alpha_0 \sum_{i=0}^{k} (Acc)_{t-i} + \alpha_1 \sum_{i=0}^{k} i(Acc)_{t-i} - \alpha_2 \sum_{i=0}^{k} i^2 (Acc)_{t-i} \qquad \text{............ (3.4.2)}$$

Under the circumstances the objective function can be simplified as

Maximize:

$$h_O = \frac{u_1 GDP_t}{v_1 Land_t + v_2 Lab_t + v_3 Cap_t + \alpha_0 \sum_{i=0}^{k} (Acc)_{t-i} + \alpha_1 \sum_{i=0}^{k} i(Acc)_{t-i} - \alpha_2 \sum_{i=0}^{k} i^2 (Acc)_{t-i}}$$

.... *(3.4.3)*

Equation (3.4.3) is used to estimate the lagged effect of accessibility in the conventional DEA approach.

3.5 Analytical Approach

3.5.1 Framework for choice theoretic SDEM to measure efficiency

Efficiency of a Decision Making Unit (DMU) is defined as the ratio of aggregate output and input. It is assumed that there exists a stochastic error term in the calculation of efficiency. Each DMU chooses its own production function as the function yields optimum output. Mathematical formulation of the model is shown in Equation (3.5.1).

$$\text{Model: } \quad \text{Maximize}_{u,v} \quad h_O = \frac{f(y_{kj})}{g(x_{lj})} + \varepsilon_j \quad \forall j \qquad \text{............ (3.5.1)}$$

Where, y_{kj} = amount of output k from unit j

x_{lj} = amount of input l to unit j

ϵ_j = Identical and independently distributed (IID) error term

f(.) and g(.) are the output and input functions respectively.

Using the very well known formulations used in maximum utility in discrete choice and originally developed by Domencich and McFadden (1975) and refined further by Ben-Akiva and Lerman (1985), it is assumed that each DMU (in this study the region) chooses the input and output functions with an objective to maximize the efficiency among the feasible choice set of C_n comprising functions utilized by all the DMUs. For the j-th DMU probability of choosing specific input-output function set can be defined as follows.

$$\Pr(h_j) = \Pr\left[\frac{f(y_{kj})}{g(x_{lj})} + \varepsilon_j \geq max_i\left[\frac{f(y_{ki})}{g(x_{li})} + \varepsilon_i\right] where\, i \in C_n \; and\; i \neq j\right]$$

Now, we assume that the error term is IID Gumbel Distributed with parameters (0, μ) and define

$$H_i^* = max_i\left[\frac{f(y_{ki})}{g(x_{li})} + \varepsilon_i\right]$$

From the properties of Gumbel Distribution, it can be inferred that H_i^* is Gumbel distributed with parameters $\left[\frac{1}{\mu}\ln\left(\sum_{i\in C_n}^{i\neq j} \exp\left\{\mu\frac{f(y)}{g(x)}\right\}\right), \mu\right]$.

We can write, $H_i^* = h_i^* + \varepsilon_i^*$ where $h_i^* = \frac{1}{\mu}\ln\left(\sum_{i\in C_n}^{i\neq j} \exp\left\{\mu\frac{f(y)}{g(x)}\right\}\right)$ and ε_i^* is Gumbel distributed with parameters (0, μ). Hence,

$$\Pr(h_j) = \Pr\left[h_j + \varepsilon_j \geq h_i^* + \varepsilon_i^*\right] = \Pr\left[(h_i^* + \varepsilon_i^*) - (h_j^* + \varepsilon_j^*) \leq 0\right]$$

Using the properties of Gumbel Distribution we can write,

$$Pr(h_j) = \frac{1}{1+e^{\mu(h_i^* - h_j)}} = \frac{\exp\left(\frac{f(y_j)}{g(x_j)}\right)}{\exp\left(\frac{f(y_j)}{g(x_j)}\right) + \exp\left[\ln\sum\exp\left(\frac{f(y_i)}{g(x_i)}\right)\right]} = \frac{\exp\left(\frac{f(y_j)}{g(x_j)}\right)}{\sum_{i\in C_n}\exp\left(\frac{f(y_i)}{g(x_i)}\right)} \quad \text{... (3.5.2)}$$

Although the functional form resembles conventional Logit model, it is non-linear in formulation. It can further be simplified by using monotonic logarithmic transformation of the efficiency function and assuming Cob-Douglas type multiplicative form of the input and output functions as follows, where m and n designates output and input elements respectively and, u and v are corresponding parameters. Consequently, transformed efficiency score can be expressed as,

$$\ln\left(\frac{f(y)}{g(x)}\right) = \ln f(y) - \ln g(x) = \ln\left(\prod_m y_m^{u_m}\right) - \ln\left(\prod_n x_n^{v_n}\right) = \sum_m u_m \ln(y_m) - \sum_n v_n \ln(x_n)$$

.... *(3.5.3)*

Consequently Equation (3.5.2) is simplifies to the following linear in parameter Logit Model.

$$Pr(h_j) = \frac{\exp\left(\sum_m u_m \ln(y_{mj}) - \sum_n v_n \ln(x_{nj})\right)}{\sum_{i \in C_n} \exp\left(\sum_m u_m \ln(y_{mi}) - \sum_n v_n \ln(x_{ni})\right)} \qquad \text{............ } (3.5.4)$$

The parameters of the function can be estimated using Maximum Likelihood method having the following Log-Likelihood function, where, *k* designates the DMUs.

$$L = \sum_k \left[\left(\sum_m u_m \ln(y_{mj}^k) - \sum_n v_n \ln(x_{nj}^k) \right) - \ln\left\{ \sum_{i \in C_n} \exp\left(\sum_m u_m \ln(y_{mi}^k) - \sum_n v_n \ln(x_{ni}^k) \right) \right\} \right]$$

.... *(3.5.5)*

Any statistical package capable of dealing with conventional multinomial logit model can be used for estimation purpose. Analysis has been performed using BIOGEME Statistical Software. Use of maximum likelihood approach facilitates the use of goodness-of-fit statistics like Likelihood Ratio Statistics and Likelihood Index to check integrity of the model and t-Statistics to examine reliability of the parameters.

Thus, according to the SDEA efficiency model,

$$\text{Log - Efficiency score of k-th DMU} = \sum_m u_m \ln(y_{mj}^k) - \sum_n v_n \ln(x_{nj}^k)$$

The model specified for this study considering, $m = 1$, $n = 4$, $y_1 = GDP$, x_1 = Land Area (*Land*), x_2 = Labour Force (*Lab*), x_3 = Industrial Capital (*Cap*) and x_4 = Accessibility Index (*Acc*) for *j*-the alternative is as follows:

Log- Efficiency score of k-th DMU

$$= u_1 \ln GDP_j - v_1 \ln Land_j - v_2 \ln Lab_j - v_3 \ln Cap_j - v_4 \ln Acc_j \qquad \text{...... } (3.5.6)$$

After estimating the parameters efficiency scores can be measured using the above model (Equation 3.5.6) and relative efficiency can be predicted as the ratio of the efficiency scores.

3.5.2 Framework for dynamic analysis

The lagging effect of accessibility in conventional DEA model in the form of polynomial lag function has already been discussed in section 3.4. Considering the lagging effects, basic structure of efficiency formulation (Equation 3.5.3) can be expressed as:

$$\ln\left(\frac{f(y)}{g(x)}\right) = u_1 \ln y_{1(t)} - v_1 \ln x_{1(t)} - v_2 \ln x_{2(t)} - v_3 \ln x_{3(t)} - \sum_{r=0}^{k'} \beta_i \ln x_{4(t-r)}$$

The effect of input x_4 (here in this study it is accessibility index) spreads over a period of time. This implies that the current value of output y depends not just on $x_{4(t)}$ but also on some past values of $x_{4(t)}$.

Thus, the logit model in equation (3.5.4) becomes:

$$Pr(h_j) = \frac{\exp\left(u_1 \ln y_{1j(t)} - v_1 \ln x_{1j(t)} - v_2 \ln x_{2j(t)} - v_3 \ln x_{3j(t)} - \sum_{r=0}^{k'} \beta_i \ln x_{4j(t-r)}\right)}{\sum_{i\in C_n} \exp\left(u_1 \ln y_{1i(t)} - v_1 \ln x_{1i(t)} - v_2 \ln x_{2i(t)} - v_3 \ln x_{3i(t)} - \sum_{r=0}^{k'} \beta_i \ln x_{4i(t-r)}\right)}$$

Again the log likelihood function in equation (3.5.5) can be written as:

$$L = \sum \left[\begin{array}{l} \left(u_1 \ln y_{1j(t)} - v_1 \ln x_{1j(t)} - v_2 \ln x_{2j(t)} - v_3 \ln x_{3j(t)} - \sum_{r=0}^{k'} \beta_i \ln x_{4j(t-r)}\right) \\ - \ln\left\{ \sum_{i\in C_n} \exp\left(u_1 \ln y_{1i(t)} - v_1 \ln x_{1i(t)} - v_2 \ln x_{2i(t)} - v_3 \ln x_{3i(t)} - \sum_{r=0}^{k'} \beta \ln x_{4i(t-r)}\right)\right\} \end{array} \right]$$

Using Equation (3.4.1) and (3.4.2) the above equation can be written as for this study is:

$$L = \sum \left[\begin{array}{l} \left(\begin{array}{l} u_1 \ln GDP_{j(t)} - v_1 \ln Land_{j(t)} - v_2 \ln Lab_{j(t)} - v_3 \ln Cap_{j(t)} \\ - \alpha_0 \sum_{r=0}^{k'} (Acc)_{j(t-r)} - \alpha_1 \sum_{r=0}^{k'} r(Acc)_{j(t-r)} + \alpha_2 \sum_{r=0}^{k'} r^2 (Acc)_{j(t-r)} \end{array} \right) \\ - \ln\left\{ \sum_{i\in C_n} \exp \left(\begin{array}{l} u_1 \ln y_{1i(t)} - v_1 \ln x_{1i(t)} - v_2 \ln x_{2i(t)} - v_3 \ln x_{3i(t)} \\ - \alpha_0 \sum_{r=0}^{k'} (Acc)_{i(t-r)} - \alpha_1 \sum_{r=0}^{k'} r(Acc)_{i(t-r)} + \alpha_2 \sum_{r=0}^{k'} r^2 (Acc)_{i(t-r)} \end{array} \right) \right\} \end{array} \right]$$

………… *(3.5.7)*

Here r is period of lag ($0 \le r \le k'$) and α's are estimable parameters. The parameters of the above equation can be solved using the same statistical package as discussed in previous section. The value of α_0, α_1 and α_2 will provide the value of β, which will be used to assess the dynamic effect of each DMUs.

3.5.3 Framework for policy implication

As the analytical framework is based on Cobb-Douglas type production function, analysis can further be extended to assess a number economic parameters discussed in the following sections.

Cobb Douglas production function

Economic interpretations, which include elasticity, cost and demand function, are based on estimated production functions shown below using equation (3.5.6).

$$\ln Eff. = u_1 \ln GDP_j - v_1 \ln Land_j - v_2 \ln Lab_j - v_3 \ln Cap_j - v_4 \ln Acc_j$$

$$u_1 \ln GDP = \ln Eff. + v_1 \ln Land + v_2 \ln Lab + v_3 \ln Cap + v_4 \ln Acc$$

$$\ln GDP^{u_1} = \ln\left(Eff \cdot Land^{v_1} \cdot Lab^{v_2} \cdot Cap^{v_3} \cdot Acc^{v_4}\right)$$

$$GDP = Eff^{1/u_1} \cdot Land^{v_1/u_1} \cdot Lab^{v_2/u_1} \cdot Cap^{v_3/u_1} \cdot Acc^{v_4/u_1}$$

The above equation follows the four factor Cobb-Douglas production, which can be denoted as:

$$q = c \cdot L^{\alpha} \cdot P^{\beta} \cdot I^{\gamma} \cdot A^{\theta} = f(L, P, I, A) \qquad \text{............ (3.5.8)}$$

Here, q = product (GDP), L = Land, P = Population (labour force), I = Industrial Capital, A = Accessibility Index

$$c = Eff^{1/u_1}, \quad \alpha = v_1/u_1, \quad \beta = v_2/u_1, \quad \gamma = v_3/u_1, \quad \theta = v_4/u_1$$

Cobb Douglas cost function

Production function needs to have certain properties, which is ensured by solving least cost problem. Finding the values of *L, P, I, A* and μ that minimizes the lagrangian, where *wL, wP, wI* and *wA* are price of land, labour, industrial capital and accessibility:

$$G(q; L, P, I, A, \mu) = wL \times L + wP \times P + wI \times I + wA \times A + \mu[q - f(L, P, I, A)]$$

Differentiating the above equation with respect to (L, P, I, A, μ)

a. $G_L = wL - \mu \times f_L = 0$

b. $G_P = wP - \mu \times f_P = 0$

c. $G_I = wI - \mu \times f_I = 0$

d. $G_A = wA - \mu \times f_A = 0$

e. $G_\mu = q - f(L, P, I, A) = 0$

From a, b, c and d, we get:

f. $\frac{wL}{wP} = \frac{f_L}{f_P} = \frac{\alpha \cdot P}{\beta \cdot L} \Rightarrow P = \frac{L \cdot \beta \cdot wL}{\alpha \cdot wP}$

g. $\frac{wL}{wI} = \frac{f_L}{f_I} = \frac{\alpha \cdot I}{\gamma \cdot L} \Rightarrow I = \frac{L \cdot \lambda \cdot wL}{\alpha \cdot wI}$

h. $\frac{wL}{wA} = \frac{f_L}{f_A} = \frac{\alpha \cdot A}{\theta \cdot L} \Rightarrow A = \frac{L \cdot \theta \cdot wL}{\alpha \cdot wA}$

substituting equation f, g, h in Cobb Douglas production function:

$$q = c \cdot L^\alpha \cdot \left(\frac{L \cdot \beta \cdot wL}{\alpha \cdot wP}\right)^\beta \cdot \left(\frac{L \cdot \lambda \cdot wL}{\alpha \cdot wI}\right)^\gamma \cdot \left(\frac{L \cdot \theta \cdot wL}{\alpha \cdot wA}\right)^\theta$$

Solving for L yields:

$$L = \left\{\frac{q}{c \cdot \left(\frac{\beta \cdot wL}{\alpha \cdot wP}\right)^\beta \cdot \left(\frac{\lambda \cdot wL}{\alpha \cdot wI}\right)^\gamma \cdot \left(\frac{\theta \cdot wL}{\alpha \cdot wA}\right)^\theta}\right\}^{\frac{1}{\alpha+\beta+\gamma+\theta}}$$

i. $$L = q^{\frac{1}{\alpha+\beta+\gamma+\theta}} \cdot \frac{\alpha}{wL} \cdot \left(\frac{wL^\alpha \cdot wP^\beta \cdot wI^\gamma \cdot wA^\theta}{c \cdot \alpha^\alpha \cdot \beta^\beta \cdot \gamma^\gamma \cdot \theta^\theta}\right)^{\frac{1}{\alpha+\beta+\gamma+\theta}}$$

substituting f, g, h, i into the cost function:

$$C(q) = wL \cdot L + wP \cdot P + wI \cdot I + wA \cdot A$$

yields the cost function, as a function of output, depending on the input price and the parameters of the Cobb Douglas production function.

$$C(q)=q^{\frac{1}{\alpha+\beta+\gamma+\theta}}\cdot(\alpha+\beta+\gamma+\theta)\cdot\left(\frac{wL^{\alpha}\cdot wP^{\beta}\cdot wI^{\gamma}\cdot wA^{\theta}}{c\cdot\alpha^{\alpha}\cdot\beta^{\beta}\cdot\gamma^{\gamma}\cdot\theta^{\theta}}\right)^{\frac{1}{\alpha+\beta+\gamma+\theta}}$$

Solving explicitly for $C(q)$:

$$C(q;wL,wP,wI,wA)=h(q)\cdot C(wL,wP,wI,wA)$$

where returns to scale function is :

$$h(q)=q^{\frac{1}{\alpha+\beta+\gamma+\theta}}$$

a continuous increasing function of $q(q\geq 1)$, *with* $h(0)=0$ *and* $h(1)=1$, the unit cost function is :

$$C(wL,wP,wI,wA)=B\cdot\left(wL^{\alpha}\cdot wP^{\beta}\cdot wI^{\gamma}\cdot wA^{\theta}\right)^{1/(\alpha+\beta+\gamma+\theta)} \quad \text{...... (3.5.9)}$$

where, $B=(\alpha+\beta+\gamma+\theta)/\left[\left(c\cdot\alpha^{\alpha}\cdot\beta^{\beta}\cdot\gamma^{\gamma}\cdot\theta^{\theta}\right)^{1/(\alpha+\beta+\gamma+\theta)}\right]$

The unit cost function $C(wL,wP,wI,wA)$ looks like its parent - Cobb Douglas production function, which is called homothetic, because the Cobb Douglas cost function is can be separated (factored) into a function of output, q, times a function of input prices wL,wP,wI,wA.

Factored demand function

Taking the derivative of the following cost function with respect to an input price, factored demand function of that input is achieved.

$$C(q;wL,wP,wI,wA)=h(q)\cdot C(wL,wP,wI,wA)$$

$$=q^{\frac{1}{\alpha+\beta+\gamma+\theta}}\cdot B\cdot\left(wL^{\alpha}\cdot wP^{\beta}\cdot wI^{\gamma}\cdot wA^{\theta}\right)^{1/(\alpha+\beta+\gamma+\theta)}$$

Taking derivative with respect to price of accessibility, wA :

$$\frac{\partial C}{\partial wA}=B\cdot\frac{\theta}{\alpha+\beta+\gamma+\theta}\cdot\frac{1}{wA}\left(q\cdot wL^{\alpha}\cdot wP^{\beta}\cdot wI^{\gamma}\cdot wA^{\theta}\right)^{1/(\alpha+\beta+\gamma+\theta)}$$

...... *(3.5.10)*

3.6 Summary

In this chapter, a framework for stochastic DEA model has been formulated integrating Data Envelopment Analysis and choice theoretic approach. Dynamic affect of transportation infrastructure investment in terms of time lag has also been formulated based on same framework. As the analytical framework is based on Cobb-Douglas type production function, analysis is further extended to assess numbers of economic parameters like degree of homogeneity, production elasticity, cost per unit output, factored demand of inputs etc. The next chapter describes overall transportation system of Bangladesh followed by data collection and analysis fitted for the framework explained in this chapter.

4. TRANSPORTATION SECTOR OVERVIEW OF BANGLADESH

4.1 Introduction

The strategic role of transport sector in enabling sustained economic and social development to take place in a society is self-evident. As efficient distribution system becomes increasingly critical to sustained growth of economic activities. As the income in society increases, there is also increasing demand for access to various social services like health, sanitation and education. Transport sector is thus called upon to provide strategic support services on an increasing scale. Even when the transport sector itself may make relatively modest direct contribution to the national income, it acts as a powerful catalyst in promoting production in other sectors. Its' overall impact on economy is therefore is highly significant.

Transport system of Bangladesh consists of roads, railways, inland waterways, twp seaports, maritime shipping and civil aviation catering for both domestic and international traffic. The transport network system in the country has changed completely over the past twenty-five years. During the first ten years of independence since 1971, very little was added except for the reconstruction and rehabilitation of the transport infrastructure damaged during the liberation war. By end of this decade, the long sustained status quo in the sector started breaking to bring-in a change in the structure of the system. Prior to independence, there were no national or regional highways, but few roads connecting Dhaka with the rest of the country.

During the first few years of post independence, government resources were largely used for rehabilitating the infrastructure and service facilities that existed before 1971. During the 1980s, the priority was sharply redirected towards road infrastructure and this trend has continued to date resulting in a relative marginalization of IWT and the railway systems. Many waterways are no longer navigable, due to withdrawal of water from the upstream and highly inadequate dredging. Many tributaries and canals have dried-up or, taken over for construction of all types of structures, including roads and housing settlements. Railway also suffered from inadequate investments, and lost competitiveness to road transport, which received virtually exclusive attention of the successive governments since eighties. Railway has not had a coherent investment plan for maintaining its assets and developing its infrastructure and service base. As a result it has not been able to establish a robust case for a higher allocation of resources.

4.2 Transport Sector Policy

In September 2000, at a special assembly of the United Nations 147 heads of state and government signed the *millennium declaration* on poverty reduction. The Declaration addressed a number of broad issues of which the overarching objective is to reduce absolute poverty by 2015. Following the millennium declaration, the Government adopted a Poverty Reduction Strategy, abandoning the traditional five-year planning approach to development, to achieve accelerated poverty reduction.

a. Poverty Reduction Strategy (PRS)

The PRS is founded on four strategic blocks:

- Enhancing pro-poor growth;
- Boosting critical sectors for pro-poor economic growth;
- Devising effective safety nets and targeted programmes; and
- Ensuring social development.

A critical review of the PRS suggests that it is essentially about programming (scarce) resources:

- Building on past achievements;
- Preventing slippages; and
- Addressing implementation - targeted interventions
  - Efficient
  - Equitable

b. National Land Transport Policy (NLTP), 2004

The Government has recently approved a National Land Transport Policy (NLTP) in April 2004, the first of its kind in Bangladesh. The scope of NLTP is limited to roads and railways. The objective is to develop a safe, reliable and affordable transport service. The scope of NLTP is limited to road and railway sub-sectors, and the key strategy interventions proposed are as follows:

<u>Strategic and Integrated Policies</u>

- Greater private sector participation
- Improved co-ordination in inter-modal transport
- Improved training in both the public and private sectors
- Transport users should pay for the costs of services

- Access to subsidies for the provision of services for social and economic benefit
- To create policy awareness and further participation in policy development
- To promote improved employment conditions
- Better integration with inland water transport
- Increased access to transport and services in rural areas

Policies for Roads

- Clarify government responsibilities for roads and highways
- Introduce long-term network planning
- Maintain the road network at a level which protects the value of the investment
- To secure a sustainable means of funding road expenditure
- To improve the management of traffic on the network to make the best use of the assets
- To manage the road-side activities in a way that maximises use of road assets
- To involve the private sector more in infrastructure, services and maintenance
- To better protect the environment from road construction
- Fostering Inter-Regional Links

Policies for Road Traffic

- To regulate vehicle weights in order to encourage better quality and more efficient vehicles
- To reduce pollution from vehicles
- Improvement of Road Safety
- Improvement of driving standards
- Allowing the road freight industry to operate more efficiently
- Development of parking policies
- Fostering the taxi industry
- To ensure the continued role of BRTC in setting good vehicle operating practices

Policies for Non-Motorised Transport

- Fostering Safer Rickshaw Use
- To create better conditions for pedestrians

Policies for Railways

- To encourage greater private sector participation in the provision of services
- To enhance the operational capacity of railways

- To obtain a greater share of the freight market
- More efficient management of the railway's assets
- Improving Financial Efficiency
- More effective provision of services for social need
- Fostering Inter-Regional Links
- Improvement of Rail Safety
- Improvement of institutional capability of Bangladesh Railway

c. Integrated Multi-modal Transport Policy (IMTP)

In addition to PRS, the government has recently approved an Integrated Multi-modal Transport Policy (IMTP), the first of its kind in Bangladesh to develop the transport sector combining road transport with railways, civil aviation and inland Water Transport (IWT). It visions for providing safe, dependable, effective, efficient, and fully integrated transport operations and infrastructure which will best meet the needs of freight and passenger customers by improving levels of service and minimize cost in a manner which supports government strategies for economic and social development whilst being environmentally and economically sustainable. In addition, it should be efficient in a regional context to allow Bangladesh to export its unique geographical position.

IMTP has two themes:

- Development of a transport system that best meets users needs at fair prices and an economic cost; and
- Integration, especially to address Bangladesh's competitiveness in the export market, and to help reduce the cost of imports.

IMTP objectives are as follows:

- Most economic use of resources: Achieve more rational investment in the transport sector that provides choices for users and integration of services, and mentions that the Government will ensure the development of the following sub-sector master plans:
    - ❑ Road Master Plan
    - ❑ Railway Development Plan
    - ❑ Transport safety Strategy
    - ❑ IWT Master Plan
    - ❑ Air passenger and freight targets
    - ❑ Urban transport plans

- *Economic, social and human development*: Integrate multi-modal transport to further economic, social and human development for poverty reduction. It says that access to transport services by the poor will be enhanced by target-oriented subsidies and intervention, where required rather than blanket subsidy. It also refers to safety in all modes is a priority concern.

- *Roads*: Protect the value of the existing and future assets; and, ensure its proper role in the multi-modal transport network. It says that a Road Maintenance Fund will be created for maintenance of roads.

- *Railways*: Improve BR's role in the multi-modal transport network, both as a business and as a service provider in the multi-modal environment.

- *Ports and shipping*: Modernize to compete effectively in the world trade market.

- *IWT*: Modernize IWT to provide an efficient, safe and cheap mode of transport in a multi-modal environment:
  - Dredge to maintain the waterways to provide efficient drainage to avoid widespread flooding and interruption to transport services;
  - Encourage mechanization of country boats, and simplify registration;
  - Promote private sector to introduce door-to-door services using IWT and the trucking industry;
  - Enforce (strongly) the rules & regulations concerning (vessel) design, over loading and skills of the masters – to improve safety of IWT; and
  - Ensure that IWT's share of diesel taxes, collected by the Road Maintenance Fund is made available for dredging and maintenance of the waterways.

- *Air*: Make international and domestic air transport system dynamic, profitable, and efficient by modern standards.

- *Rural transport*: Foster a range of motorized and non-motorised (multi-modal) modes of transport to improve access to employment, markets, along with education, health and the full range of social facilities. Connectivity of rural roads is a priority, both in terms of infrastructure and transport services.

- *Urban transport*: Enhance transport systems to encourage economic growth, and to meet the transport needs of all sectors of society at affordable fares along with the integration of transport services through physical, operational and common ticketing measures. It refers to insufficient planning and lack of coordination between the agencies concerned; and further mentions that the Government will set up Unified Metropolitan Transport Authorities (UMTAs) in all major cities to facilitate more co-ordinated planning and implementation of urban transport programmes and projects and the integrated management of urban transport systems.

- *Regional cooperation*: Take advantage of Bangladesh's geographical position to develop international links that generate revenue for the nation.

- *Institutional development*: Develop a strong, professional and focused capability to direct the implementation of the integrated multi-modal transport policy, and to co-ordinate the delivery of improved transport services throughout the country.

d. Water Transport Policy (National Shipping Policy, 2000)

In 2000, a National Shipping Policy was approved to introduce reform and private sector participation in ports and inland waterways. Highlights of the policy regarding inland water transportation are :

- Development and maintenance of main channels of seaport and main and important channels of inland water transport movement
- Establishment of internal communication among the main river ports, quays, inland container ports and depots along with the development of the existing seaports
- Rationalisation of fleet of ships and development of shipping movement and inland shipping sector by providing benefits with a view to encouraging investment in this sector
- Providing assistance to the management and development of national shipping lines
- Providing passenger and transport services to the coastal islands with landing facilities thereof
- Modernisation and expansion of training facilities for the cadets of sea-going vessels, sailors and staff of the inland vessels
- Protection of waterways from environmental erosion
- Enhancing dredging capacity in order to protect the navigability of waterways.
- Improvement of salvaging operations
- Updating of existing rules and regulations relating to the control of sea-vessels, ports and water transport sector to the international standard.
- Expansion of working area to the ministerial level with a view to providing improved services in respect of framing policy, planning, enacting rules and regulations and their application.

- Ensuring the best utilisation of latest information technology in water transport sector.
- Setting up naval museum as an edifying instrument for future generation.
- Ensuring proper naval security.
- Providing regional and sub regional sea transport/ port facilities.

e. National Civil Aviation Policy, 2001

The policy is focused on 10 major objectives.

- Development and growth of civil aviation movement facilities towards establishment of comfortable and safe transportation system
- Establish Bangladesh Biman as profitable commercial enterprise through competitive business action
- Develop domestic transportation system specially in remote areas
- Accelerate relief distribution activities during natural calamities
- Extend the commercial use of the aviation boundary and airports of Bangladesh
- Function as a part of the protection of sovereignty of the country
- Increase efficiency and quality of service of Civil Aviation Authority and Bangladesh Biman
- Increase business, commerce specially expand the export sector and dvelop tourism industry through civil aviation
- Extend the operation of Bangladesh Biman in international arena in a productive way
- Identify the problems and difficulties related to travel of Bangladeshi citizens, who used to travel for work or those who are working in foreign countries, and take steps to solve those problems.

4.3 Transportation Network and Services

Prior to independence in 1971, there were hardly any rural roads but (paved) national roads of less than 3,000 km. The roads network continued grow particularly since 1980s; and in the last ten years, the growth of the rural roads has been phenomenal. The current transport networks, excluding urban/municipal roads in the country is more 300,000 km, of which roads alone account for more than 97%; and amongst the roads, 85% is rural - 250,000 km of which only 14% is paved.

Railway route network, although decreased marginally in the nineties increased again to pre-1971 level at 2,835 km in 2006. However, many branch line service operations which turned to be non-profitable, due to development of roads have been closed. It is also worth noting that many inter-city service operations have been marginalized due to significant development of roads and lack of investment in railway.

In 1971, there were more than 12,000 km waterways round the year. The network shrank (by siltation) to 5,200 km in 1991 and 3,568 km in 2006 due to withdrawal of water in the upstream and lack of dredging. Siltation has now reached such a magnitude that even the ferry channel at Paturia, where 80% of the dredging by BIWTA is performed is not adequate. Ferry service was disrupted even during high season in 2006. Table 4.1 shows the growth of transport network of Bangladesh.

Table 4.1: Transport Network of Bangladesh

Length in kilometer

Year	Road					Railway	IWT	Air	TOTAL
	National		Rural		Sub-total				
	Paved	Unpaved	Paved	Unpaved					
1991	9704	5966	9634	175492	185126	2768	5200	1116	194210
2006	17434	4127	33985	215848	249833	2835	3568	1628	257864

Source: *RHD, LGED, BR, CAAB*

a. Roads and Highways

Road Types, Definitions and Ownership/Responsibility

In November 2003, the Government has made a change to earlier road classification system and delineated the ownership/responsibility of each category of roads for their improvement and maintenance. (Bangladesh Gazette volume-I, dated 6th November 2003). The new definition classifies the road system into six main categories. The road type/category, definition and, ownership and responsibility are listed in Table 4.2.

Table 4.2: Road Types, Definitions and Ownership/Responsibility in Bangladesh

Sl No	Type/Category	Definition	Ownership /Responsibility
1	National Highway	Highways connecting National capital with Divisional HQs or seaports or land ports or Asian Highway.	RHD
2	Regional Highway	Highways connecting District HQs or main river or land ports or with each other not connected by National Highways.	RHD
3	Zila Road	Roads connecting District HQ/s with Upazila HQ/s or connecting one Upazila HQ to another Upazila HQ by a single main connection with National/Regional Highway, through shortest distance/route.	RHD
4	Upazila Road	Roads connecting Upazila HQ/s with Growth Center/s or one Growth Center with another Growth Center by a single main connection or connecting Growth Center to Higher Road System, through shortest distance/route.	LGED/LGI
5	Union Road	Roads connecting Union HQ/s with Upazila HQs, growth centres or local markets or with each other.	LGED/LGI
6	Village Road	a) Roads connecting Villages with Union HQs, local markets, farms and ghats or with each other. b) Roads within a Village.	LGED/LGI
7	Urban road	Urban roads are defined as those roads come under the jurisdiction of the City Corporation, Municipality or Pouroshova. These roads are owned, built and maintained by the charged agency (City Corporation, Pouroshova etc.), some times with technical help from LGED.	City Corporation, Pouroshova

Note: The roads belong to the Pourashavas and the City Corporations have not been included under the above list. The responsibility for development and maintenance of such roads will lie with the respective Pourashavas and the City Corporations.

Source: *Published in Bangladesh Gazette, Volume 1, 6th November, 2003*

Road Network and Physical Characteristics

National Network (RHD). The Roads and Highways Department (RHD) in Bangladesh is responsible for over 20,000 km of roads which are classified in. Not all the roads, particularly in the Zila Road category, are yet paved, or even exist as passable tracks by motorised vehicles. Figure 4.1 shows the current RHD network. The growth of the national roads network particularly in the last twenty years or so has been remarkable. Prior to independence in 1971 when the roads were not classified, the network in the country was only 3,764 km, including 2,455 km paved and 1,309 km unpaved roads. In the next ten years covering the period up to 1981, the paved roads increased by less than 8% to 2,649 km and unpaved roads by about 73% to 2,262 km. However, during 1982-1991, the paved roads increased phenomenally by more than 185% to 7,559 km and unpaved roads by 139% to 5,399 km. The paved roads continued to increase further by

65% to 12,463 km by 2001; and most remarkably by another 68% to 20,878 km within next three years (TSC, 2006). The hyper growth of the road network can be explained by increasingly higher ADP allocations for paving the unpaved roads, as well as construction of new roads.

Rural Network (LGED). They provide local access to markets, farms, social and welfare institutions; village service delivery centres and markets where buyers and sellers assemble to trade products of agriculture and rural cottage industries and other consumer goods. They also provide access to modern agricultural inputs, such as, fertiliser, certified seeds and pesticides. During the 1970s, 1980s and 1990s, the GoB invested heavily in expanding the rural road network through Food for Works and other Rural Development Programmes. During the last decades, GoB's major effort has been focusing on improving the condition of the rural road network. The main activities have included improving road embankments, bituminous carpeting and improvement of drainage facility. Of the total 36,166 km of Upazila Road about 21,277 km or 59% and total of 42,329 km of Union Road about 11,780km or 28% are paved with some sort of hard surfacing (Table 4.3).

Table 4.3: Road Network, Structure and Existing Gap

Road Type	Number of Road	Road Length (km)			Structure		Existing Gap	
		Total	Paved	Unpaved	Number	Span (m)	Number	Span (m)
RHD Network:								
National Highway	66	3508	3472	36	3617	64837	4	5800
Regional Highway	112	4119	3949	170	3535	43828	11	10870
Zila Road	617	13251	9330	3921	7560	75933	37	20746
Sub-Total (RHD)	**795**	**20878**	**16751**	**4127**	**14712**	**184598**	**52**	**37416**
LGED Network:								
Upazila Road	4254	36166	17889	18277	46698	270060	6314	112233
Union Road	7510	42331	8513	33818	43320	205142	11164	125267
Village Road-A	29719	94059	6501	87558	51604	230439	28018	216957
Village Road-B	38268	77277	1082	76195	23094	92703	24733	156226
Sub-Total (LGED)	**79751**	**249833**	**33985**	**215848**	**164716**	**798344**	**70229**	**610683**
Urban Road:								
Cities (6)	-	5001	3182	1819	-	-	-	-
Municipalities (250)	-	17901	7847	10054	-	-	-	-
Sub-Total (Urban)	**-**	**22902**	**11029**	**11873**	**-**	**-**	**-**	**-**
TOTAL*	**80546**	**270711**	**50736**	**219975**	**179428**	**982942**	**70229**	**610683**

**Excluding urban roads*

***Source**: RMMS, 2006; RRMP, 2005; TSC wing*

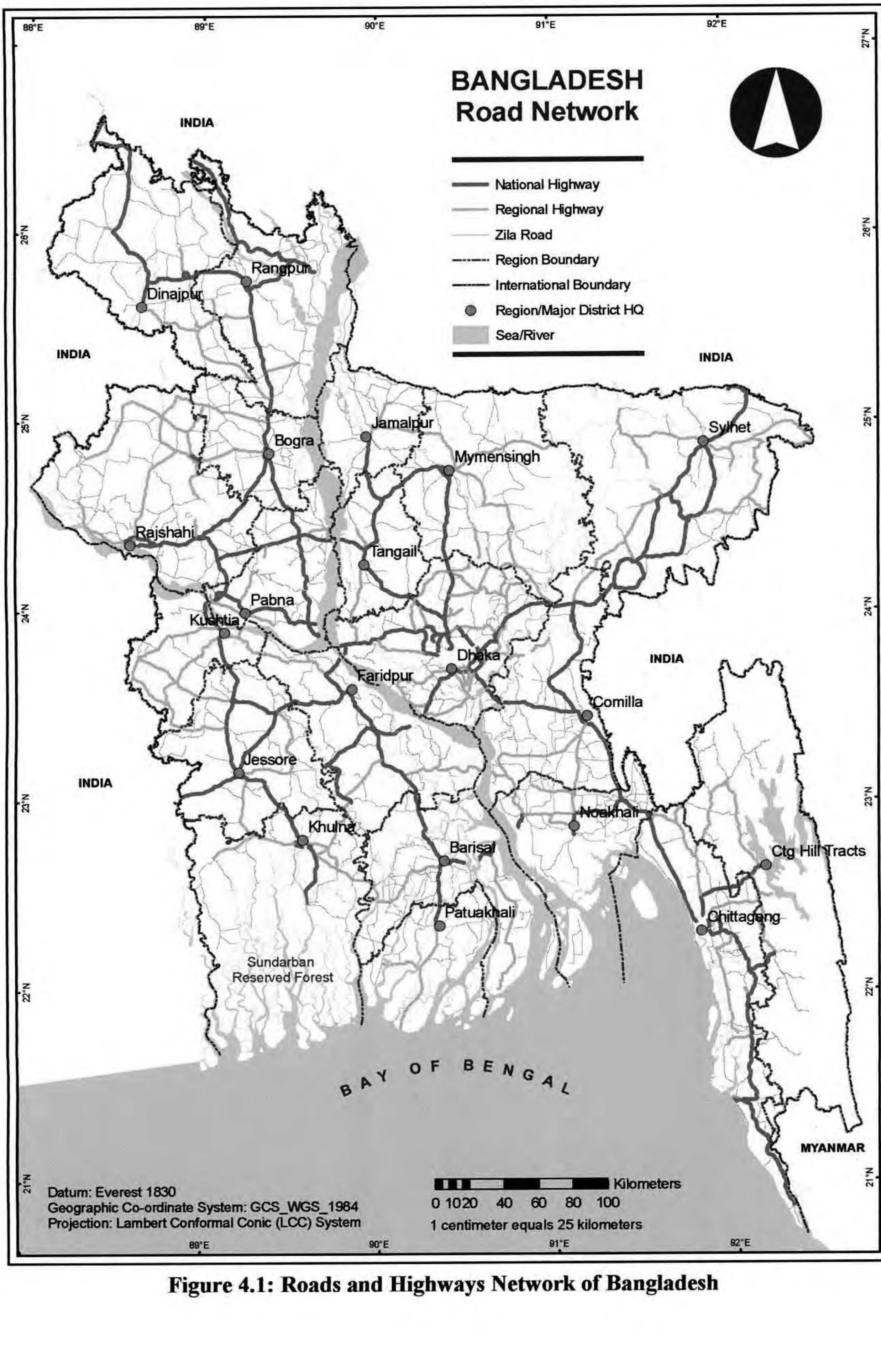


Figure 4.1: Roads and Highways Network of Bangladesh

Urban Roads. Roads located within the city and municipal areas are considered as urban. These are constructed and maintained by city and municipal authorities, with the exception of roads width of which is more than 60 feet. These roads are constructed by city development authorities, e.g., RAJUK in Dhaka under the administrative control of the Ministry of Works (MoW). The roads, after construction are handed over to the city corporations for maintenance. City development authorities also construct roads to provide connectivity with the new settlements and townships around the cities. The network of urban roads, as percentage of the total road transport network is negligible. However, importance of these roads is very high in terms of traffic generation. Majority of the urban roads are narrow and not suitable for public transport. It is worth mentioning that the percentage of roads suitable for public bus transport service operations in other three cities is highly inadequate while it is virtually nonexistent in all municipal areas. The urban transport is dominated by NMT, which is not segregated from MT except few kilometers in Dhaka city. The large majority of the urban dwellers commute on foot. However, the pedestrian facilities are awfully inadequate. Available few footpaths are occupied by hawkers, storage of construction materials, etc. Few foot-over bridges are largely under utilized, due to wrong design and location. There is no, or a handful of un-maintained public toilets. The roads are unsafe particularly for the elderly, women and children.

b. Railway

Railway Network Growth

BR has a total network of 2,835 route-km of two different gauges divided into two zones, the East Zone and the West Zone on the two sides of Jamuna River (Figure 4.2). Of the total, 933 km of route, all falling in the West Zone, consists of Broad Gauge (BG), 1.676 m wide. In addition the West Zone has 678 km of Meter Gauge (MG), 1.0 m wide. The East Zone has 1,266 route-km of MG track. In addition, there is 375 km of Dual Gauge (catering for both BG and MG trains). This DG track, passing over Jamuna Multipurpose Bridge (JMB), provides the only link between the East Zone and the West Zone (Table 4.4).

Bridges, Ferries, Level Crossings

BR network has 3,650 bridges (1.3 bridges/km), of which 546 are major ones (a major bridge/ 5 kms). Condition of some of the bridges has deteriorated requiring imposition of speed restriction. Before construction of JMB, passenger ferry services were operated between Jagannathganj Ghat and Sirajganj Ghat, and between Bahadurabad Ghat and Balashi Ghat. These ferry services have been discontinued now. An MG wagon ferry service is still operating between Bahadurabad Ghat and Balashi Ghat, which is likely to be discontinued soon, when MG freight service over JMB becomes fully operational.

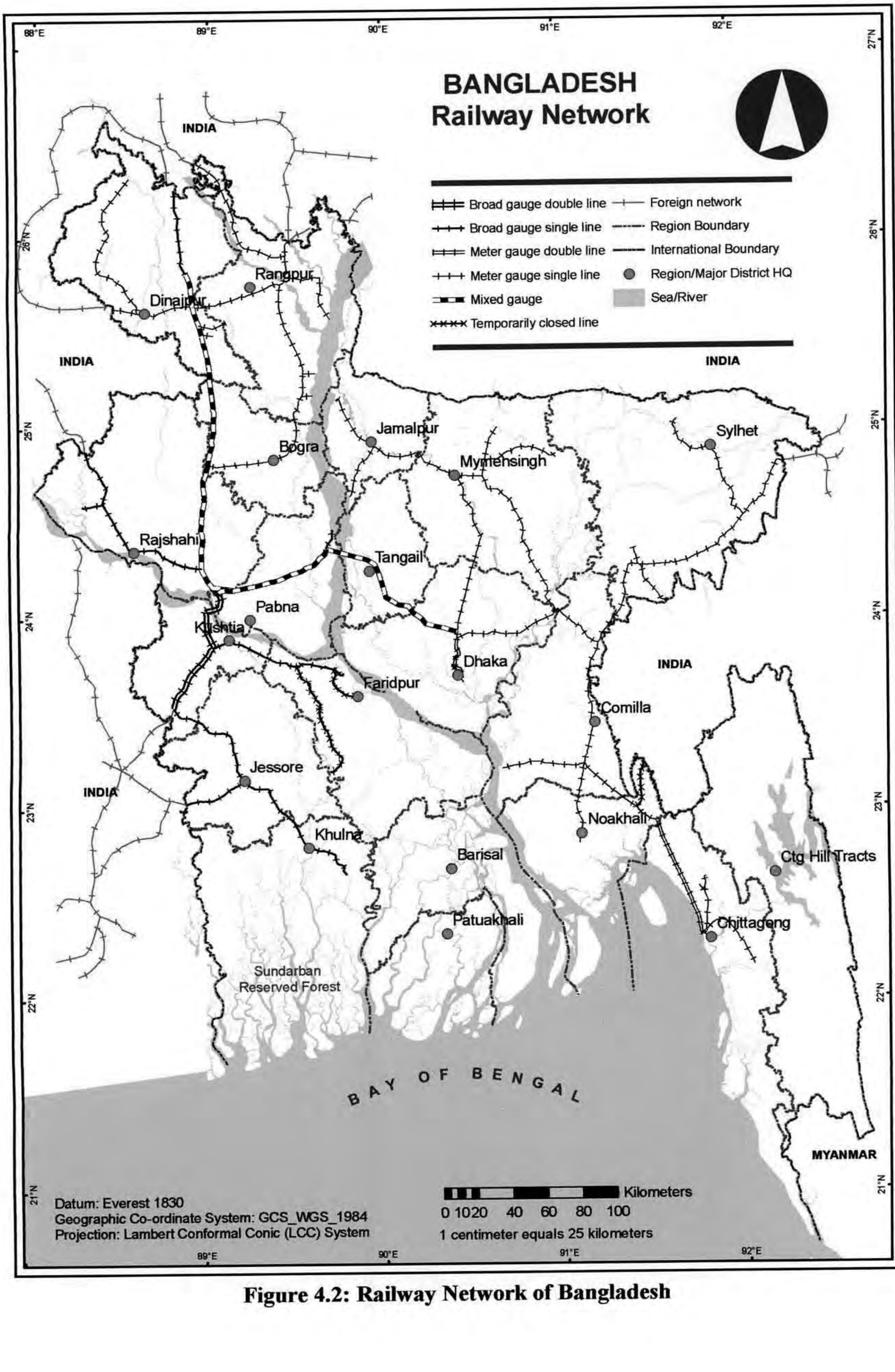


Figure 4.2: Railway Network of Bangladesh

The 2,835 route-km of BR track has as many as 1610 level crossing, of them only 207 are manned round the clock. The rest with relatively light road traffic are intermittently manned or unmanned.

Table 4.4: Railway Route and Track Network

Year	Route/Track Kilometer	Metre Gauge (MG)			Broad Gauge (BG)	Dual Gauge (DG)	System Total		
		East	West	Total	Total (West only)	Total (West only)	East	West	Total
1970	RK			1935	923				2858
	TK			2908	1540				4448
1995	RK	1279	543	1822	884		1279	1427	2706
	TK	1959	877	2836	1528		1959	2405	4364
2000	RK	1279	553	1832	936		1279	1489	2768
	TK	1959	888	2847	1584		1959	2471	4430
2005	RK	1277	553	1830	660	365	1277	1578	2855
	TK	1889	888	2777	1276	390	1889	2553	4443
2006	RK	1266	535	1801	659	375	1266	1569	2835
	TK	1879	678	2557	933	484	1879	2094	3973

Source: BR 2006

Rolling Stock (Locomotive, passenger Coaches, Wagons)

BR owns a fleet of 286 locomotives, basically of two types – diesel electric (253) and diesel hydraulic (33). Majority of the locomotives are old. Of the total holding of 286, 25 are already kept 'off schedule' awaiting condemnation. Out of the remaining 261, 70% are more than 20 years old and will have to be phased out within the next 10 to 15 years. Only 66 MG and 13 BG locomotives are below 20 years of age. The percentage of locomotives under/awaiting repairs, hence not available for service, is about 25 on BG and 14 on MG. The availability of BG locomotives is very low, which is due to the poor condition of the aging fleet requiring more time and resources for repairs. Average number of hours an engine works per day has been about 12 on BG and 13 on MG, which indicates a very poor rate of utilization. The age profile of passenger coaches is no different from that of locomotives. Over 69% passenger coaches are over 25 years of age. Only 122 MG and 21 BG coaches are within 15 years of age. The percentage of passenger coaches under/awaiting repairs is 20 on BG and 19 on MG. The reason for low availability is the same as in case of locomotives – poor condition of the aging fleet requiring more time and resources for repairs. The passenger coaches in service make on average 229 km/day on BG and 236 km/day on MG. Current average occupancy of passenger coaches is more than 90%. The fleet of freight wagons is almost entirely over-aged and obsolete. Over 97% of the wagons are over 20 years of age, and about 77% over 25 years. All the BG wagons are over 20 years of age and only 188 MG wagons (376 counted as 4-wheeler equivalent) are within 20 years of age. The percentage of freight wagons under/awaiting repairs is about 29 on BG and 16 on MG, which could not be much better given the poor condition of the wagons.

Services

BR's flagship inter-city trains succeeded to maintain only about 66% of the schedule, followed by local trains about 54% and mail & express trains only 47%. Maintenance of the schedules also varied significantly between zones. Schedule performance in the West zone (BG) has been relatively more unsatisfactory. For example, only 62% of inter-city trains, 44% of local trains and 37% of mail & express trains could maintain schedules in 2006.

c. Waterway

Waterway Network

Bangladesh is a riverine country. A dense network of rivers, canals, creeks cover almost all parts of the country, providing a natural infrastructure for waterways. More than half the country's land area and three quarters of commercial activities are within 10 km to navigable waterways in all seasons. Out of nearly 24,000 km of waterways, about 6,000 km in the monsoon period and only about 3,800 km in the dry period are navigable by mechanized water transport. Only about 1,700 km are maintained all year. The non-mechanized (country) boats have accessibility throughout the year in almost all the waterways. Water transport provides the cheapest, and the only means of transport during monsoon in the flood affected areas. The inland waterways network has been classified into class I, II, III and IV depending upon the minimum water depth available round the year (Figure 4.3). The network is shown in Table 4.5.

Table 4.5: Inland Water Transportation Route Network

IWT Route*	Draft (meter)	Length (km)	% of Total Route	Horizontal Clearance (meter)
Class I: Trunk routes (4 nos.)	3.60-3.90	683	11%	76.22
Class II: Transit/Link routes (7 nos.)	2.10-2.40	1000	17%	76.22
Class III: Secondary routes (12 nos.)	1.50-1.80	1885	32%	30.48
Class IV: Seasonal routes	>1.50	2400	40%	20.00
Total :		**5968**		

**Classified on the basis of LAD (Least Available Depth)*

***Source:** BIWTA 2006*

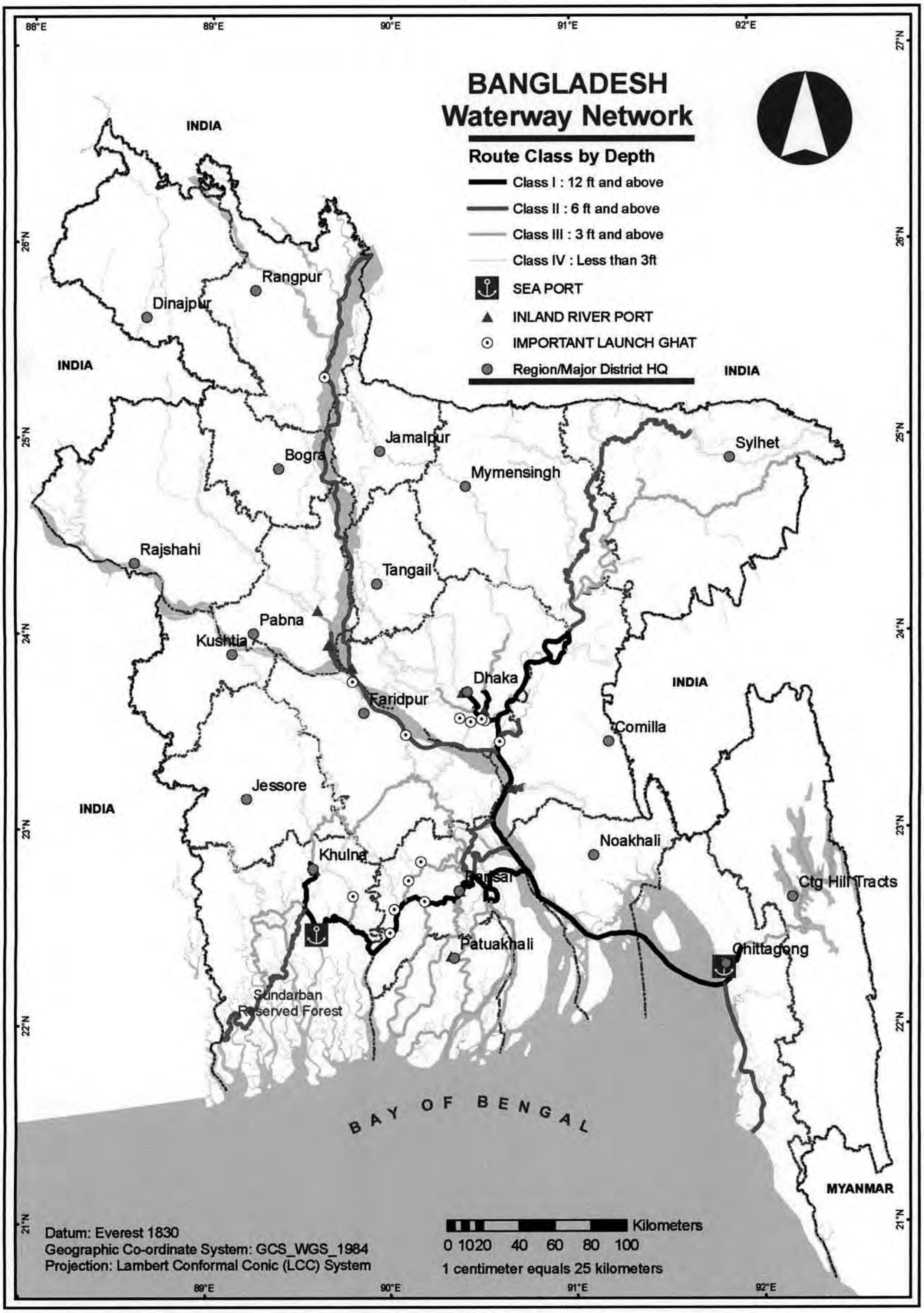


Figure 4.3: Inland Water Transportation Network of Bangladesh

Infrastructure

IWT infrastructure including ports, stations, cargo handling equipment (at ports) and navigational aids are provided almost exclusively by the (public sector) Bangladesh Inland Water Transport Authority (BIWTA). At present there are 19 ports, including 8 new, declared as ports in 2004:

Old: Dhaka, Narayanganj, Chandpur, Barisal, Khulna, Patuakhali, Baghabari, Aricha, Nagarbari, Daulatdia and Narsingdi;

New: Tongi, Mirkadim, Mowa, Charjanaja, Nowapara, Ashuganj- Bhairab Bzar, Barguna and Bhola.

There are 827 Launch Ghats/ landing stations, installed by BIWTA and 178 dedicated/ common landing private ghats which are installed and operated by private sector for river based industries. Besides there are more than 400 ghats which are installed and leased out by either the District Council or the LGED.

Capacity and Services

IWT sub-sector service operations used to be dominated by the public sector in the early seventies and before. The role of the public sector in IWT eroded gradually over the past years. The private sector responded spontaneously to fill-up the gap between demand and supply of transport services – which previously used to be provided almost exclusively by the public sector, namely, Bangladesh Inland Water Transport Corporation (BIWTC). Current operations & service of IWT for both passenger and cargo is the domain of the private sector.

There are as many as 234 established passenger routes, including few coastal routes. Private sector operates on all these routes, but few coastal routes which are not commercially viable. The historical role of BIWTC has shrunk to providing passenger services on only six Class-I routes, including inland, coastal and off-shore routes. It operates 24 passenger vessels in 13 routes, including coastal service routes which are not commercially viable for the private sector.

BIWTC has maintained monopoly in providing ferry services, the demand of which has however decreased considerably over the past years due to construction of bridges on many rivers in the country. It currently provides day and night ferry services to connect northern and southern regions with the eastern region of the country with 35 ferries in five routes:

i. Paturia - Kazirhat - Paturia
ii. Paturia – Daulatdia - Paturia
iii. Mawa - Charjanajat - Mawa
iv. Mawa - Kathalbari - Mawa
v. Chandpur - Shariatpur- Chandpur

Total annual capacity of IWT vessels are summarized in Table 4.6.

Table 4.6: Annual Capacity of IWT Passenger and Cargo Vessels

	No. of vessel	Static capacity (ton)	Trips per year (no.)	Annual Transport Capacity (million ton)
Total annual transport capacity for passenger vessels				
Private sector	1800	220000	320	70
Public sector (BIWTC)				
i. inland steamer	8	3914	153	0.6
ii. coastal steamer + seatruck	18	3572	140	0.5
iii. ferry	35	5248	2579	14.0
	61	12700		15.0
Total	**1900**	**230000**		**85**
Total annual transport capacity for cargo vessels				
Private				
i. cargo	2000	1000000	12	12.00
ii. tanker	110	100000	36	3.60
iii. bay crossing	140	130000	24	3.12
	2250	1230000		18.72
Public				
i. cargo	30	4000	12	0.05
ii. tanker	10	10000	36	0.36
iii. bay crossing	30	30000	24	0.72
	70	44000		1.28
Total	**2320**	**1274000**	**-**	**20.00**

Source: Khan P.A.A., 2006

c. Air Transport

Air Route Network

Though the share of haulage of Civil Aviation is still quite meager in the overall transport of Bangladesh, it plays important strategic roles in fulfilment of objectives of the transport sector as a whole. Thus aviation being an integral part of the transport system, needs to be well integrated and tuned with other modes which operate in competing, parallel and linked transport routes.

Aviation industry in Bangladesh starting with one airport and only one aircraft in 1972 has by now attained significant development. Currently there are eight conventional full-scale airports, eight airports for Short Take-Off and Landing (STOL) aircraft and some heliports in thana headquarters. Eight full scale air ports are (Figure 4.4): (i) Zia International Air Port (Dhaka), (ii) Osmany International Airport (Sylhet), (iii) Amanat Shah Airport (Chittagong), (iv) Cox's Bazar Airport, (v) Saidpur Airport, (vi) Ishwardi Airport, (vii) Jessore Airport, and (viii) Barisal Air port.

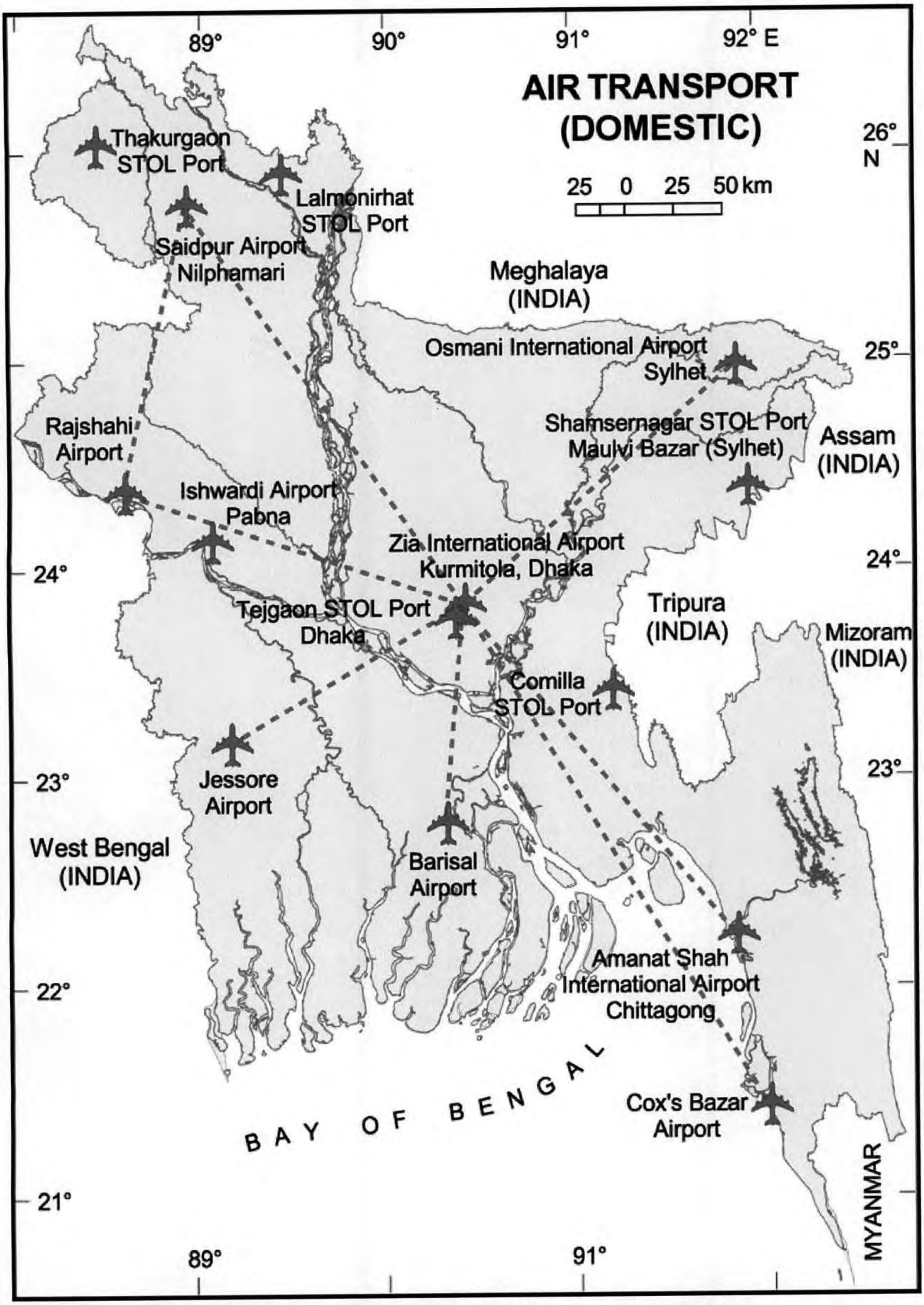


Figure 4.4: Domestic Air Transport Network of Bangladesh

Some of the British built military airstrips within Bangladesh territory were converted into civil airports but some were not so converted which include Lalmonirhat, Thakurgaon, Feni, Ragendrapur, Pahar Kanchanpur, Chokoria and Rosulpur. Almost all upazilas are claimed to have emergency helicopter landing facilities. It may be noted here that the unused airstrips have strategic importance as regards landing facilities during emergency. As evident from the list of airports, the first three are international, as well as domestic. The remaining five airports are domestic only. The domestic routes of the civil aviation are shown in Figure 4.4.

Actors

Mainly three agencies are involved with different operational aspects of civil aviation in Bangladesh. They include The Civil Aviation Authority of Bangladesh (CAAB), Biman Bangladesh Airlines, and private GMG and United Airlines. They all operate under the administrative of the Ministry of Civil Aviation and Tourism. Civil Aviation Authority of Bangladesh (CAAB) is an autonomous body for management of civil aviation of Bangladesh. It is responsible for airports, runways and air traffic control, taxiway, terminal buildings, warehouses, control towers, operation and administrative buildings, car parking, air navigation and radio communication system. Biman Bangladesh Airlines, the national Airliner in Bangladesh domestic flights on all eight established routes, as well as and international flights. GMG and United Airlines operate domestic flights, also on all established routes. GMG has recently started limited international flights in the South Asia region.

4.4 Transportation Investment Scenario

The structural change that took place in the transport sector can be largely explained by the government resource allocations. The first five year plan, FY 1973-FY1978 allocated Tk. 4,149 million to the transport sector (excluding international shipping/ports), of which 36% was allocated for road, 30% for rail, 18% for IWT and 16% for air or civil aviation. Sub-sector allocations changed noticeably in the third five year plan period 1985-1990 (Table 4.7). The plan allocated more than 54% to road, about 33% to railway, 8% to civil aviation, and less than 5% to IWT. The fourth five year plan, 1990-95 allocated about 76% and the fifth five year plan, 1997-02 more than 66% to the road sub-sector. The higher allocation for the road sub-sector can be partly explained by the Jamuna Bridge, which accounted for 14% of the third plan, 22% in the fourth plan, about 53% of the two year plan and 15% of the fifth plan allocations for the road sub-sector. The fifth plan was almost relieved of the pressure of the Jamuna Bridge. However, the plan made an allocation of about 21% to railway and less than 7% to inland water transport.

Table 4.7: Plan Allocations for Transport Sector, 1973-2002

Figures in million Tk. (as base year prices in respective plans)

Modes	FFYP (1973-78)	FTYP (1978-80)	SFYP (1980-85)	TFYP (1985-90)	FFYP (1990-95)	STYP (1995-97)	FFYP (1997-02)
Road	1496	1688	4090	13853	44650	39146	76706
Rail	1261	1231	4134	8360	8350	3987	24000
Inland water	736	259	1167	1220	3220		7700
Air	656	483	1472	2100	2800	1027	7500
TOTAL	**4149**	**3661**	**10863**	**25533**	**59020**	-	**115906**

Source: *Bangladesh Planning Commission*

Five-year plan allocations are indicative. They change, and the actual allocations are reflected in annual development programmes (ADPs). A closer look at the recent ADP allocations for FY2000-FY2008 reveals almost the same trend, heavily biased toward road sub-sector and further away from railway and particularly IWT. ADP allocations to IWT including BIWTA and BIWTC varied between less than 1% and 4% during 2000-2008 period. The highest allocation for IWT in 2002 was for procurement of dredgers by BIWTA. On the other hand, BIWTC, the public sector IWT service provider currently receives no allocation, but on average a subsidy of only Tk. 5 million per year (Table 4.8). It is currently surviving on its own, cross subsidizing passenger service by income earning from cargo service.

Table 4.8: ADP Allocations for the transport sector, FY2000 - FY2008

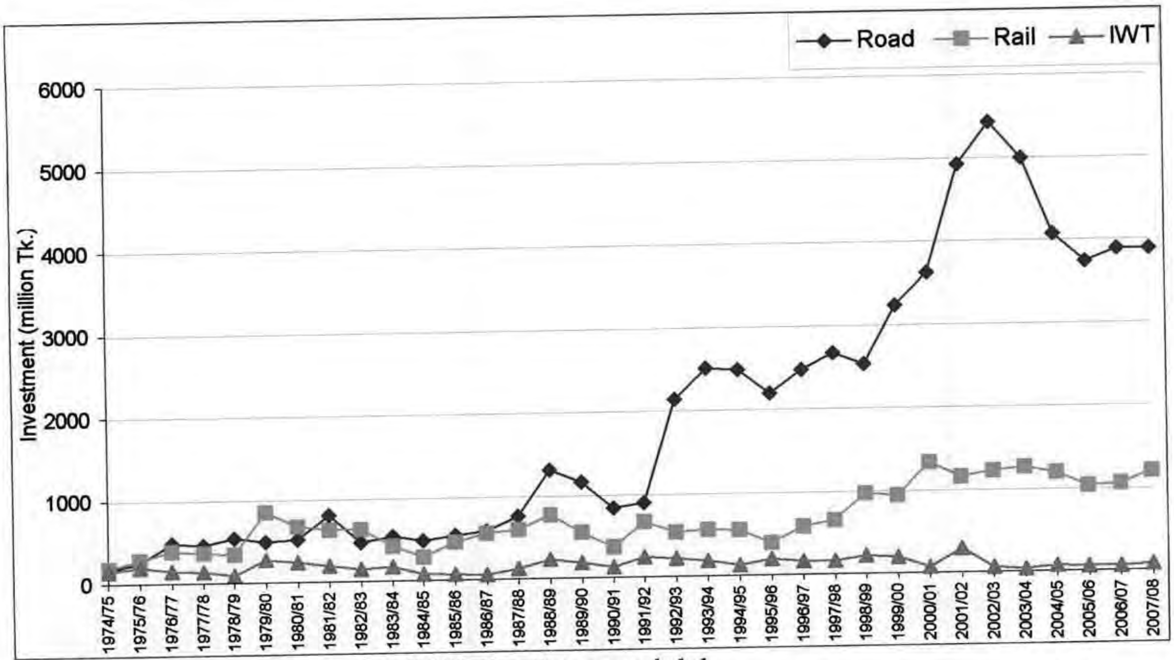
Figures in million Tk.

	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005	FY2006	FY2007	FY2008
ROAD	31550 (80%)	38659 (82%)	33879 (83%)	35856 (85%)	46786 (88%)	43615 (87%)	41990 (86%)	43944 (87%)	44001 (86%)
RHD	16923	4457	22046	22892	24542	23552	19357	21517	21595
LGED	12696	32690	10463	11384	20013	17887	21839	21978	22063
GDTPCB/DTCB	412	512	545	1570	2228	1661	174	0	0
JMBA	1520	1000	825	10	3	515	620	450	343
Rail	4251 (11%)	6132 (13%)	5434 (13%)	5779 (14%)	6083 (11%)	6085 (12%)	5513 (11%)	5967 (12%)	6852 (13%)
IWT	1469 (<4%)	473 (1%)	557 (>1%)	253 (<1%)	347 (<1%)	372 (<1%)	328 (<1%)	298 (<1%)	439 (<1%)
CAAB	1942 (5%)	1950 (4%)	920 (2%)	230 (<1%)	205 (<1%)	338 (<1%)	851 (<2%)	258 (<1%)	100 (<1%)
Total	**31550**	**38659**	**33879**	**35856**	**46786**	**43615**	**41990**	**43944**	**44001**

Note: LGED allocation includes cluster projects (road); BRTA, BRTC, Ports and Shipping allocations not included.

Source: *RADP, 2000-2008 (Planning Commission), LGED*

Investment data are also documented from the year 1974-75 to 2007-08 and shown in Figure 4.5. Figures are also adjusted using the construction cost index of the preceding year (BBS, 1990-2004). The graph clearly depicts that road sector investment went up sharply from FY1992 and continue in the present allocation of FY2008.



Note: Construction cost index adjusted. LGED allocations are excluded.

Source: *RADP, 1975-2008*

Figure 4.5: Transportation Investment by Sub-Sector

4.5 Transport Sector Performance and Macro-Modal Split

Road is the all time dominant in transporting both passenger and freight in Bangladesh. The modal shares for the passenger transportation is presented in Table 4.9. The trend shows historical and projected increase in road share in passenger transportation while waterways has intermittent increase in share.

Table 4.9: Share for Different Mode of Transport, 1974-2006

Year	Passenger				Freight			
	Total Passenger (billion pass-km)	Road (%)	Rail (%)	IWT (%)	Total Freight (billion Ton-Km)	Road (%)	Rail (%)	IWT (%)
1974/75	17	54	30	16	2.6	35	28	37
1984/85	35	65	20	16	4.8	48	17	35
1988/89	57	68	17	15	6.3	59	11	30
1992/93	66	75	12	13	9.0	61	7	32
1996/97	72	73	13	14	10.0	63	7	30
2000/01	98	77	11	12	21.0	65	8	27
2005/06	125	80	10	10	37.0	67	8	25

Source: *BITSS, 1998; RMMS; BR, 2006; TSC Wing, Planning Commission*

The road seems to be the growing transport sector in passenger transport in Bangladesh. Though the table is an estimate following previous studies and data supplied by the concerned agency, it seems that waterways is losing passenger transport portion significantly. This trend may reflect the fact the most of the Upazilla is now connected by roads and passenger transport by road is now actively competing with the other modes in terms of lower travel time and safety in transportation. Besides, the waterway of the country is diminishing in a very frightening rate as the rovers getting silted and waterways transportation is becoming hazardous. Railway is maintaining a consistent and constant level of service to the passenger. This can be seen in the ways that the limited resources available to railway make it to serve the current demand, but there may be latent demand looking for improved and safer service from rail mode.

The similar case is found in the freight transportation as in passenger transportation. Road sector dominates and continues to lead in the transportation of goods. Railway seems to have better performance in transporting goods as compared to passenger transportation. This is because of the direct link between Chittagong port to Dhaka Inland Container Depot (ICD). The trend of freight transportation is also shown in Table 4.9.

The water mode is making sharp improvement in the last reported year. But this is an estimation made from average approximate trip length. The similar case is here for the rail mode. The little improvement in performance in 2000-01 is due to the share of containers it is transporting to the Dhaka ICD. Railway is running with fixed numbers of flat cars for transporting containers from Chittagong port to Dhaka. They are planning to increase freight rolling stock to provide service to this demanding sector. It shoud be noted here that waterways can be a very potential mode in transporting the containers from Chittagong port as 89% of the containers are transported as broken bulk goods by different modes fro Chittagong port. Water sector can be a major stack holder in transporting containers.

5. DATA COLLECTION AND ANALYSIS

5.1 Introduction

As stated in Chapter 3 Data Envelopment Analysis (on constant returns to scale basis) and Choice Theoretic Stochastic Data Envelopment Analysis are used in technical efficiency calculation of the 20 greater districts of Bangladesh. From the analysis the technically inefficient districts are identified. From the calculated weights attached to the input variables the reasons for inefficiency are also identified. The Accessibility Indices are calculated using the method described in Section 3.2.3.

With the aim in addressing the research questions raised in Chapter 1 Section 1.3, the input and output variables, the analytical framework and the model specification are described in the following sections.

5.2 Data Collection

The purpose of this study is to construct a best practice regional production frontier from the data of 20 greater districts (or region) of Bangladesh. As present, there are 64 districts in Bangladesh. These 64 districts actually are the divisions of the previous 20 greater of former districts (Figure 5.1). The data for the year 2005 of former 20 districts has been analysed using conventional DEA and choice theoretic SDEM considering each district as an individual production unit utilizing its land, labour, capital and efficiency of transportation infrastructure to produce output.

For each of the 20 districts the input to be considered are:

1. Agricultural land area in sq. km
2. Civilian labour force
3. Industrial asset expressed in terms of million BDT
4. Accessibility index

A region with poor quality agricultural land with relatively more manufacturing or service industries may attract more people to live in that region. Again, a region with fertile and relatively abundant agricultural land may or may not attract more people to live there depending on land ownership, technology applied in agricultural production, etc. There could be several reasons of higher population density, however people gather in places where more scopes of earning are available. Here in study economically active population over 10 years of age has been used to be proxy variable to capture district specified effects.

The output variables i.e. Gross Regional Product (GRP), that is GDP in current market price of each region has been used.

Figure 5.1: 20 Study Regions of Bangladesh

5.2.1 Gross regional product

Figure 5.2 is constructed from the GDP share of 20 greater districts (Gross Regional Product) of the country for the year 2005. The GDP is at constant market price and expressed in billion taka (BDT). It is observed that Dhaka contributes most significant amount of national income followed by Chittagong.

Bangladesh has relied heavily on the service sector for its economic performance, to the extent that this sector now accounts for about 50 percent of the GDP (Table 5.1). The table also shows that Dhaka and Chittagong region are is more industrialized (23% and 21% of regional GDP respectively) than any other regions of the country.

Table 5.1: Gross Regional Product by Sector, 2005

Sl. No.	Region	Total GDP	Agriculture	Industry	Services
		[In million TK]			
1.	Dhaka	386,467	33,111	168,313	185,043
2.	Mymensingh	152,884	41,240	28,263	83,382
3.	Jamalpur	71,026	15,500	25,110	30,416
4.	Tangail	63,273	15,671	15,244	32,357
5.	Faridpur	119,882	25,667	25,242	68,972
6.	Chittagong	295,789	37,302	149,879	108,608
7.	Chittgong Hill Tracts	73,678	41,937	8,975	22,766
8.	Noakhali	88,493	19,498	19,861	49,134
9.	Comilla	179,541	34,165	42,766	102,610
10.	Sylhet	155,539	35,925	37,514	82,099
11.	Rajshahi	124,988	34,959	22,235	67,794
12.	Dinajpur	80,613	22,622	15,961	42,030
13.	Rangpur	148,744	41,383	28,533	78,828
14.	Bogra	72,171	20,973	13,656	37,542
15.	Pabna	73,518	16,046	17,372	40,101
16.	Khulna	143,324	36,880	39,714	66,730
17.	Barisal	117,519	27,041	22,395	68,083
18.	Patuakhali	44,165	14,400	10,083	19,681
19.	Jessore	102,923	30,287	19,138	53,498
20.	Kushtia	61,577	15,242	16,463	29,871

Source: *Bangladesh Bureau of Statistics*

From Figure 5.3, the relative position of the regions and the trend of GDP increase are evident. The GDP is almost doubled within the last ten years. Although within this period many development projects have been implemented in many districts, the relative position remains almost same, as it was in ten years back.

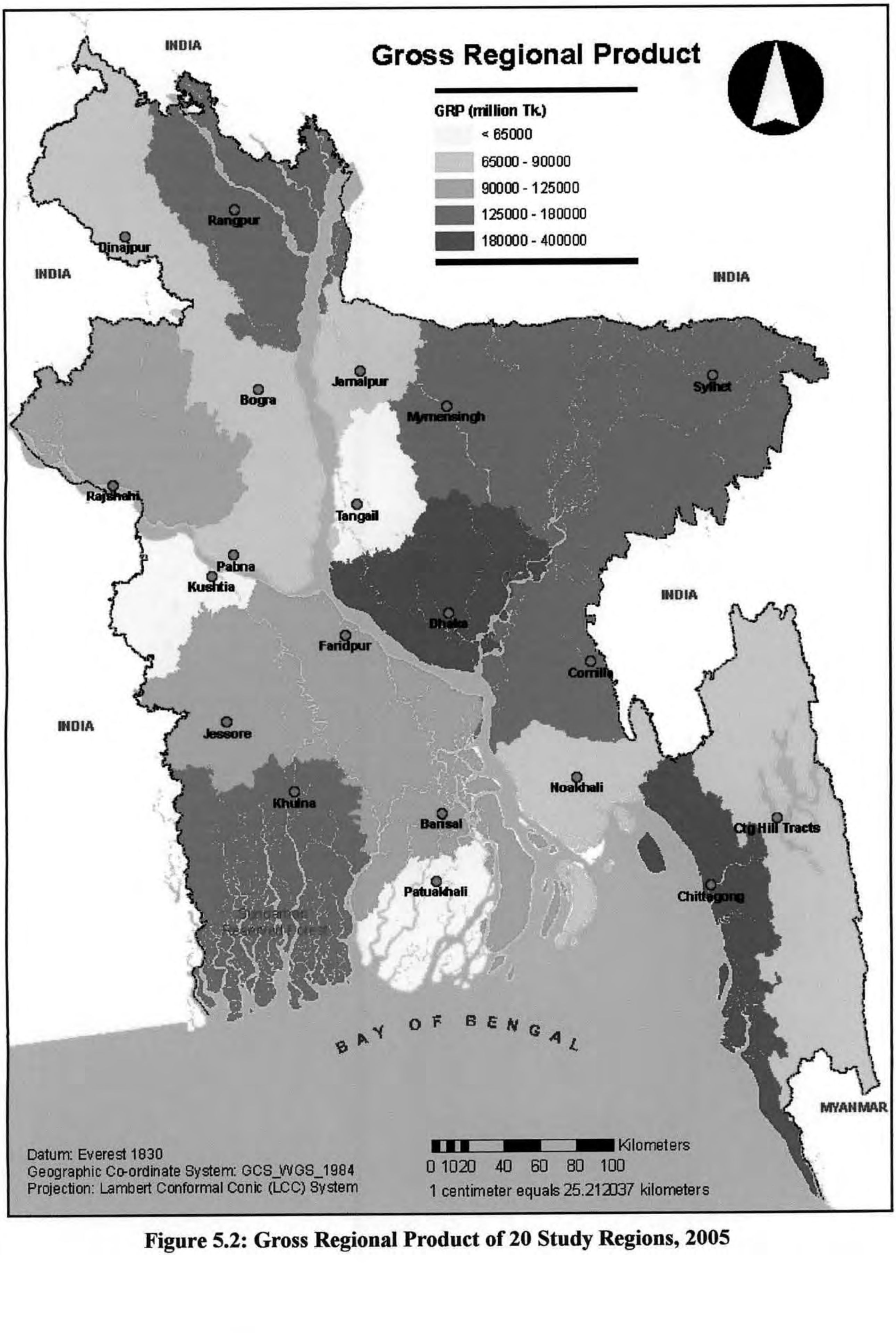
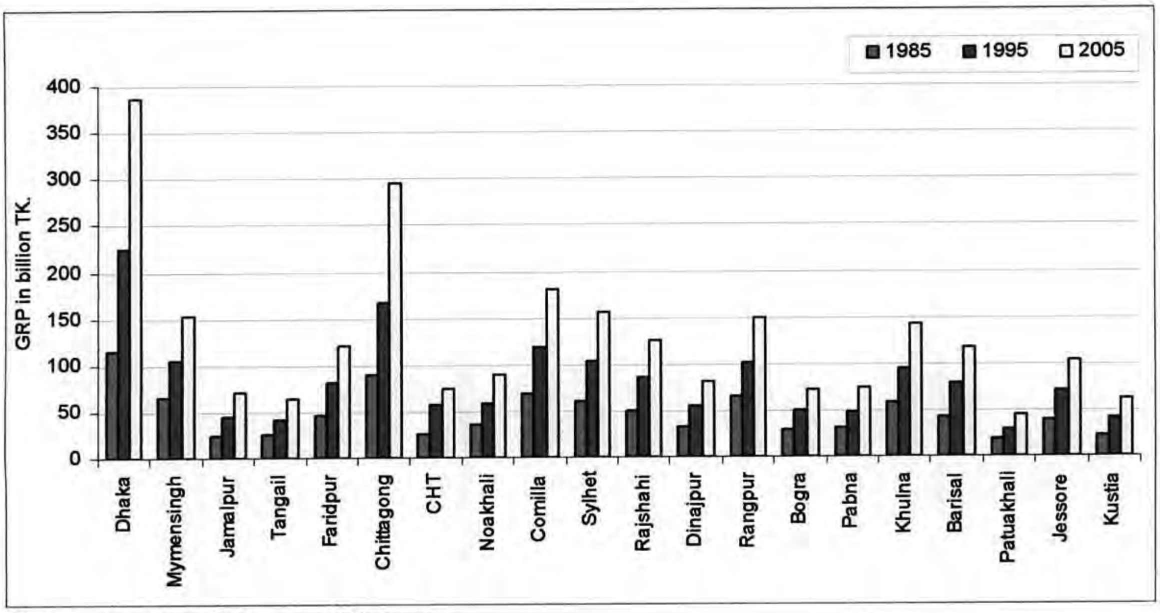


Figure 5.2: Gross Regional Product of 20 Study Regions, 2005



Source: *Bangladesh Bureau of Statistics*

Figure 5.3: Gross Regional Production for Last 20 Years

5.2.2 Effective land area

Agricultural land area of each district expressed as square km includes agricultural land (single, double, triple), forestland, mining area, water bodies etc. and excludes industrial areas, settlements and other institutional areas. The assumption is that the agricultural land area is being utilized for primary production (agriculture, mining, forestry etc.). The water bodies are being utilized for fisheries and aquaculture, etc. Industrial asset expressed in million BDT represents each districts manufacturing industrial capital. Table 5.2 represent the actual area, effective area and land utilization index of the 20 study regions of Bangladesh as in the year 2005. It is observed that, Rangpur is the largest and Tangail is the smallest districts based on actual and effective area under consideration in the study. But in term of land utilization, Bogra region is the most effective a followed by Jessore, Jamalpur and Dinajpur, whereas Chittagong Hill Tracts are the least effective (Figure 5.4).

5.2.3 Civilian labour force

Population density is determined as the ratio of total population of any district to the total area of that district. Higher population density may imply higher economic activity. But this variable cannot capture the available labour force, as each district is different with respect to various micro units. Thus population share of economically active person of 10 years of age is taken as a input variable against civilian labour force. Population, population density and civilian labour force data have been collected from Statistical Year Book of Bangladesh and shown in Table 5.3. Figure 5.5 shows total available civilian labour force for the year 2005. It is observed that, Dhaka and Comilla contain highest labour force than any other districts.

Table 5.2: Actual Land Area and Effective Land Area, 2005

Sl. No.	Region	Actual Land Area [sq. km]	Effective Land Area [sq. km]	Land Utilization [Eff./Actual]
1.	Dhaka	7439.41	10713.46	1.44
2.	Mymensingh	9862.5	15651.04	1.59
3.	Jamalpur	3395.74	5773.52	1.70
4.	Tangail	3414.38	5407.92	1.58
5.	Faridpur	7007.93	10663.92	1.52
6.	Chittagong	7774.84	10237.03	1.32
7.	Chittgong Hill Tracts	13294.71	13622.78	1.02
8.	Noakhali	5985.29	8729.12	1.46
9.	Comilla	6716.34	10973.91	1.63
10.	Sylhet	12595.95	15780.25	1.25
11.	Rajshahi	9441.29	12872.09	1.36
12.	Dinajpur	6652.13	11277.24	1.70
13.	Rangpur	9665.52	15878.25	1.64
14.	Bogra	3885.34	6988.96	1.80
15.	Pabna	4869.42	7546.06	1.55
16.	Khulna	12211.9	13940.19	1.14
17.	Barisal	8244.09	12910.72	1.57
18.	Patuakhali	5051.46	6673.34	1.32
19.	Jessore	6566.66	11079.28	1.69
20.	Kushtia	3494.65	5595.50	1.60

Source: *BBS 2005*

Table 5.3: Population, Population and Civilian Labour Force, 2005

Sl. No.	Region	Population [000]	Population Density [per sq. km]	Labour Force [000]
1.	Dhaka	20742	2788	8443
2.	Mymensingh	10238	1038	4378
3.	Jamalpur	3853	1135	1546
4.	Tangail	3731	1093	1406
5.	Faridpur	6782	968	3275
6.	Chittagong	9655	1242	4693
7.	Chittgong Hill Tracts	1541	116	503
8.	Noakhali	5987	1000	2130
9.	Comilla	10437	1554	4805
10.	Sylhet	8947	710	3675
11.	Rajshahi	8707	922	3966
12.	Dinajpur	5368	807	2789
13.	Rangpur	10376	1074	5208
14.	Bogra	4447	1144	1880
15.	Pabna	5508	1131	2506
16.	Khulna	6439	527	3495
17.	Barisal	6577	798	4560
18.	Patuakhali	2568	508	1825
19.	Jessore	6306	960	2798
20.	Kushtia	3791	1085	1730

Source: *BBS 2005, LFS 2005*

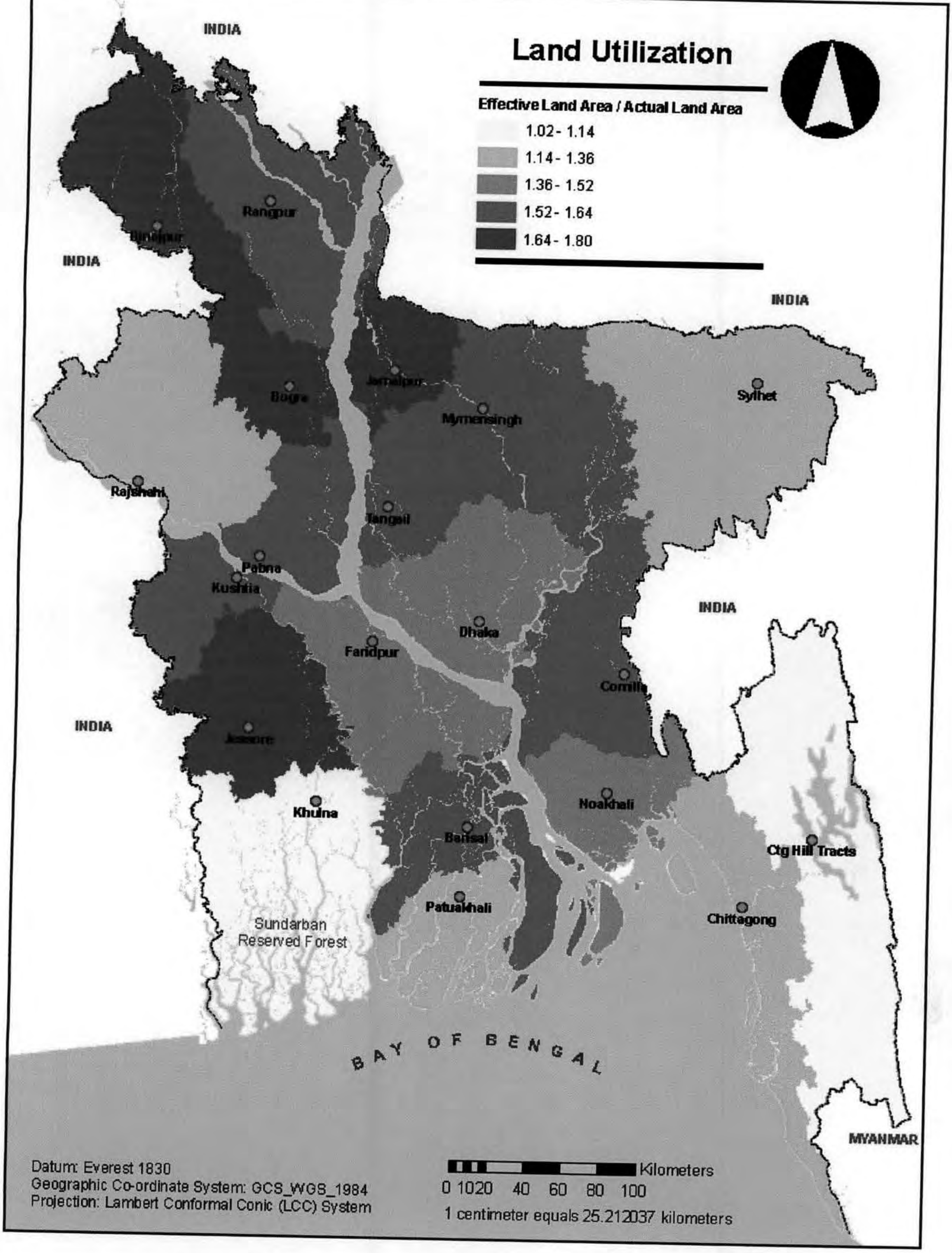


Figure 5.4: Land Utilization of 20 Study Regions, 2005

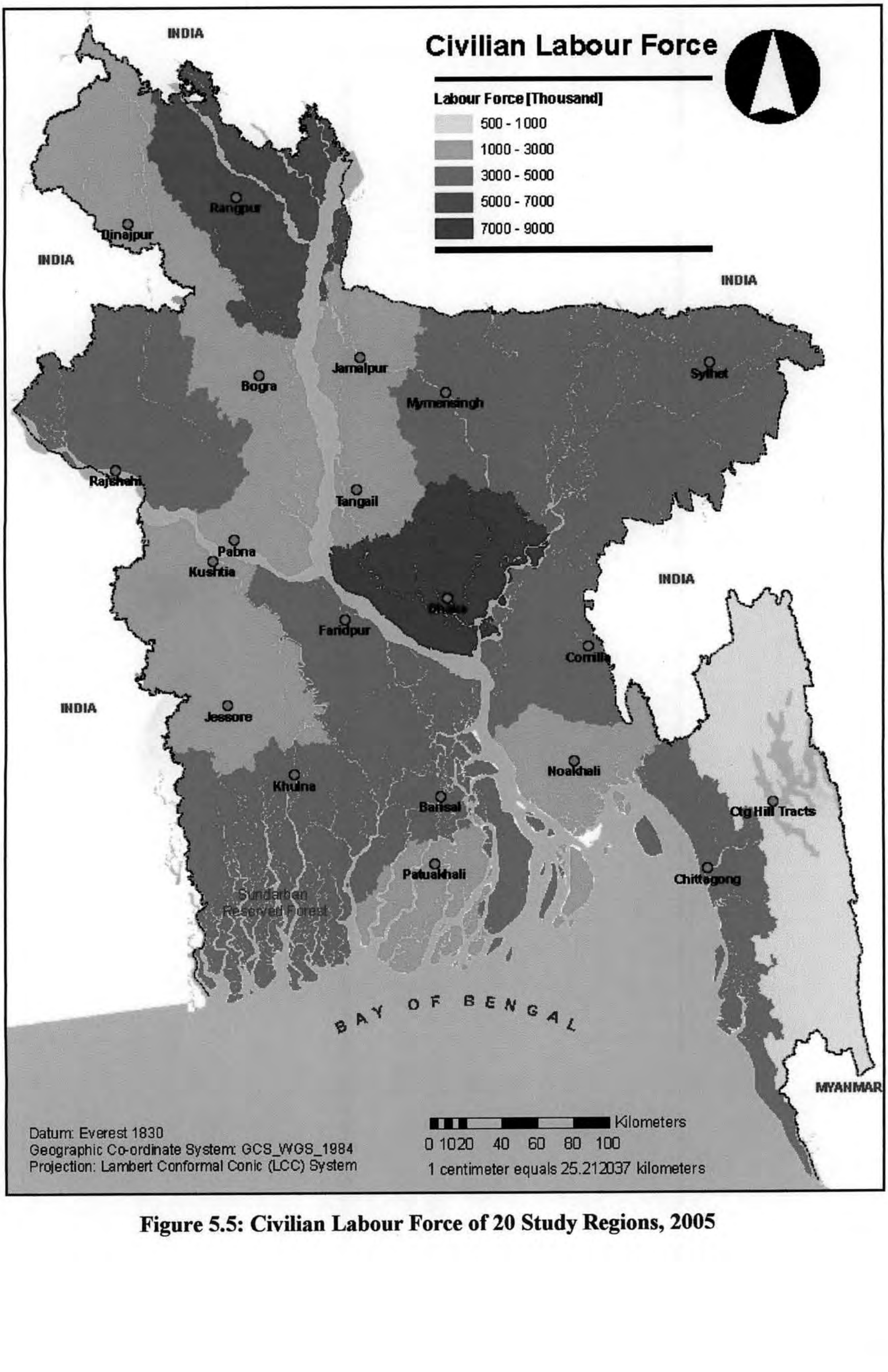


Figure 5.5: Civilian Labour Force of 20 Study Regions, 2005

5.2.4 Industrial capital

Capital goods can be defined as real products that are used in the production of other products but are not incorporated into the new product (these are termed Consumer Goods). They are often called fixed human-made means of production. Capital goods include factories, machinery, tools, and other buildings. They are different from raw materials, which are used up in the production of goods. Industrial capital data has been collected from Industrial Survey done by Bangladesh Bureau of Statistics in 2003 and forecasted using gross output and value added on factored cost of the concerned years with industrial GDP of the year 2005. Table 5.4 shows the industrial capital and average annual growth rate of last 10 years. The data clearly shows that Dhaka region holds the higher capital goods followed by Chittagong than any other regions of the country. Average annual growth rate of capital goods is the highest in Dhaka, which is very low in case of Chittagong. Data is also shown in Figure 5.6 to capture the spatial distribution of industrial assets in the country.

Table 5.4: Industrial Capital and Average Annual Growth, 2005

Sl. No.	Region	Industrial Capital [million TK.]	Avg. Annual Growth rate [% of last 5 years]
1.	Dhaka	371,581	9.67
2.	Mymensingh	37,263	4.11
3.	Jamalpur	21,574	0.23
4.	Tangail	10,873	2.11
5.	Faridpur	27,699	3.42
6.	Chittagong	138,561	0.32
7.	Chittgong Hill Tracts	15,442	4.21
8.	Noakhali	62,748	2.13
9.	Comilla	77,593	6.99
10.	Sylhet	55,139	5.84
11.	Rajshahi	21,054	3.76
12.	Dinajpur	47,826	4.62
13.	Rangpur	30,008	5.15
14.	Bogra	24,161	5.25
15.	Pabna	23,693	3.99
16.	Khulna	58,928	0.24
17.	Barisal	21,025	4.19
18.	Patuakhali	13,172	6.87
19.	Jessore	51,068	7.82
20.	Kushtia	22,090	5.03

***Source:** ISB, 2003; BBS 2005*

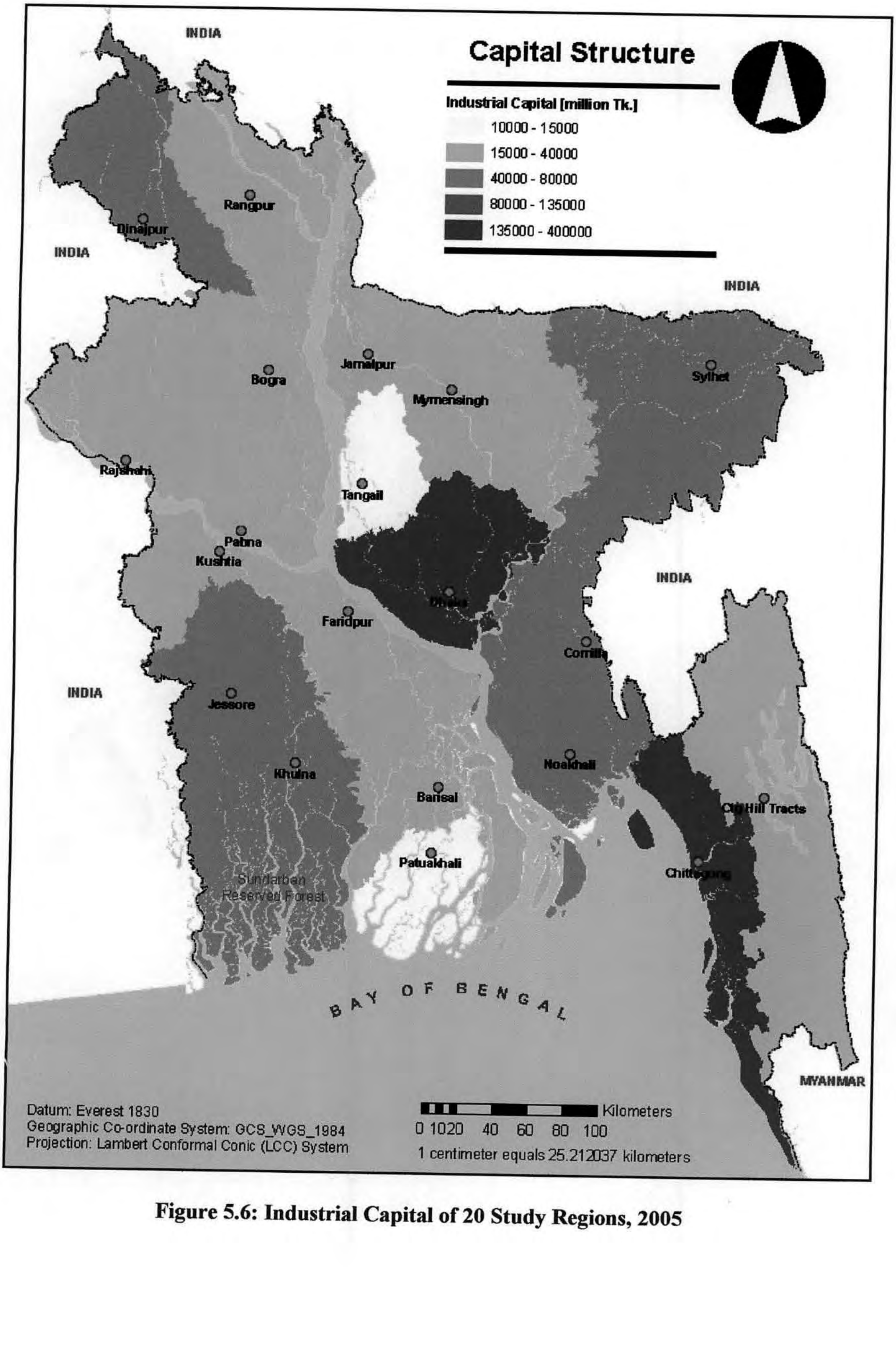


Figure 5.6: Industrial Capital of 20 Study Regions, 2005

5.2.5 Accessibility

In this research, Accessibility Index of each of the 20 districts is used as a measure of the available transportation infrastructure and service to travel from one district to the other 19 districts. Accessibility indices value for the year 2005 is used to measure relative efficiency in conventional DEA and choice theoretic SDEM approach. For dynamic analysis, accessibility data of 25 years (at 5 years intervals) is used to assess time lag between transportation investment and economic development.

Data Used for Accessibility Index Calculation

The Accessibility indices of each of 20 greater districts (regions) of Bangladesh are calculated for the years, 1980, 1985, 1990, 1995, 2000 and 2005. For this purpose, the following data are collected from the transportation network maps and relevant reports of the respective years:

1. Shortest inter-district travel distance for all three modes (roadway, railway and inland waterway).
2. Respective travel time.
3. Fare rates.
4. Value of travel time/Travel time cost
5. Population percentage (of the total population of Bangladesh) of the districts.

Travel Distance

Shortest inter-district travel distances are calculated from digital maps (GIS coverage) using Network Analyst Tool of ArcGIS 9.1. Updated GIS data of road network for the year 2005 has been collected from Roads and Highways Department. Railway and IWT network data have been collected from Transport Sector Coordination Wing of Planning Commission. Previous years' (1980-2000) for all three modes are collected from the respective years transport network maps. It is observed that only the road network has been improved within the observation period (1980-2005). A significant number of new roads and bridges have been constructed in this period resulting in reduction of inter-district travel distances. LGED road network is not considered for this study because it serves the micro level population and ultimately it acts as a feeder road to the RHD network. During measuring IWT network, seasonal routes (2400 km) are not considered.

Travel Time

Factors that influence travel time in a transport corridor which has three components (May and Montgomery, 1984).

- *Inter-vehicle variation* is caused by differences in characteristics of the vehicle, driving styles and traffic conditions met.
- *Inter-period variation* is the effect of traffic volume, traffic composition, specific incidents, weather, time, day and week, secular trends etc.
- *Inter-route variation* which is influenced by route length, geometry, land use and pattern of demand

In this research, accessibility in effect of transport infrastructure component is calculated using the inter-regional travel time on multi-modal transport network, where first two factors have insignificant impact on measuring travel time. Travel time varies with the length of the route and speed of the transport service. Speed varies with the number of ferries, road quality and transport service quality in case of roadway transportation; in case of railway transportation, speed varies with the number of stops and their duration, condition of railway track and continuity of the train service i.e. whether it is an intercity train or express train etc., and with the service quality in case of inland waterway transport.

Standard speed in each classes of road, rail and waterway network are taken to calculate travel time. Narrow bridges, ferry gaps etc are also considered in this exercise. Due to comparatively large investment on the improvement in road network the travel time has been reduced to a certain extent within the observation period. Overall travel time would be improved a lot if congestion is managed in major city access (e.g., Dhaka, Chittagong, Bogra etc.). Vehicle speed will be much lower in city streets, which is considered during travel time calculation for through traffic.

The introduction of intercity and express trains and upgrading of the rail tracks also contributed significantly in the reduced railway travel time over the years. Unfortunately the quality and therefore the speed of inland waterway transport system remain unchanged.

Value of Travel Time and Fare Rates

Travel Time Costs (TTC), also referred to as Values of Time, are an important component of transport user costs. The concept of travel time costs is based around the premise that time spent in travelling has an "opportunity cost" and could be used in an alternative activity which also produce or may produce some significant utility popularly known as benefit. If the alternative activity can have a monetary value assigned to it this can be used as a part of RUC in the economic appraisal of projects, particularly of the transport projects having relation with consumption of time in the use of their output. TTC may vary from country to country, even from project to project in the same country. This can vary in size from 20 per cent of total RUC to over 80 per cent of the same in the economic and/or financial appraisal of schemes depending on the extent of time delays involved in case of the project under study as well as the income pattern of the users of the project output. In case of the construction of a major new bridge to replace a ferry for example, TTC will be immensely significant compared to a road improvement project without any change in its alignment or pavement and/or shoulder capacity. Again, value of time will be much higher in a more developed country like the USA or Britain than that in a less developed country like Bangladesh or Afganistan. Similarly this variation in value of time may exist between a more developed region or society of a country and a relatively less developed part or habitation of the same country.

Time costs may be broken down into "in vehicle time" and "out of vehicle time". The latter may be important to bus passengers waiting for a vehicle, but is specialised in its application and is not considered in this study which focuses on "in vehicle time" values only.

Several studies have been done to assess the travel time cost in context of Bangladesh. The Economics Circle of RHD has been undertaking TTC survey almost every year as a part of RUC Annual Report. The survey was based on the Average Wage approach whereby the wage rates of vehicle occupants are assessed and then their average rates have been estimated to reflect the value of time of occupants in different vehicles. In similar method, travel time cost for railway and waterway users have been measured in various Development Project Proposal (DPP) developed by Bangladesh Railway and BIWTA. These DPPs are evaluated by Rail and Waterway Wing of Planning Commission.

Travel Time Cost for road users are considered bus passengers comparing to major intercity travellers of railway and waterway, all of which are set out in Table 5.5.

Fare rate in taka per km of respective modes have been collected from Statistical Yearbook of Bangladesh (BBS 2004) and shown in Table 5.5.

Table 5.5: Travel Time Cost and Fare Rate, 2005

Mode	Value of Time (Tk/hr)		Fare Rate (Tk/km)
	Financial	Economic	
Road	22.0	17.6	0.72
Rail	18.9	15.1	0.39
IWT	16.0	14.5	0.29
Air	320	285	3.40

***Source:** RUCS, 2005; TSC Wing, Planning Commission; BBS 2004*

For the interest of dynamic analysis, the relative accessibility values of different districts have been measured considering their changes over time and the value of travel time for the year 2005 has been used for all years. Similarly, the fare rate for the year 2005 has been applied to all other years.

Population Percentage

The product of population percentage of the origin and destination districts of the respective years is used as a measure of P_j^n - the attraction of the destination district. The population figures are collected from Statistical Yearbook of Bangladesh.

Calculation of Accessibility Index

To calculate the accessibility index of a certain district the shortest travel paths for each mode between that district and the remaining 19 districts are determined. The travel time is then calculated. Details of the accessibility index calculation for the year 2005 are shown in Appendix A. One of the 20 data sets for the year 2005 is presented in Table 5.6. The generalized cost and composite time of travel from Dhaka to other 19 districts is calculated from this table using equation (3.2.3). An example for calculating composite time is given below.

Travel impedance for any mode from Dhaka to Khulna,

$$t_{(Dhaka-Khulna)mode} = a_1 \times T_{Dhaka-Khulna} + a_2 \times F_{Dhaka-Khulna}$$

For Road, $t_{(Dhaka\text{-}Khulna)road}$ = 22.0 [Tk/Hr] × 6.2 [Hr] + 1 × 0.72 [Tk/Km] × 179 [Km]
= 265.3 [Tk]
= 265.3 [Tk] / 22.0 [Tk/Hr]
= 12.1 [Hr] or 726 [Min]

For Rail, $t_{(Dhaka\text{-}Khulna)rail}$ = 18.9 [Tk/Hr] × 11.6 [Hr] + 1 × 0.39 [Tk/Km] × 405 [Km]
= 377.2 [Tk]
= 377.2 [Tk] / 18.9 [Tk/Hr]
= 19.9 [Hr] or 1194 [Min]

For Waterway, $t_{(Dhaka\text{-}Khulna)waterway}$ = 16.0 [Tk/Hr] × 24.3 [Hr] + 1 × 0.29 [Tk/Km] × 352 [Km]
= 490.9 [Tk]
= 490.9 [Tk] / 16.0 [Tk/Hr]
= 30.7 [Hr] or 1842 [Min]

where, a_1 (value of travel time in Tk/Hr) for road, rail and water are 22.0, 18.9 and 16.0 respectively (Table 5.5). Fare rate in Tk/Km for road, rail and water are 0.72, 0.39, 0.29 respectively and $a_2 = 1$.

Thus, compound travel impedance or composite time for Dhaka to Khulna according to equation (3.2.1):

$$t_{(Dhaka\text{-}Khulna)} = \frac{-1}{\lambda} \ln \sum_{m} P_{(Dh-Kh)m} \exp(-\lambda\, t_{(Dh-Kh)m})$$

$$= -ln[0.92 \times exp(-0.01 \times 726) + 0.05 \times exp(-0.01 \times 1194) + 0.03 \times exp(-0.01 \times 1842)]$$

$$= 7.34$$

where, P_{ijm} (Dhaka to Khulna) for road, rail and water are 0.92, 0.05 and 0.03 respectively (using equation 3.2.2). λ is assumed to be 1. t_{ijm} is used using a scale factor 0.01.

The Accessibility Indices has been calculated using this composite travel time (t_{ij}), product of population percentage from Dhaka to Khulna, E_{ij} (Table 5.3) and appropriate value of calibration parameter μ and formulated in equation (3.2.1). A useful estimate of μ is one over the average travel cost (Ortúzar and Willumsen, 2000), which is found to be 0.0654. Apart from the average cost approach to determine the value of μ, it is also estimated for this study. The value of μ is found to be 0.138.

Table 5.7 contains the accessibility index values of each of the 20 districts for different years.

Table 5.6: Multimodal Transportation Distance, Travel Time and Generalised Cost (For Dhaka, 2005)

Origin Region	Destination Region	Roadway				Railway			Waterway			Composite Time [Hr]
		Distance [Km]	No. of Ferries	Travel Time [Hr]	Generalised Cost [Hr]	Distance [Km]	Travel Time [Hr]	Generalised Cost [Hr]	Distance [Km]	Travel Time [Hr]	Generalised Cost [Hr]	
Dhaka	Dhaka	0	0	0	0	0	0	0	0	0	0	0
	Mymensingh	123	0	2.5	6.5	123	3.5	6.1	-	-	-	3.785
	Jamalpur	179	0	3.6	9.4	183	7.5	11.3	321	25.9	31.7	6.033
	Tangail	92	0	1.8	4.9	97	2.8	4.8	213	16.9	20.8	2.965
	Faridpur	104	1	3.2	6.6	336	13.4	20.3	135	10.4	12.8	4.040
	Chittagong	242	0	4.8	12.8	320	9.1	15.7	283	18.9	24.0	7.868
	Ctg. Hill Tracts	292	0	6.2	15.7	-	-	-	373	27.9	34.7	9.429
	Noakhali	165	0	3.9	9.3	242	8.7	13.7	113	7.5	9.5	5.794
	Comilla	99	0	2.1	5.3	171	4.9	8.4	-	-	-	3.317
	Sylhet	226	0	4.8	12.2	296	8.5	14.6	302	23.3	28.8	7.511
	Rajshahi	257	0	5.1	13.5	256	8.9	14.2	-	-	-	8.194
	Dinajpur	338	0	7.7	18.7	390	11.4	19.5	-	-	-	11.317
	Rangpur	304	0	6.1	16.1	325	13.0	19.7	414	33.6	41.1	9.713
	Bogura	197	0	3.9	10.4	284	10.4	16.3	285	22.9	28.1	6.282
	Pabna	157	1	4.7	9.9	197	5.6	9.7	-	-	-	5.896
	Khulna	179	1	6.2	12.1	405	11.6	19.9	352	24.3	30.7	7.338
	Barisal	171	1	5.7	11.3	-	-	-	165	11.8	14.8	7.518
	Patuakhali	206	3	6.8	13.5	-	-	-	235	18.6	22.9	9.029
	Jessore	196	1	5.0	11.4	346	9.9	17.0	-	-	-	6.929
	Kustia	173	0	5.1	10.7	245	7.4	12.4	-	-	-	6.562

Table 5.7: Accessibility Indices of Different Districts of Different Years

Regions	1980	1985	1990	1995	2000	2005
Dhaka	5.141	5.407	5.867	6.539	6.801	6.969
Mymensingh	2.403	2.529	2.807	3.097	3.332	3.814
Jamalpur	0.893	0.953	1.082	1.222	1.347	1.336
Tangail	1.202	1.270	1.402	1.547	1.674	2.358
Faridpur	1.302	1.384	1.540	1.716	1.756	2.144
Chittagong	1.279	1.360	1.502	1.741	1.785	2.418
Ctg. Hill Tracts	0.102	0.112	0.131	0.158	0.165	0.275
Noakhali	0.887	0.953	1.060	1.250	1.292	1.859
Comilla	1.966	2.106	2.308	2.730	2.818	3.871
Sylhet	1.107	1.171	1.326	1.465	1.560	2.490
Rajsahi	1.537	1.656	1.871	2.090	2.259	3.003
Dinajpur	0.914	0.962	1.066	1.169	1.271	1.393
Rangpur	1.787	1.873	2.059	2.264	2.532	3.318
Bogura	0.794	0.855	0.972	1.094	1.303	1.669
Pabna	0.994	1.073	1.231	1.402	1.568	2.002
Khulna	1.252	1.329	1.482	1.648	1.715	2.029
Barisal	1.304	1.389	1.559	1.761	1.818	2.140
Patuakhali	0.385	0.411	0.466	0.529	0.545	0.707
Jessore	1.208	1.297	1.459	1.634	1.725	2.175
Kustia	0.814	0.885	0.998	1.113	1.197	1.327

The Accessibility Index of each district has three components – (i) Road (ii) Rail, and (iii) Inland Waterway Transport. The analyses show that most of the transport sector investment has been made on Roadway sub sector resulting in significant improvements of both infrastructure stock and service of the road transport system of the country. In the railway sub sector investments have been made chiefly to improve the rail service and to repair and maintain the existing railway tracks. Within the last five years only significant investment was to construct the dual gauge railway track from Joydebpur to Jamtail junction over Jamuna Bridge. Investment on inland waterway sub sector has been largely to keep the navigability of the existing waterway. As a result there has been no improvement in the waterway transportation service; specifically average speed and therefore the travel time remains the same for the last 25 years. The Accessibility improvement of overall transport network trend is evident from Table 5.7.

Figure 5.7 shows that the improvement in accessibility is not uniform throughout the country. The accessibility of Dhaka has been improved the most. Accessibility of Chittagong Hill Tracts and Patuakhali has almost no improvement. The other 17 districts have experienced moderate improvements in their respective accessibility. The largest improvement in accessibility of Dhaka may also imply that all investment to improve accessibility has been centered on Dhaka i.e. priority was given to improve the inter-district communication of Dhaka with the rest of the districts. As a result the accessibility of Dhaka is excellent compared to other districts. But this increased accessibility when viewed as attractiveness also has a negative effect - severe congestion in city access. Product of population also contributes a significant factor influencing the value of accessibility indices. Population of Dhaka has increased exponentially over the last 20 years, which results higher increase rate of accessibility indices than any other regions.

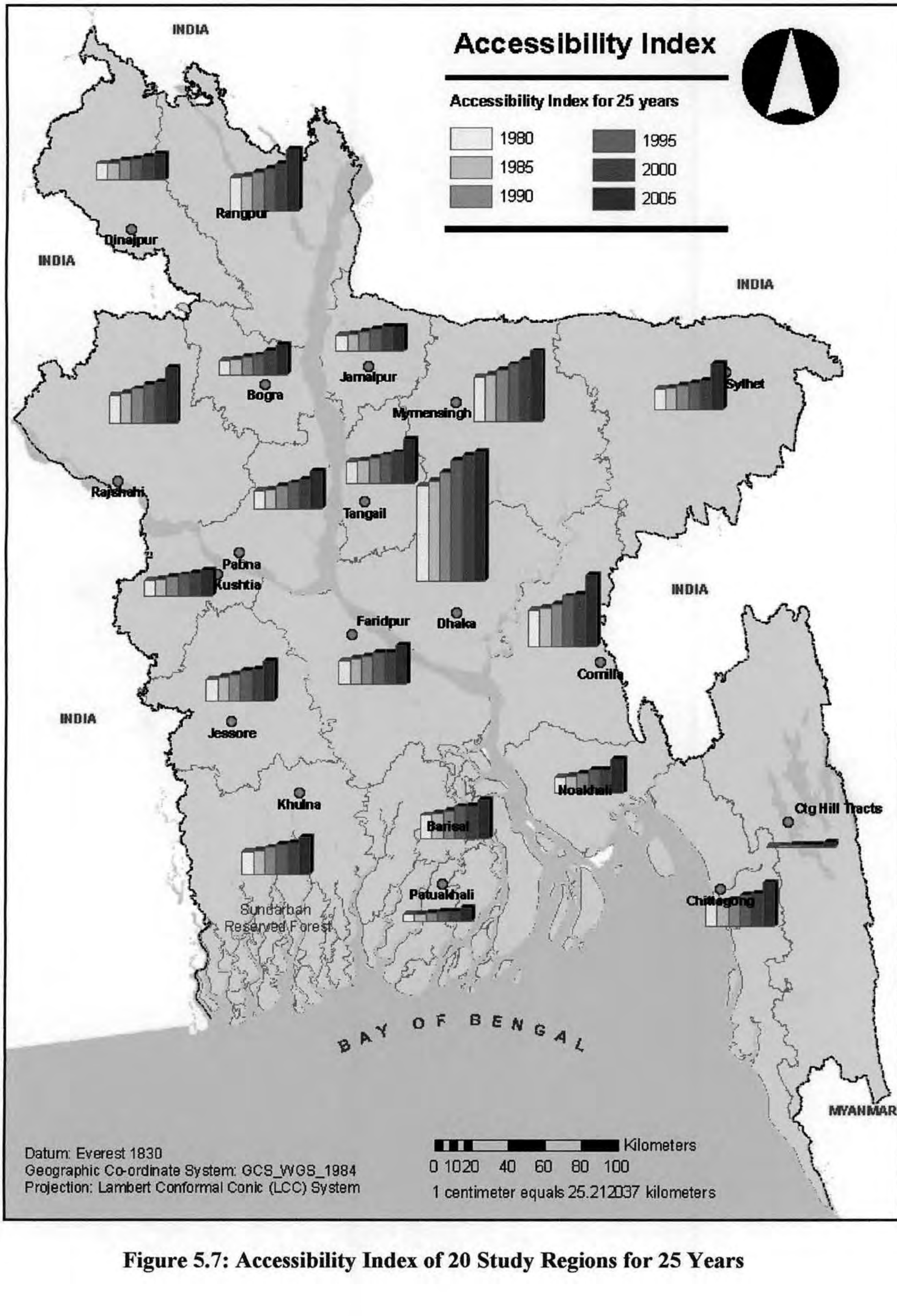


Figure 5.7: Accessibility Index of 20 Study Regions for 25 Years

5.3 Data Analysis and Results

This section illustrates the details of analysis for measuring technical efficiency and assessing lagging effect of accessibility using the input and output parameters set out in the previous section. Both conventional Data Envelopment Analysis (DEA) and choice theoretic Stochastic Data Envelopment Model (SDEM) are formulated based on the discussion in Chapter 3.

5.3.1 Measuring efficiency

Table 5.8 presents the data set of year 2005 for Efficiency analysis. For the purpose of the analysis in DEA approach, input and output data sets are to be normalized with respect to the maximum value of corresponding variables.

Table 5.8: Input and Output Data for Year 2005

Region	GDP [Mill Tk]	Land [Sq. Km]	Labour [Mill]	Capital [Mill Tk]	Accessibility Index	Normalized				
						GDP	Land	Labour	Capital	Accessibility
Dhaka	386467	10713.46	8443	371581	6.969	1.000	0.675	1.000	1.000	1.000
Mymensingh	152884	15651.04	4378	37263	3.814	0.396	0.986	0.519	0.100	0.547
Jamalpur	71026	5773.52	1546	21574	1.336	0.184	0.364	0.183	0.058	0.192
Tangail	63273	5407.92	1406	10873	2.358	0.164	0.341	0.167	0.029	0.338
Faridpur	119882	10663.92	3275	27699	2.144	0.310	0.672	0.388	0.075	0.308
Chittagong	295789	10237.03	4693	138561	2.418	0.765	0.645	0.556	0.373	0.347
CHT	73678	13622.78	503	15442	0.275	0.191	0.858	0.060	0.042	0.039
Noakhali	88493	8729.12	2130	62748	1.859	0.229	0.550	0.252	0.169	0.267
Comilla	179541	10973.91	4805	77593	3.871	0.465	0.691	0.569	0.209	0.555
Sylhet	155539	15780.25	3675	55139	2.490	0.402	0.994	0.435	0.148	0.357
Rajshahi	124988	12872.09	3966	21054	3.003	0.323	0.811	0.470	0.057	0.431
Dinajpur	80613	11277.24	2789	47826	1.393	0.209	0.710	0.330	0.129	0.200
Rangpur	148744	15878.25	5208	30008	3.318	0.385	1.000	0.617	0.081	0.476
Bogra	72171	6988.96	1880	24161	1.669	0.187	0.440	0.223	0.065	0.239
Pabna	73518	7546.06	2506	23693	2.002	0.190	0.475	0.297	0.064	0.287
Khulna	143324	13940.19	3495	58928	2.029	0.371	0.878	0.414	0.159	0.291
Barisal	117519	12910.72	4560	21025	2.140	0.304	0.813	0.540	0.057	0.307
Patuakhali	44165	6673.34	1825	13172	0.707	0.114	0.420	0.216	0.035	0.101
Jessore	102923	11079.28	2798	51068	2.175	0.266	0.698	0.331	0.137	0.312
Kushtia	61577	5595.50	1730	22090	1.327	0.159	0.352	0.205	0.059	0.190

Conventional Data Envelopment Analysis (DEA) Approach

The linear programming formulation of the Charnes, Cooper and Rhodes (1978) DEA model, often called as CCR version of DEA model is used in calculation the relative technical efficiencies of the 20 greater districts of Bangladesh. Using the model for this study (model 3.3.1), the relative efficiencies of all of the 20 greater districts of

Bangladesh are calculated for 2005. The inefficient districts and the reason for their inefficiencies are determined from the relative efficiency values and the endogenous weights of the inputs respectively. The efficiency/inefficiency patterns for different districts are also identified from the year-wise efficiency values. The data set presented in Table 5.8 is considered in constructing the example with the assumption that the endogenously determined weights are known. Applying model (3.3.1), the relative efficiency of Mymensingh region with respect to all 20 regions is:

Maximize, $h_0\,(\text{Mymensingh}) = 0.396\,u$

Subject to, $0.986\,v_1 + 0.519\,v_2 + 0.100\,v_3 + 0.547\,v_4 = 1$

$1.000\,u - 0.675\,v_1 - 1.000\,v_2 - 1.000\,v_3 - 1.000\,v_4 \leq 0$ ...(for Dhaka)

$0.184\,u - 0.364\,v_1 - 0.183\,v_2 - 0.058\,v_3 - 0.192\,v_4 \leq 0$ ...(for Jamalpur)

...... for 19 districts

Thus, linear programs for each of the 20 regions are formulated and analyses are accomplished using MATLAB. As stated earlier, the weights leading to the maximum efficiency score are produced during the calculation and shown in Table 5.9.

Table 5.9: Relative Efficiency and Weights of Input and Output - DEA Model

Region	Efficiency	Weight of the parameters				
		GDP	Land	Labour	Capital	Accessibility
Dhaka	1.000	1.000	1.282	0.071	0.042	0.021
Mymensingh	0.880	3.728	0.001	1.589	2.137	0.001
Jamalpur	0.737	8.876	0.001	3.787	5.088	0.001
Tangail	0.845	10.696	0.001	4.564	6.131	0.001
Faridpur	0.810	5.664	0.170	0.001	3.680	1.978
Chittagong	1.000	2.611	0.124	0.138	0.219	2.231
Chittagong Hill Tracts	0.836	23.212	0.001	0.001	0.001	25.616
Noakhali	0.607	4.601	0.110	0.396	2.836	1.295
Comilla	0.714	3.131	0.627	0.001	2.706	0.001
Sylhet	0.806	3.988	0.120	0.001	2.591	1.393
Rajshahi	1.000	4.717	0.170	0.048	14.164	0.080
Dinajpur	0.740	5.785	0.001	0.001	3.225	2.914
Rangpur	0.888	4.016	0.121	0.001	2.609	1.403
Bogra	0.801	7.774	0.001	3.316	4.456	0.001
Pabna	0.938	6.655	0.001	2.839	3.815	0.001
Khulna	0.893	4.512	0.001	1.539	2.598	0.374
Barisal	0.937	6.003	0.001	2.051	3.456	0.495
Patuakhali	1.000	14.085	0.044	0.414	8.968	6.044
Jessore	0.792	4.799	0.001	2.046	2.752	0.001
Kushtia	0.849	8.932	0.001	3.811	5.120	0.001

The estimated efficiency explains the overall level of economic activity with respect to the input factors. The higher the efficiency, the better is the utilization of input resources. Also higher values of the weights of the input variables imply that such variables become binding constraints in the process of optimization. Marginal rate of return for further investment is provided by the values of the weights. A uniform value of the weight implies a balanced utilization of resources. The result of DEA Model is shown in Table 5.9. It is observed that four regions, among the twenty regions considered in the analysis, operate at highest efficiency level. But even among these regions there exists imbalance in utilization of input factors. In the case of Dhaka unavailability of land area is more prominent. On the contrary, Chittagong and Patuakhali regions suffer from lack of accessibility. It is also notable that for all the regions, except Dhaka and Chittagong, lack of capital is identified as the most significant cause of inefficiency.

As shown in Table 5.9, the most inefficient regions are Jamalpur, Comilla, Dinajpur and Jessore. From the Table although it is observed that most of these regions are inefficient with relative efficiencies lower than 80 percent, there exists no correlation between relative efficiency and GDP. The values of the weights of input variables, as shown in the table, provide information regarding their effects on efficiency.

Choice Theoretic Stochastic Data Envelopment Model (SDEM)

Previous analyses estimated the efficiency of aggregate production, measured by total GDP, on the basis of cross sectional data based on DEA approach (Alam *et. al.*, 2003 and 2005). A comparison among the estimates provided by different approaches is presented here.

As mentioned earlier, regional efficiencies are measured as a weighted ratio of output and input elements. The factors considered in the analysis include effective land resources, workforce, aggregate of public and private industrial capital and regional accessibility as input elements and Gross Domestic Product (GDP) as well as sector specific GDP as output elements. Data from 1980 to 2005 used in the analysis are presented in Appendix B.

As described in section 3.5.1 the modeling framework requires alternative options for the DMUs. For this purpose DMUs are grouped into the categories of Agricultural, Industrial and Service based on the most dominant component their aggregate GDP. It is assumed that a particular DMU chooses one of the categories from the three alternative types in order to optimize its efficiency score. Input data set rearranged for equation (3.5.1) is presented in Appendix B. Any statistical package capable of dealing with Multinomial Logit model can be used for this estimation purpose. The parameters of

Choice Theoretic SDEM estimated by BIOGEME statistical software are presented below in Table 5.10.

After estimating the parameters, efficiency scores is measured using the models and relative efficiency has been predicted as the ratio of the efficiency scores.

Table 5.10: Estimated Parameters of Choice Theoretic SDEM

Coefficient	Value	Standard Error	t-Statistics
GDP (u)	8.674	1.574	5.509
Land (v_1)	-4.529	1.090	-4.153
Labour (v_2)	-1.726	0.394	-4.382
Capital (v_3)	-2.930	0.526	-5.572
Accessibility (v_4)	-1.086	0.523	-2.076

Log Likelihood Ratio, $\rho^2 = 1 - \frac{L(\beta)}{L(0)}$ = 0.526

Log Likelihood Index, $-2\{L(0) - L(\beta)\}$ = 115.661

Number of Observations = 120 (Data of 20 Zones for 25 Years)

Log Likelihood Index is asymptotically distributed chi-squared with (K-1) degrees of freedom.

As shown in Table 5.10, all the parameters are statistically significant and have agreeable sign. Estimated regional efficiencies based on Stochastic Data Envelopment Models (SDEM), mentioned in equation (3.5.6), are presented in Table 5.11. Relative efficiency is measured as the ratio of efficiency score of target DMU to the maximum efficiency score among the peer group.

Table 5.11: Regional Efficiencies Estimated by SDEM and DEA Based Models

Region	Choice Theoretic SDEM		DEA Model
	Efficiency	Relative Efficiency	Relative Efficiency
Dhaka	12.720	0.797	1.000
Mymensingh	11.571	0.725	0.880
Jamalpur	13.865	0.868	0.737
Tangail	14.605	0.915	0.845
Faridpur	13.405	0.840	0.810
Chittagong	15.966	1.000	1.000
Chittagong Hill Tracts	14.573	0.913	0.836
Noakhali	9.652	0.605	0.607
Comilla	12.375	0.775	0.714
Sylhet	11.231	0.703	0.806
Rajshahi	12.921	0.809	1.000
Dinajpur	8.981	0.562	0.740
Rangpur	12.030	0.753	0.888
Bogra	12.317	0.771	0.801
Pabna	11.621	0.728	0.938
Khulna	11.678	0.731	0.893
Barisal	13.229	0.829	0.937
Patuakhali	11.925	0.747	1.000
Jessore	10.226	0.640	0.792
Kushtia	12.735	0.798	0.849

For example, regional efficiency for Dhaka using equation (3.5.6),

$$\text{Log - efficiency of Dhaka} = 8.674 \ln(386467) - 4.529 \ln(10713) - 1.726 \ln(20742) - 2.930 \ln(371581) - 1.086 (6.969)$$

$$= 12.720$$

From Table 5.11 it is evident that there is wide variation in production efficiencies among the regions as estimated by Stochastic Data Envelopment Models and relative efficiencies estimated by DEA model provide similar results. Results also imply that Dhaka, despite being largest contributor in country's GDP, performs at relatively lower level of efficiency. Efficiency level of Dhaka is reduced due to the fact that it enjoys much higher level of input endowments without being able to take their advantage. When compared to Tangail, Dhaka possesses twice the land area, twenty-four times the industrial asset and four times the accessibility but producing only five times more, thereby resulting in inferior efficiency. It is observed that although the absolute values of estimated efficiency vary between the two approaches, except for Dhaka the pattern of variation in efficiency among DMUs remain similar.

5.3.2 Dynamic analysis - polynomial lag model

As explained in section 3.4, transportation investment can have a time varying effect of economic activities. In the analyses the time considered for analyses is 5 years for short term, 11 years for medium term and 25 years for long term. Table 5.8 and Table 5.12 presents input data for dynamic analysis.

Table 5.12: Input Data Set for Dynamic Analysis

Region	Short Term			Medium Term			Long Term		
	$\sum Acc_{5i}$	$\sum iAcc_{5i}$	$\sum i^2 Acc_{5i}$	$\sum Acc_{11i}$	$\sum iAcc_{11i}$	$\sum i^2 Acc_{11i}$	$\sum Acc_{24i}$	$\sum iAcc_{24i}$	$\sum i^2 Acc_{24i}$
Dhaka	-33.219	-65.795	196.934	-68.946	-332.998	2299.387	-141.863	-1590.534	25170.163
Mymensingh	-16.190	-31.675	94.085	-33.125	-157.939	1084.529	-66.658	-736.602	11610.733
Jamalpur	-6.485	-12.595	37.285	-13.159	-62.245	425.840	-25.554	-275.146	4283.819
Tangail	-8.116	-15.851	47.045	-16.992	-81.740	561.603	-33.783	-371.405	5831.025
Faridpur	-8.699	-17.292	51.745	-18.211	-87.680	599.758	-36.283	-399.947	6287.584
Chittagong	-8.803	-17.497	52.391	-17.937	-85.483	585.221	-36.091	-397.675	6249.448
CHT	-0.809	-1.599	4.775	-1.630	-7.679	52.161	-3.066	-32.109	490.909
Noakhali	-6.376	-12.626	37.710	-13.034	-62.110	425.045	-25.549	-276.573	4304.321
Comilla	-13.914	-27.564	82.340	-28.304	-134.649	921.461	-55.919	-609.302	9527.415
Sylhet	-7.520	-14.800	44.200	-15.508	-74.510	513.709	-30.892	-339.506	5328.427
Rajshahi	-10.941	-21.386	63.518	-22.154	-105.035	719.946	-43.696	-476.432	7472.830
Dinajpur	-6.100	-11.920	35.453	-12.466	-59.344	407.094	-25.197	-279.614	4423.904
Rangpur	-12.106	-23.420	69.227	-24.750	-117.870	811.580	-50.414	-559.931	8843.985
Bogra	-6.048	-11.493	33.749	-11.892	-54.975	373.954	-22.961	-245.578	3835.254
Pabna	-7.405	-14.369	42.657	-14.863	-69.823	476.473	-28.791	-310.201	4851.072
Khulna	-8.508	-16.882	50.378	-17.572	-84.624	583.126	-35.272	-390.434	6155.497
Barisal	-8.959	-17.755	53.071	-18.536	-88.739	606.748	-36.705	-402.305	6311.858
Patuakhali	-2.676	-5.309	15.897	-5.558	-26.809	184.695	-11.066	-120.994	1886.294
Jessore	-8.393	-16.538	49.350	-17.244	-82.206	561.946	-34.248	-376.074	5914.497
Kushtia	-5.864	-11.539	34.304	-11.884	-56.419	386.229	-23.643	-258.960	4064.295

The above table is generated using the summation of accessibility index for 5 years as short term, 11 years times corresponding years as medium term and 25 years times square of corresponding years as long term lagging effect.

Out of 20 districts, 19 districts (excluding Chittagong Hill Tracts) are analyzed, although all 20 districts data are used in the analyses. In the case of Chittagong Hill Tracts (CHT) the weight of accessibility is very high implying that the region suffers severely from lack of accessibility and marginal rate of return for investment in accessibility of the region would be very high. This is caused by the fact that CHT lacks connectivity to the rest of the country.

Conventional DEA Approach

Based on the modelling framework mention in Chapter 3 (model 3.4.3), 20 linear programs have been formulated and the relative efficiencies of all of the 20 greater districts of Bangladesh are calculated for 2005. However, as the model 3.4.3 I mathematically intractable, the linear program is defined by constraining denominator to be equal to unity. Applying this form of linear program, relative efficiency for Mymensingh is presented below. The data set presented in Table 5.8 for GDP, Land, Labour and normalized value of accessibility having lagging effect in Table 5.12 (normalized by 100.0) are considered in constructing the example for short term lagging effect.

Maximize, h_0(Mymensingh) = $0.396\,u$

Subject to, $0.986\,v_1 + 0.519\,v_2 + 0.100\,v_3 + 0.162\,\alpha_0 + 0.317\,\alpha_1 - 0.941\,\alpha_2 = 1$

$1.000\,u - 0.675\,v_1 - 1.000\,v_2 - 1.000\,v_3 - 0.332\,\alpha_0 - 0.658\,\alpha_1 + 1.969\,\alpha_2 \leq 0$ ...(for Dhaka)

$0.184\,u - 0.364\,v_1 - 0.183\,v_2 - 0.058\,v_3 - 0.065\,\alpha_0 - 0.126\,\alpha_1 + 0.373\,\alpha_2 \leq 0$ ...(for Jamalpur)

...... for 19 districts

Thus, linear programs for each of the 20 regions as short, medium and long term are formulated and analyses are accomplished using MATLAB. The weights of associated accessibility index leading to the maximum efficiency score are produced during the calculation and shown in Table 5.13.

Based on equation (3.4.1), lagging effect of accessibility (β_i) has quadratic polynomial characteristics. β_i has been calculated using the estimated parameters in Table 5.13 for each of the 19 regions and lagged year constants (β_0) are shown in Table 5.15.

Table 5.13: Relative Efficiency and Weights of Inputs and Output - Dynamic DEA Model

Region	Short Term (5 Years)					Medium Term (11 Years)					Long Term (25 Years)				
	Efficiency	Weight of parameters				Efficiency	Weight of parameters				Efficiency	Weight of parameters			
		GDP	α_0	α_1	α_2		GDP	α_0	α_1	α_2		GDP	α_0	α_1	α_2
Dhaka	1.00	1.00	50.92	53.89	33.35	1.00	1.00	48.06	53.94	11.21	1.00	1.00	52.62	62.61	4.56
Mymensingh	1.00	2.09	70.65	67.38	35.54	1.00	2.09	0.62	0.23	0.58	1.00	2.09	78.08	93.30	6.45
Jamalpur	1.00	5.04	63.33	58.41	44.76	1.00	5.04	64.91	70.48	15.62	0.89	4.48	0.00	0.05	0.00
Tangail	1.00	5.24	9.19	19.02	7.30	1.00	5.24	72.38	76.69	14.43	1.00	5.24	51.87	57.12	4.26
Faridpur	0.93	2.55	0.00	0.00	0.23	1.00	2.73	82.06	91.30	16.34	1.00	2.73	3.65	1.77	0.13
Chittagong	1.00	1.37	35.58	54.46	18.57	1.00	1.37	10.19	11.57	1.94	1.00	1.37	19.40	6.16	0.49
Noakhali	1.00	3.72	37.07	64.06	23.49	0.96	3.57	0.00	0.00	0.12	0.71	2.63	0.00	0.00	0.01
Comilla	1.00	1.86	51.98	51.60	46.23	1.00	1.86	45.13	40.85	11.84	1.00	1.86	0.90	0.20	0.02
Sylhet	1.00	2.14	91.04	93.51	35.27	0.99	2.11	0.00	0.18	0.00	0.98	2.10	0.00	0.09	0.00
Rajshahi	1.00	2.54	53.45	57.61	27.60	1.00	2.54	40.08	45.40	8.56	1.00	2.54	1.68	1.95	0.14
Dinajpur	0.68	2.72	0.00	0.82	0.00	0.68	2.73	0.00	0.23	0.00	1.00	3.99	45.72	95.43	6.28
Rangpur	0.94	2.03	0.00	0.29	0.00	0.94	2.03	0.00	0.09	0.00	1.00	2.16	73.04	91.15	6.28
Bogra	1.00	4.43	0.51	0.95	1.46	1.00	4.43	1.01	19.47	3.16	0.95	4.21	0.00	0.05	0.00
Pabna	1.00	4.52	48.70	48.81	51.66	1.00	4.52	51.18	58.30	15.04	0.81	3.67	0.00	0.05	0.00
Khulna	0.91	2.16	100.00	100.00	38.12	0.83	1.95	0.00	0.16	0.00	0.87	2.05	0.00	20.95	1.32
Barisal	1.00	2.74	71.36	78.59	29.09	1.00	2.74	2.66	2.02	0.35	1.00	2.74	6.36	0.33	0.05
Patuakhali	0.90	6.63	100.00	100.00	36.82	0.93	6.87	100.00	3.99	3.36	0.81	6.01	0.00	0.21	0.00
Jessore	0.92	2.85	100.00	100.00	38.09	0.81	2.51	0.00	0.21	0.00	0.86	2.65	0.00	4.36	0.28
Kustia	0.93	5.11	0.75	0.00	1.13	0.92	5.04	0.00	0.00	0.21	0.86	4.73	0.00	0.06	0.00

Choice Theoretic SDEM

The lagging effect of accessibility in conventional DEA model in the form of polynomial lag function has been analysed in the previous section. Considering the lagging effects, the effect of accessibility index (x_4 in Equation 3.5.3) spreads over a period of time. Using equation (3.5.7), parameters of the log likelihood function has been solved using the same statistical package as discussed in section 5.3.1 and shown in Table 5.14. The value of α_0, α_1 and α_2 will provide the value of β, which will be used to assess the dynamic effect of each DMUs.

Table 5.14: Estimated Parameters of Dynamic Choice Theoretic SDEM

Coefficient	Short Term			Medium Term			Long Term		
	Value	Std err	t-test	Value	Std err	t-test	Value	Std err	t-test
GDP (u)	9.437	1.827	5.165	9.220	1.778	5.186	8.969	1.718	5.219
Land (v_1)	-1.146	1.028	-1.115	-1.436	1.079	-1.332	-1.462	1.062	-1.377
Labour (v_2)	-2.637	0.570	-4.628	-2.652	0.581	-4.563	-2.690	0.586	-4.592
Capital (v_3)	-1.506	0.487	-3.093	-1.688	0.489	-3.451	-1.639	0.482	-3.403
Accessibility (α_0)	-1.339	0.761	-0.104	-1.622	0.442	-0.536	-1.433	0.469	-0.585
Accessibility (α_1)	-1.976	0.235	-0.008	-1.704	0.141	-0.012	-2.764	0.151	-0.045
Accessibility (α_2)	-1.775	0.162	-0.060	-0.328	0.105	-0.174	-0.176	0.111	-0.154
Log Likelihood Ratio		0.485			0.504			0.503	
Log Likelihood Index		106.510			110.632			110.587	

As shown in above table, all the parameters have agreeable sign and except accessibility parameters all parameters are found statistically significant. Other indicators show that overall model for short, medium and long terms are found statistically sound.

As shown in Figure 4.39, the time span for lagging effect of transportation is found to vary from between 2 to 3 years for short term, 6 to 8 years for medium term and 15 to 20 years for long term cases.

In the analysis it is observed that the value of β_0, which designate the current year need for accessibility, varies with respect to time span of the analysis. It implies that current year demand might demonstrate different characteristics depending on the analysis period using panel data. Again, as mentioned earlier, on the basis of cross sectional data the current demand for increased accessibility is demonstrated by weights of accessibility as presented in Table 5.9.

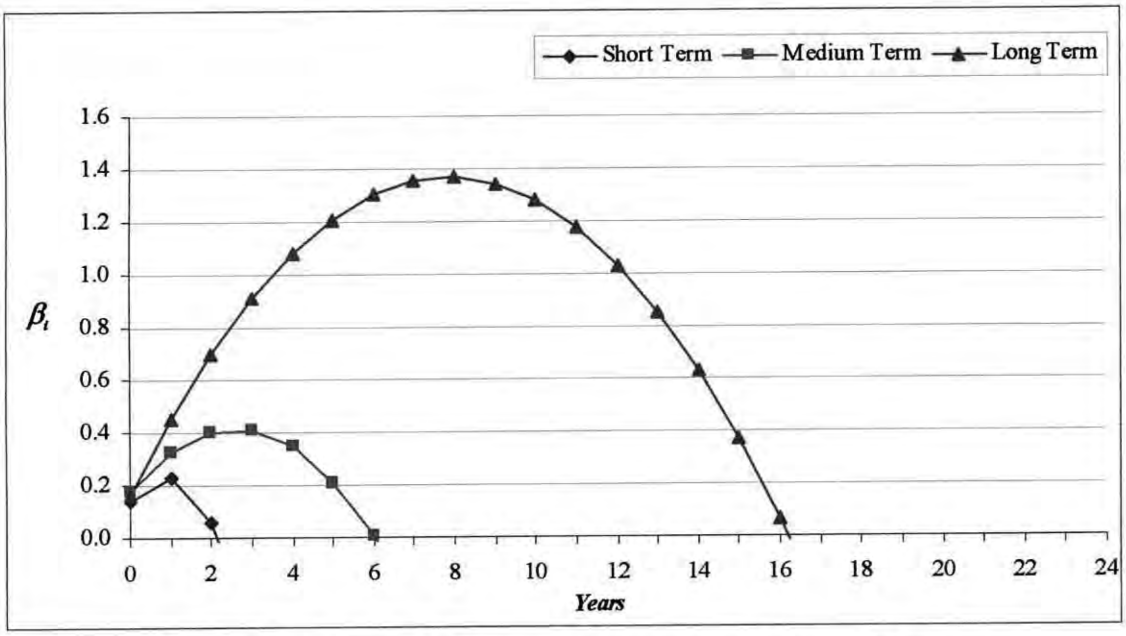


Figure 5.8 : Short, Medium and Long Term Lagging Effects

5.3.3 Policy Implication

Analytic framework based on Cobb Douglas type production function has been developed to assess a number of economic parameters, which has been discussed in Chapter 3 (Section 3.5.3).

Production Function

Framework of production function as developed in equation (3.5.8), which is specified using the estimated parameters of Table 5.10.

$$GDP = Eff^{1/8.674} + (Land)^{-4.529/8.674} + (Lab)^{-1.726/8.674} + (Cap)^{-2.930/8.674} + (Acc)^{-1.086/8.674}$$

Production Function for Dhaka (Eff. = 12.72, Table 5.11):

$$GDP = 1.341 * Land^{0.522}\ Lab^{0.20}\ Cap^{0.338}\ Acc^{0.125} \qquad \ldots\ldots \ (5.3.1)$$

Return to Scale: The model shows that there exists increasing return to scale as demonstrated by the degree of homogeneity of the production function. It also implies that a good degree of homogeneity exists in the production process.

Degree of homogeneity = 0.522 + 0.20 + 0.338 + 0.125 = 1.185

Production Elasticity: Estimated production elasticities imply that changes in land, capital and accessibility inventory can influence regional output significantly.

Variable	Estimated Elasticity of GDP with respect to Production Factors
Land	0.522
Labour	0.200
Capital	0.338
Accessibility	0.125

Cost Function

For planning purpose it is important to understand expenditure response of increased regional production which can be grasped through regional cost function. Based on Cobb-Douglas production function, framework of cost function (equation 3.5.9) has been developed. The cost function for Dhaka region is estimated as follows, where wL, wP, wI and wA are price of land, labour, industrial capital and accessibility respectively.

Cost per unit GDP Output for Dhaka

$$= 1.185/(1.341 \times 0.522^{0.522} \times 0.2^{0.2} \times 0.338^{0.338} \times 0.125^{.125})^{(1/1.185)}$$
$$\times (wL^{0.522} \times wP^{0.2} \times wI^{0.338} \times wA^{0.125})^{(1/1.185)}$$
$$= 2.74 * wL^{0.441}\, wP^{0.168}\, wI^{0.285}\, wA^{0.105} \qquad \ldots\ldots (5.3.2)$$

Demand Functions

Estimated production function also facilitates prediction of factor demand function and demand elasticity. Framework of factored demand function has been developed and shown in equation (3.5.10). Demand for accessibility for Dhaka region is shown in equation (5.4.3). Demand elasticity of accessibility is -0.90 for stochastic data envelopment model.

Demand for accessibility for Dhaka

$$= 1.185/(1.341 \times 0.522^{0.522} \times 0.2^{0.2} \times 0.338^{0.338} \times 0.125^{.125})^{(1/1.185)}$$
$$\times (0.125/1.185) \times (1/wA) \times (GDP \times wL^{0.522} \times wP^{0.2} \times wI^{0.338} \times wA^{0.125})^{(1/1.185)}$$
$$= 0.288 * GDP^{0.844}\, wL^{0.441}\, wP^{0.168}\, wI^{0.285}\, wA^{-0.895} \qquad \ldots\ldots (5.3.3)$$

Similarly, production, cost and demand function of other regions are as follows:

Production function for i^{th} region, $GDP = A^* Land^{0.522} Lab^{0.20} Cap^{0.338} Acc^{0.125}$

Cost per unit GDP Output of i^{th} region = $B * wL^{0.441} wP^{0.168} wI^{0.285} wA^{0.105}$

Demand for Accessibility for i^{th} region = $C * GDP^{0.844} wL^{0.441} wP^{0.168} wI^{0.285} wA^{-0.895}$

Values for A, B and C are shown in Table 5.15.

Table 5.15: Production, Cost and Demand Function

Region	Variable Coefficient of production, cost and demand function		
	A	B	C
Dhaka	1.341	2.740	0.288
Mymensingh	1.326	2.766	0.291
Jamalpur	1.354	2.718	0.286
Tangail	1.362	2.704	0.284
Faridpur	1.349	2.726	0.287
Chittagong	1.341	2.740	0.288
Chittagong Hill Tracts	1.362	2.704	0.284
Noakhali	1.299	2.815	0.296
Comilla	1.337	2.748	0.289
Sylhet	1.322	2.774	0.292
Rajshahi	1.343	2.736	0.288
Dinajpur	1.288	2.835	0.298
Rangpur	1.332	2.755	0.290
Bogra	1.336	2.749	0.289
Pabna	1.327	2.765	0.291
Khulna	1.328	2.763	0.291
Barisal	1.347	2.730	0.287
Patuakhali	1.331	2.758	0.290
Jessore	1.308	2.799	0.294
Kushtia	1.341	2.740	0.288

Production, cost and demand of accessibility function for each region can be used in regional planning and decision making process. Figure 5.9 shows the demand of accessibility for Dhaka with respect to GDP and unit price of accessibility using equation (5.3.3). Unit price of land, labour and capital are kept constant (100, 80 and 0.12 respectively) to get the effect of other to factors on measuring accessibility demand. Real GDP of Dhaka for base year is considered as 100 assuming an 8 percent growth rate. Unit price of accessibility for base year is taken as 10 considering an annual growth rate of 8 percent (similar to the growth rate of construction cost index).

As shown in the figure, at same price of accessibility (14 unit) having 8 percent annual growth of GDP of 10 years, demand of accessibility will be increased by 94%. To meet the increased demand, government has to improve accessibility in the region by developing of new roadway/rail track, increase capacity, improve services etc. or raise the unit price of accessibility by 92%.

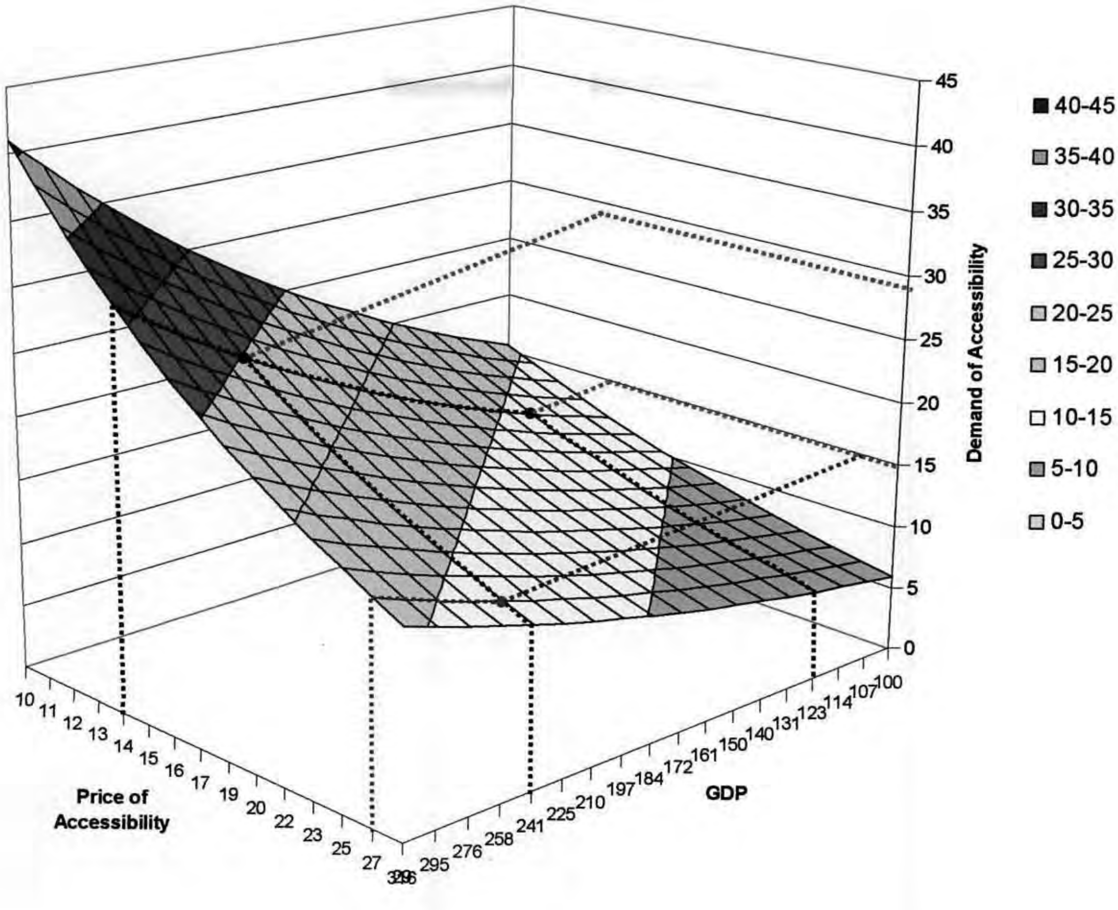


Figure 5.9: Accessibility Demand for Dhaka with respect to Price of Accessibility and GDP

Table 5.16: Demand Elasticity of Accessibility with respect to GDP and Price of Accessibility for Dhaka

Elasticity	Value
Demand of accessibility w.r.t GDP at constant price of accessibility	0.846
Demand of accessibility w.r.t price of accessibility at constant GDP	-0.448

Based on the elasticity value, it is clearly stated that 1% increase of GDP will result 0.85% increase of accessibility demand for Dhaka at constant price of accessibility. Again, we can state that 1% increase of the price of accessibility will decrease the demand by 0.45%. More apparent interpretation could be produced from the following matrix shown in Table 5.17.

Table 5.17: Demand of Accessibility Matrix with respect to Price of Accessibility and GDP Increase for Dhaka

In percentage

GDP ↓	Price of Accessibility → Base	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Base	0.0	-8.2	-15.1	-20.9	-26.0	-30.4	-34.3	-37.8	-40.9	-43.7	-46.2
10%	8.4	-0.5	-7.9	-14.3	-19.8	-24.6	-28.8	-32.6	-36.0	-39.0	-41.7
20%	16.6	7.1	-0.9	-7.8	-13.7	-18.9	-23.4	-27.5	-31.1	-34.3	-37.3
30%	24.8	14.6	6.0	-1.3	-7.7	-13.2	-18.1	-22.4	-26.3	-29.7	-32.9
40%	32.8	22.0	12.8	5.0	-1.7	-7.6	-12.8	-17.4	-21.5	-25.2	-28.6
50%	40.8	29.3	19.6	11.3	4.2	-2.0	-7.5	-12.4	-16.8	-20.7	-24.3
60%	48.7	36.5	26.3	17.6	10.0	3.4	-2.4	-7.5	-12.1	-16.3	-20.0
70%	56.5	43.7	32.9	23.7	15.8	8.9	2.8	-2.7	-7.5	-11.9	-15.8
80%	64.2	50.8	39.5	29.9	21.5	14.2	7.8	2.1	-3.0	-7.5	-11.7
90%	71.9	57.8	46.0	35.9	27.2	19.6	12.9	6.9	1.6	-3.2	-7.6
100%	79.5	64.8	52.5	41.9	32.8	24.9	17.9	11.6	6.1	1.1	-3.5

The above matrix is produced from the accessibility demand function shown in equation (5.3.3). The result shows the percentage increase of transportation demand with respect to incremental increase of GDP in row and cost of transportation in column. The table explains that If GDP is increased by 50%, demand of transportation for Dhaka will be increased by 40.8%. As a result, cost of transportation will increase by 48% (approx.). Similarly, 50% increase of transportation cost will cause 30.8% decreased of transportation demand and will have negative impact on GDP. The results of this study could be very useful to policy makers to contrive with a decision to take balance actions between investing more on transport sector and increasing transport cost.

5.4 Summary

In this chapter, elaborate analyses of the significance of accessibility in the efficiency of regional production of Bangladesh have been done. Dynamic analysis has also been evolved to develop polynomial lag model for assessing time lag between transportation investment and economic development. The approach is devised on the basis of stochastic data envelopment model. The result has been compared with the result of conventional data envelopment approach.

Analyses have been further extended to establish policy entailment for assessing number of economic parameters e.g., production elasticity, cost per unit GDP output and demand of accessibility.

6. CONCLUSIONS

6.1 General

The study presented in this research examined the role of transportation investment in regional economic development of Bangladesh and compared its effectiveness with input parameters like land area, labour force, industrial capital and accessibility index, which is considered as transportation infrastructure component.

In previous studies, DEA methodology was applied by Alam *et al.* (2004 and 2005) to measure regional efficiency and to assess the dynamic relationship between transportation investment and economic development of Bangladesh using the data of 1980 to 2000. Here in this study, same analyses have been done based on a new framework: choice theoretic stochastic data envelopment model (SDEM). Data set used in the study has also been updated to 2005 considering the same study area of 20 greater districts of Bangladesh and the results of analysis using the choice theoretic SDEM have been compared with results of the conventional DEA method using the updated data. One of the input parameters, accessibility index for 20 regions, has been calculated using network analysis tool of ArcGIS. Road, rail and waterway network data in GIS format for the year 2005 have been collected from the concerned authorized sources. The result of SDEM model has been used to develop production function, factored cost and demand function for policy implication.

6.2 Findings

In this study a stochastic DEA model has been devised integrating Data Envelopment Analysis and choice theory framework. Besides enabling us to overcome limitations of conventional DEA approach the proposed framework provides insight into regional production process through assessment of elasticities and factor demand functions. Total analyses have been divided into three steps. First step consists of regional technical efficiency calculation based on both conventional DEA and choice theoretic SDEM approach using cross sectional data of the year 2005 with an objective to determine how accessibility contributes to regional technical efficiency. In the second step, the time lag between transportation infrastructure investment and materialization of its effect on economic development has been studied based on choice theoretic SDEM using time series data from the year 1980 to 2005 and compared the result with the analysis done in conventional DEA approach. In the third step, number of economic parameters has been assessed to identify the implication on policy formulation.

Analysis of efficiency on the basis of conventional DEA with current (year 2005) cross-sectional data have shown that most of the regions perform inefficiently thereby causing imbalance in input factors of production and waste of resources. It also identified specific regions where production efficiency is severely constraint by lack of public and private industrial capital.

But optimized efficiencies and weight factors estimated in DEA approach varies when the target DMU changes, thus create difficulty to compare among measured efficiencies. Results in stochastic data envelopment model (SDEM) suggest that the proposed framework facilitates relaxation of the constraints although it enables incorporation of stochastic error to in assessing production frontiers. All the parameters measured using SDEM are found highly significant.

It is observed from the estimated efficiency that although Dhaka is the largest contributor in national GDP its relative efficiency is significantly low compared to other regions with smaller contribution. Also, there exists considerable variation in the efficiency level of different regions. Efficiency level of Dhaka is reduced due to the fact that it enjoys much higher level of input endowments without being able to take their advantage. When compared to Tangail, Dhaka possesses twice the land area, twenty-four times the industrial asset and four times the accessibility but producing only five times more, thereby resulting in inferior efficiency. According to the analysis, most efficient regions are Chittagong and Tangail, whereas inefficient are Sylhet, Jessore, Noakhali and Dinajpur. It is observed that although the absolute values of estimated efficiency vary between the two approaches, except for Dhaka the pattern of variation in efficiency among DMUs remain similar.

In the second step, analytic framework has been developed to capture time lag between transportation investment and its utilization in economic activities based on stochastic approach. The analysis reveals that the lag time ranges between 2-3 years for short term, 6-7 years for medium term and 16-17 years for long term in case of Bangladesh.

Using the estimated parameters of SDEM, Cobb-Douglas type production function has been developed for the DMUs. Estimated production function demonstrates a recognizable level of increasing return to scale on aggregate. At individual DMU level land, labour, capital and accessibility have significant influence on production level. Analyses show that many regions perform inefficiently and there exists imbalance in input factors of production as demonstrated by the value of exponents. It also shows that there are specific regions where production efficiency is severely constrained by lack of land and industrial capital. Assessment of factor demand functions demonstrate that price elasticity of accessibility is around -0.90.

The analytical procedures for assessing elasticities and demand functions may have significant implication on policy formulation and resource allocation at regional level. For example, demand of accessibility function for Dhaka reveals that current GDP growth ensues high increase of transport demand, which can be regulated by increasing unit price of transportation cost or providing transport infrastructure/service or balancing between the two.

6.3 Recommendations for Future Study

The methodological framework proposed in the study can be extended in several directions. Further investigation is required to accommodate mixed production, recognize congestion effect and effect of international connectivity. Additional work is required to correlate the size of transportation investment and phase of project with period of time lag. Research should also focus on techniques of integrated assessment using input-output framework. The proposed framework of the study can be examined in small environment to assess impacts of input elements on micro economy.

The analytical approach of SDEM can be introduced with an assumption of random variable exists in the framework. For estimation of DMU specific random variation model simulation based estimation technique is required to be used.

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APPENDIX-A

Accessibility Index Calculation

Table A-1: Distance Matrix (in km) by Road

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	123	179	92	104	242	292	165	99	226	257	338	304	197	157	179	171	206	196	173
MYM	123	0	88	94	199	365	414	287	221	195	238	320	286	179	193	302	293	329	287	231
JAM	179	88	0	87	193	421	471	344	278	270	232	313	279	172	187	328	319	355	281	225
TAN	92	94	87	0	105	335	384	257	191	289	165	247	213	106	121	240	232	267	193	158
FAR	104	199	193	105	0	328	377	214	199	326	208	311	277	170	106	139	130	166	97	95
CTG	242	365	421	335	328	0	66	143	153	372	499	581	547	440	400	365	325	360	420	415
CHT	292	414	471	384	377	66	0	193	203	422	549	630	596	489	449	414	374	410	470	464
NKL	165	287	344	257	214	143	193	0	75	295	418	503	469	362	316	251	211	246	307	305
COM	99	221	278	191	199	153	203	75	0	229	356	437	403	296	256	257	217	253	291	271
SYL	226	195	270	289	326	372	422	295	229	0	433	515	481	374	375	401	393	428	419	391
RAJ	257	238	232	165	208	499	549	418	356	433	0	254	220	115	105	276	334	370	214	122
DIN	338	320	313	247	311	581	630	503	437	515	254	0	78	141	265	436	437	473	374	283
RAN	304	286	279	213	277	547	596	469	403	481	220	78	0	107	231	402	403	439	340	249
BGR	197	179	172	106	170	440	489	362	296	374	115	141	107	0	124	297	296	332	235	144
PBN	157	193	187	121	106	400	449	316	256	375	105	265	231	124	0	203	232	268	141	50
KHL	179	302	328	240	139	365	414	251	257	401	276	436	402	297	203	0	119	152	62	153
BAR	171	293	319	232	130	325	374	211	217	393	334	437	403	296	232	119	0	40	181	221
PAT	206	329	355	267	166	360	410	246	253	428	370	473	439	332	268	152	40	0	214	257
JSR	196	287	281	193	97	420	470	307	291	419	214	374	340	235	141	62	181	214	0	91
KST	173	231	225	158	95	415	464	305	271	391	122	283	249	144	50	153	221	257	91	0

Table A-2: Distance Matrix (in km) by Rail

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	123	183	97	336	320	9999	242	171	296	256	390	325	284	197	405	9999	9999	346	245
MYM	123	0	60	162	401	343	9999	265	194	320	302	267	202	161	262	470	9999	9999	412	311
JAM	183	60	0	222	357	403	9999	325	254	380	243	207	142	101	218	426	9999	9999	368	266
TAN	97	162	222	0	239	367	9999	289	218	344	159	302	309	217	100	308	9999	9999	250	148
FAR	336	401	357	239	0	606	9999	528	457	583	198	342	348	256	139	270	9999	9999	212	90
CTG	320	343	403	367	606	0	9999	174	149	375	526	610	545	504	467	675	9999	9999	617	516
CHT	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
NKL	242	265	325	289	528	174	9999	0	71	297	449	532	467	426	389	597	9999	9999	539	438
COM	171	194	254	218	457	149	9999	71	0	226	377	461	396	355	318	526	9999	9999	467	366
SYL	296	320	380	344	583	375	9999	297	226	0	503	587	522	481	444	652	9999	9999	593	492
RAJ	256	302	243	159	198	526	9999	449	377	503	0	227	234	142	59	268	9999	9999	209	108
DIN	390	267	207	302	342	610	9999	532	461	587	227	0	65	163	203	411	9999	9999	352	251
RAN	325	202	142	309	348	545	9999	467	396	522	234	65	0	131	209	418	9999	9999	359	258
BGR	284	161	101	217	256	504	9999	426	355	481	142	163	131	0	117	325	9999	9999	267	166
PBN	197	262	218	100	139	467	9999	389	318	444	59	203	209	117	0	208	9999	9999	150	49
KHL	405	470	426	308	270	675	9999	597	526	652	268	411	418	325	208	0	9999	9999	59	180
BAR	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999
PAT	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999
JSR	346	412	368	250	212	617	9999	539	467	593	209	352	359	267	150	59	9999	9999	0	121
KST	245	311	266	148	90	516	9999	438	366	492	108	251	258	166	49	180	9999	9999	121	0

Table A-3: Distance Matrix (in km) by Waterway

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	9999	321	213	135	283	373	113	9999	302	9999	9999	414	285	9999	352	165	235	9999	9999
MYM	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
JAM	321	9999	0	107	186	498	589	328	9999	557	9999	9999	93	35	9999	568	380	451	9999	9999
TAN	213	9999	107	0	79	391	481	221	9999	449	9999	9999	200	72	9999	460	273	343	9999	9999
FAR	135	9999	186	79	0	312	403	142	9999	371	9999	9999	279	151	9999	382	194	265	9999	9999
CTG	283	9999	498	391	312	0	91	170	9999	518	9999	9999	591	463	9999	420	233	303	9999	9999
CHT	373	9999	589	481	403	91	0	261	9999	609	9999	9999	682	553	9999	511	323	394	9999	9999
NKL	113	9999	328	221	142	170	261	0	9999	348	9999	9999	421	293	9999	276	88	159	9999	9999
COM	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
SYL	302	9999	557	449	371	518	609	348	9999	0	9999	9999	650	521	9999	588	400	471	9999	9999
RAJ	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999
DIN	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999
RAN	414	9999	93	200	279	591	682	421	9999	650	9999	9999	0	128	9999	661	473	544	9999	9999
BGR	285	9999	35	72	151	463	553	293	9999	521	9999	9999	128	0	9999	532	345	415	9999	9999
PBN	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999
KHL	352	9999	568	460	382	420	511	276	9999	588	9999	9999	661	532	9999	0	187	243	9999	9999
BAR	165	9999	380	273	194	233	323	88	9999	400	9999	9999	473	345	9999	187	0	71	9999	9999
PAT	235	9999	451	343	265	303	394	159	9999	471	9999	9999	544	415	9999	243	71	0	9999	9999
JSR	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999
KST	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0

Table A-4: Travel Time Matrix (in hr) by Road

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	2.5	3.6	1.8	3.2	4.8	6.2	3.9	2.1	4.8	5.1	7.7	6.1	3.9	4.7	6.2	5.7	6.8	5.0	5.1
MYM	2.5	0	1.8	1.9	5.0	7.3	8.6	6.4	4.5	7.2	4.8	7.3	5.7	3.6	4.3	7.7	7.6	8.7	6.5	4.7
JAM	3.6	1.8	0	1.7	5.7	8.4	9.7	7.5	5.7	8.3	4.6	7.2	5.6	3.4	4.2	7.6	8.2	9.3	6.4	4.6
TAN	1.8	1.9	1.7	0	4.0	6.7	8.0	5.8	3.9	6.6	3.3	5.8	4.3	2.1	2.9	6.3	6.5	7.6	5.1	3.2
FAR	3.2	5.0	5.7	4.0	0	8.1	9.4	7.2	5.3	8.0	4.9	9.1	7.5	5.4	3.6	3.2	2.6	3.7	1.9	2.5
CTG	4.8	7.3	8.4	6.7	8.1	0	1.3	2.9	3.2	7.6	10.0	12.5	10.9	8.8	9.6	11.1	10.5	11.5	9.8	9.9
CHT	6.2	8.6	9.7	8.0	9.4	1.3	0	4.2	4.5	8.9	11.3	13.8	12.3	10.1	10.9	12.4	11.8	12.9	11.2	11.2
NKL	3.9	6.4	7.5	5.8	7.2	2.9	4.2	0	2.2	6.7	9.1	11.6	10.0	7.9	8.6	10.2	8.3	9.4	8.9	9.0
COM	2.1	4.5	5.7	3.9	5.3	3.2	4.5	2.2	0	4.8	7.2	9.7	8.2	6.0	6.8	8.3	7.7	8.8	7.1	7.1
SYL	4.8	7.2	8.3	6.6	8.0	7.6	8.9	6.7	4.8	0	9.9	12.4	10.9	8.7	9.5	11.0	10.4	11.5	9.8	9.8
RAJ	5.1	4.8	4.6	3.3	4.9	10.0	11.3	9.1	7.2	9.9	0	6.0	4.4	2.3	2.1	5.5	7.5	8.6	4.3	2.4
DIN	7.7	7.3	7.2	5.8	9.1	12.5	13.8	11.6	9.7	12.4	6.0	0	1.6	3:7	6.2	9.6	11.6	12.7	8.4	6.6
RAN	6.1	5.7	5.6	4.3	7.5	10.9	12.3	10.0	8.2	10.9	4.4	1.6	0	2.1	4.6	8.0	10.0	11.1	6.8	5.0
BGR	3.9	3.6	3.4	2.1	5.4	8.8	10.1	7.9	6.0	8.7	2.3	3.7	2.1	0	2.5	5.9	7.9	9.0	4.7	2.9
PBN	4.7	4.3	4.2	2.9	3.6	9.6	10.9	8.6	6.8	9.5	2.1	6.2	4.6	2.5	0	4.2	6.1	7.2	2.9	1.1
KHL	6.2	7.7	7.6	6.3	3.2	11.1	12.4	10.2	8.3	11.0	5.5	9.6	8.0	5.9	4.2	0	5.0	6.0	1.2	3.1
BAR	5.7	7.6	8.2	6.5	2.6	10.5	11.8	8.3	7.7	10.4	7.5	11.6	10.0	7.9	6.1	5.0	0	1.2	4.5	5.0
PAT	6.8	8.7	9.3	7.6	3.7	11.5	12.9	9.4	8.8	11.5	8.6	12.7	11.1	9.0	7.2	6.0	1.2	0	5.5	6.1
JSR	5.0	6.5	6.4	5.1	1.9	9.8	11.2	8.9	7.1	9.8	4.3	8.4	6.8	4.7	2.9	1.2	4.5	5.5	0	1.8
KST	5.1	4.7	4.6	3.2	2.5	9.9	11.2	9.0	7.1	9.8	2.4	6.6	5.0	2.9	1.1	3.1	5.0	6.1	1.8	0

Table A-5: Travel Time Matrix (in hr) by Rail

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	3.5	7.5	2.8	13.4	9.1	9999	8.7	4.9	8.5	8.9	11.4	13.0	10.4	5.6	11.6	9999	9999	9.9	7.4
MYM	3.5	0	4.0	4.6	15.3	11.2	9999	10.8	7.0	10.6	10.8	13.3	14.8	12.3	7.5	13.4	9999	9999	11.8	9.3
JAM	7.5	4.0	0	8.6	19.3	15.2	9999	14.8	11.0	14.6	14.8	15.2	11.9	9.2	11.5	17.4	9999	9999	15.8	13.2
TAN	2.8	4.6	8.6	0	10.7	10.5	9999	10.1	6.2	9.8	6.2	8.6	10.2	7.7	2.9	8.8	9999	9999	7.1	4.6
FAR	13.4	15.3	19.3	10.7	0	21.1	9999	20.7	16.9	20.5	11.1	13.6	15.2	12.6	7.8	11.6	9999	9999	9.9	6.0
CTG	9.1	11.2	15.2	10.5	21.1	0	9999	6.8	4.3	10.7	16.6	19.1	20.7	18.2	13.3	19.3	9999	9999	17.6	15.1
CHT	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
NKL	8.7	10.8	14.8	10.1	20.7	6.8	9999	0	3.9	10.3	16.2	18.7	20.3	17.8	12.9	18.9	9999	9999	17.2	14.7
COM	4.9	7.0	11.0	6.2	16.9	4.3	9999	3.9	0	6.5	12.4	14.9	16.4	13.9	9.1	15.0	9999	9999	13.4	10.8
SYL	8.5	10.6	14.6	9.8	20.5	10.7	9999	10.3	6.5	0	16.0	18.5	20.0	17.5	12.7	18.6	9999	9999	17.0	14.4
RAJ	8.9	10.8	14.8	6.2	11.1	16.6	9999	16.2	12.4	16.0	0	8.1	9.7	7.1	3.3	9.3	9999	9999	7.6	5.1
DIN	11.4	13.3	15.2	8.6	13.6	19.1	9999	18.7	14.9	18.5	8.1	0	3.2	6.1	5.8	11.7	9999	9999	10.1	7.6
RAN	13.0	14.8	11.9	10.2	15.2	20.7	9999	20.3	16.4	20.0	9.7	3.2	0	7.7	7.4	13.3	9999	9999	11.6	9.1
BGR	10.4	12.3	9.2	7.7	12.6	18.2	9999	17.8	13.9	17.5	7.1	6.1	7.7	0	4.8	10.8	9999	9999	9.1	6.6
PBN	5.6	7.5	11.5	2.9	7.8	13.3	9999	12.9	9.1	12.7	3.3	5.8	7.4	4.8	0	6.0	9999	9999	4.3	1.8
KHL	11.6	13.4	17.4	8.8	11.6	19.3	9999	18.9	15.0	18.6	9.3	11.7	13.3	10.8	6.0	0	9999	9999	1.7	5.5
BAR	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999
PAT	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999
JSR	9.9	11.8	15.8	7.1	9.9	17.6	9999	17.2	13.4	17.0	7.6	10.1	11.6	9.1	4.3	1.7	9999	9999	0	3.8
KST	7.4	9.3	13.2	4.6	6.0	15.1	9999	14.7	10.8	14.4	5.1	7.6	9.1	6.6	1.8	5.5	9999	9999	3.8	0

Table A-6: Travel Time Matrix (in hr) by Waterway

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	9999	25.9	16.9	10.4	18.9	27.9	7.5	9999	23.3	9999	9999	33.6	22.9	9999	24.3	11.8	18.6	9999	9999
MYM	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
JAM	25.9	9999	0	9.0	15.5	37.7	46.7	26.3	9999	44.7	9999	9999	7.8	2.9	9999	43.2	30.7	37.5	9999	9999
TAN	16.9	9999	9.0	0	6.5	28.7	37.8	17.4	9999	35.8	9999	9999	16.7	6.0	9999	34.2	21.7	28.5	9999	9999
FAR	10.4	9999	15.5	6.5	0	22.2	31.2	10.8	9999	29.2	9999	9999	23.3	12.5	9999	27.7	15.2	22.0	9999	9999
CTG	18.9	9999	37.7	28.7	22.2	0	9.1	11.3	9999	37.7	9999	9999	45.4	34.7	9999	28.0	15.5	22.3	9999	9999
CHT	27.9	9999	46.7	37.8	31.2	9.1	0	20.4	9999	46.8	9999	9999	54.5	43.8	9999	37.1	24.6	31.4	9999	9999
NKL	7.5	9999	26.3	17.4	10.8	11.3	20.4	0	9999	26.4	9999	9999	34.1	23.4	9999	18.9	6.4	13.2	9999	9999
COM	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
SYL	23.3	9999	44.7	35.8	29.2	37.7	46.8	26.4	9999	0	9999	9999	52.5	41.8	9999	43.2	30.7	37.5	9999	9999
RAJ	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999
DIN	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999
RAN	33.6	9999	7.8	16.7	23.3	45.4	54.5	34.1	9999	52.5	9999	9999	0	10.7	9999	50.9	38.4	45.2	9999	9999
BGR	22.9	9999	2.9	6.0	12.5	34.7	43.8	23.4	9999	41.8	9999	9999	10.7	0	9999	40.2	27.7	34.5	9999	9999
PBN	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999
KHL	24.3	9999	43.2	34.2	27.7	28.0	37.1	18.9	9999	43.2	9999	9999	50.9	40.2	9999	0	12.5	18.3	9999	9999
BAR	11.8	9999	30.7	21.7	15.2	15.5	24.6	6.4	9999	30.7	9999	9999	38.4	27.7	9999	12.5	0	6.8	9999	9999
PAT	18.6	9999	37.5	28.5	22.0	22.3	31.4	13.2	9999	37.5	9999	9999	45.2	34.5	9999	18.3	6.8	0	9999	9999
JSR	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999
KST	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0

Table A-7: Generalized Cost Matrix (in hr) by Road

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	6.5	9.4	4.9	6.6	12.8	15.7	9.3	5.3	12.2	13.5	18.7	16.1	10.4	9.9	12.1	11.3	13.5	11.4	10.7
MYM	6.5	0	4.7	5.0	11.6	19.2	22.2	15.8	11.8	13.6	12.6	17.8	15.1	9.4	10.7	17.6	17.2	19.4	15.9	12.2
JAM	9.4	4.7	0	4.6	12.0	22.2	25.2	18.8	14.7	17.2	12.2	17.4	14.7	9.1	10.3	18.3	18.7	20.9	15.6	11.9
TAN	4.9	5.0	4.6	0	7.4	17.6	20.6	14.2	10.2	16.1	8.7	13.9	11.2	5.6	6.8	14.2	14.1	16.3	11.4	8.4
FAR	6.6	11.6	12.0	7.4	0	18.8	21.8	14.2	11.8	18.7	11.8	19.2	16.6	10.9	7.1	7.7	6.9	9.1	5.1	5.6
CTG	12.8	19.2	22.2	17.6	18.8	0	3.5	7.6	8.2	19.8	26.3	31.5	28.8	23.2	22.6	23.0	21.1	23.3	23.6	23.5
CHT	15.7	22.2	25.2	20.6	21.8	3.5	0	10.5	11.1	22.7	29.3	34.5	31.8	26.1	25.6	25.9	24.0	26.3	26.5	26.4
NKL	9.3	15.8	18.8	14.2	14.2	7.6	10.5	0	4.7	16.3	22.8	28.1	25.4	19.7	19.0	18.4	15.2	17.5	19.0	19.0
COM	5.3	11.8	14.7	10.2	11.8	8.2	11.1	4.7	0	12.3	18.9	24.0	21.4	15.7	15.2	16.7	14.8	17.0	16.6	16.0
SYL	12.2	13.6	17.2	16.1	18.7	19.8	22.7	16.3	12.3	0	24.1	29.3	26.6	20.9	21.8	24.1	23.2	25.5	23.5	22.6
RAJ	13.5	12.6	12.2	8.7	11.8	26.3	29.3	22.8	18.9	24.1	0	14.3	11.6	6.0	5.6	14.5	18.4	20.7	11.3	6.5
DIN	18.7	17.8	17.4	13.9	19.2	31.5	34.5	28.1	24.0	29.3	14.3	0	4.1	8:3	14.9	23.9	25.9	28.1	20.6	15.8
RAN	16.1	15.1	14.7	11.2	16.6	28.8	31.8	25.4	21.4	26.6	11.6	4.1	0	5.7	12.2	21.2	23.2	25.5	18.0	13.1
BGR	10.4	9.4	9.1	5.6	10.9	23.2	26.1	19.7	15.7	20.9	6.0	8.3	5.7	0	6.6	15.7	17.6	19.8	12.4	7.6
PBN	9.9	10.7	10.3	6.8	7.1	22.6	25.6	19.0	15.2	21.8	5.6	14.9	12.2	6.6	0	10.8	13.7	16.0	7.5	2.7
KHL	12.1	17.6	18.3	14.2	7.7	23.0	25.9	18.4	16.7	24.1	14.5	23.9	21.2	15.7	10.8	0	8.9	11.0	3.3	8.1
BAR	11.3	17.2	18.7	14.1	6.9	21.1	24.0	15.2	14.8	23.2	18.4	25.9	23.2	17.6	13.7	8.9	0	2.5	10.4	12.3
PAT	13.5	19.4	20.9	16.3	9.1	23.3	26.3	17.5	17.0	25.5	20.7	28.1	25.5	19.8	16.0	11.0	2.5	0	12.5	14.5
JSR	11.4	15.9	15.6	11.4	5.1	23.6	26.5	19.0	16.6	23.5	11.3	20.6	18.0	12.4	7.5	3.3	10.4	12.5	0	4.8
KST	10.7	12.2	11.9	8.4	5.6	23.5	26.4	19.0	16.0	22.6	6.5	15.8	13.1	7.6	2.7	8.1	12.3	14.5	4.8	0

Table A-8: Generalized Cost Matrix (in hr) by Rail

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	6.1	11.3	4.8	20.3	15.7	9999	13.7	8.4	14.6	14.2	19.5	19.7	16.3	9.7	19.9	9999	9999	17.0	12.4
MYM	6.1	0	5.2	8.0	23.6	18.3	9999	16.3	11.0	17.2	17.0	18.8	19.0	15.6	12.9	23.1	9999	9999	20.3	15.7
JAM	11.3	5.2	0	13.2	26.6	23.6	9999	21.5	16.2	22.4	19.8	19.4	14.9	11.3	16.0	26.2	9999	9999	23.3	18.7
TAN	4.8	8.0	13.2	0	15.6	18.1	9999	16.1	10.7	16.9	9.4	14.9	16.6	12.1	4.9	15.2	9999	9999	12.3	7.7
FAR	20.3	23.6	26.6	15.6	0	33.6	9999	31.6	26.3	32.5	15.2	20.6	22.3	17.9	10.7	17.1	9999	9999	14.2	7.9
CTG	15.7	18.3	23.6	18.1	33.6	0	9999	10.4	7.3	18.5	27.5	31.7	31.9	28.6	23.0	33.2	9999	9999	30.3	25.8
CHT	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
NKL	13.7	16.3	21.5	16.1	31.6	10.4	9999	0	5.3	16.5	25.5	29.7	29.9	26.6	21.0	31.2	9999	9999	28.3	23.7
COM	8.4	11.0	16.2	10.7	26.3	7.3	9999	5.3	0	11.1	20.2	24.4	24.6	21.2	15.6	25.9	9999	9999	23.0	18.4
SYL	14.6	17.2	22.4	16.9	32.5	18.5	9999	16.5	11.1	0	26.4	30.6	30.8	27.4	21.8	32.1	9999	9999	29.2	24.6
RAJ	14.2	17.0	19.8	9.4	15.2	27.5	9999	25.5	20.2	26.4	0	12.8	14.5	10.1	4.5	14.8	9999	9999	11.9	7.3
DIN	19.5	18.8	19.4	14.9	20.6	31.7	9999	29.7	24.4	30.6	12.8	0	4.6	9.5	10.0	20.2	9999	9999	17.3	12.7
RAN	19.7	19.0	14.9	16.6	22.3	31.9	9999	29.9	24.6	30.8	14.5	4.6	0	10.4	11.7	21.9	9999	9999	19.0	14.4
BGR	16.3	15.6	11.3	12.1	17.9	28.6	9999	26.6	21.2	27.4	10.1	9.5	10.4	0	7.2	17.5	9999	9999	14.6	10.0
PBN	9.7	12.9	16.0	4.9	10.7	23.0	9999	21.0	15.6	21.8	4.5	10.0	11.7	7.2	0	10.3	9999	9999	7.4	2.8
KHL	19.9	23.1	26.2	15.2	17.1	33.2	9999	31.2	25.9	32.1	14.8	20.2	21.9	17.5	10.3	0	9999	9999	2.9	9.2
BAR	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999
PAT	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999
JSR	17.0	20.3	23.3	12.3	14.2	30.3	9999	28.3	23.0	29.2	11.9	17.3	19.0	14.6	7.4	2.9	9999	9999	0	6.3
KST	12.4	15.7	18.7	7.7	7.9	25.8	9999	23.7	18.4	24.6	7.3	12.7	14.4	10.0	2.8	9.2	9999	9999	6.3	0

Table A-9: Generalized Cost Matrix (in hr) by Waterway

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	9999	31.7	20.8	12.8	24.0	34.7	9.5	9999	28.8	9999	9999	41.1	28.1	9999	30.7	14.8	22.9	9999	9999
MYM	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
JAM	31.7	9999	0	10.9	18.9	46.7	57.4	32.3	9999	54.8	9999	9999	9.4	3.6	9999	53.4	37.5	45.6	9999	9999
TAN	20.8	9999	10.9	0	8.0	35.8	46.5	21.4	9999	43.9	9999	9999	20.3	7.3	9999	42.5	26.7	34.7	9999	9999
FAR	12.8	9999	18.9	8.0	0	27.8	38.5	13.4	9999	36.0	9999	9999	28.3	15.3	9999	34.6	18.7	26.8	9999	9999
CTG	24.0	9999	46.7	35.8	27.8	0	10.7	14.4	9999	47.1	9999	9999	56.2	43.1	9999	35.6	19.7	27.8	9999	9999
CHT	34.7	9999	57.4	46.5	38.5	10.7	0	25.1	9999	57.8	9999	9999	66.8	53.8	9999	46.3	30.4	38.5	9999	9999
NKL	9.5	9999	32.3	21.4	13.4	14.4	25.1	0	9999	32.7	9999	9999	41.7	28.7	9999	23.9	8.0	16.1	9999	9999
COM	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999
SYL	28.8	9999	54.8	43.9	36.0	47.1	57.8	32.7	9999	0	9999	9999	64.3	51.2	9999	53.9	38.0	46.0	9999	9999
RAJ	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999	9999
DIN	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999	9999	9999	9999
RAN	41.1	9999	9.4	20.3	28.3	56.2	66.8	41.7	9999	64.3	9999	9999	0	13.0	9999	62.9	47.0	55.1	9999	9999
BGR	28.1	9999	3.6	7.3	15.3	43.1	53.8	28.7	9999	51.2	9999	9999	13.0	0	9999	49.9	34.0	42.0	9999	9999
PBN	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999	9999	9999	9999	9999
KHL	30.7	9999	53.4	42.5	34.6	35.6	46.3	23.9	9999	53.9	9999	9999	62.9	49.9	9999	0	15.9	22.7	9999	9999
BAR	14.8	9999	37.5	26.7	18.7	19.7	30.4	8.0	9999	38.0	9999	9999	47.0	34.0	9999	15.9	0	8.1	9999	9999
PAT	22.9	9999	45.6	34.7	26.8	27.8	38.5	16.1	9999	46.0	9999	9999	55.1	42.0	9999	22.7	8.1	0	9999	9999
JSR	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0	9999
KST	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	9999	0

Table A-10: Probability of Using Road, $P_{road} = \dfrac{e^{t_{road}}}{e^{t_{road}} + e^{t_{rail}} + e^{t_{water}}}$

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0.33	0.64	0.59	0.80	0.95	0.79	1.00	0.80	0.85	0.75	0.80	0.80	0.92	0.96	0.80	0.92	0.40	0.40	0.93	0.80
MYM	0.64	0.33	0.58	0.86	1.00	0.60	1.00	0.46	0.34	0.92	0.95	0.90	0.95	0.99	0.75	0.87	0.60	0.60	0.90	0.88
JAM	0.59	0.58	0.33	0.97	0.98	0.56	1.00	0.76	0.66	0.94	1.00	0.60	0.80	0.80	0.80	0.80	0.80	0.80	0.92	0.80
TAN	0.80	0.86	0.97	0.33	0.58	0.85	1.00	0.80	0.80	0.56	0.61	0.80	0.96	0.73	0.80	0.80	0.60	0.60	0.53	0.38
FAR	0.95	1.00	0.98	0.58	0.33	0.98	1.00	0.60	1.00	1.00	0.79	0.80	0.89	0.77	0.69	0.99	0.80	0.80	1.00	0.70
CTG	0.79	0.60	0.56	0.85	0.98	0.33	0.98	0.78	0.80	0.60	0.60	0.60	0.91	0.95	0.10	0.80	0.75	0.75	0.94	0.80
CHT	1.00	1.00	1.00	1.00	1.00	0.98	0.33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	1.00	1.00	1.00
NKL	0.80	0.46	0.76	0.80	0.60	0.78	1.00	0.33	0.80	0.80	0.61	0.80	0.96	0.97	0.80	0.95	0.60	0.60	0.95	0.78
COM	0.85	0.34	0.66	0.80	1.00	0.80	1.00	0.80	0.33	0.80	0.80	0.80	0.94	0.97	0.80	0.80	0.65	0.75	0.96	0.75
SYL	0.75	0.92	0.94	0.56	1.00	0.60	1.00	0.80	0.80	0.67	0.67	0.51	0.97	0.99	0.80	0.98	0.75	0.75	0.95	0.60
RAJ	0.80	0.95	1.00	0.61	0.79	0.60	1.00	0.61	0.80	0.67	0.33	0.60	0.85	0.92	0.80	0.54	1.00	1.00	0.59	0.62
DIN	0.80	0.90	0.60	0.80	0.80	0.60	1.00	0.80	0.80	0.51	0.60	0.33	0.57	0.80	0.80	0.80	0.80	0.80	0.80	0.80
RAN	0.92	0.95	0.80	0.96	0.89	0.91	1.00	0.96	0.94	0.97	0.85	0.57	0.33	0.94	0.80	0.60	0.80	0.80	0.66	0.69
BGR	0.96	0.99	0.80	0.73	0.77	0.95	1.00	0.97	0.97	0.99	0.92	0.80	0.94	0.33	0.80	0.74	0.80	0.80	0.78	0.81
PBN	0.80	0.75	0.80	0.80	0.69	0.10	1.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.33	0.40	0.80	0.80	0.80	0.80
KHL	0.92	0.87	0.80	0.80	0.99	0.80	1.00	0.95	0.80	0.98	0.54	0.80	0.60	0.74	0.40	0.33	0.45	0.45	0.44	0.80
BAR	0.40	0.60	0.80	0.60	0.80	0.75	0.96	0.60	0.65	0.75	1.00	0.80	0.80	0.80	0.80	0.45	0.33	0.40	0.80	1.00
PAT	0.40	0.60	0.80	0.60	0.80	0.75	1.00	0.60	0.75	0.75	1.00	0.80	0.80	0.80	0.80	0.45	0.40	0.33	1.00	1.00
JSR	0.93	0.90	0.92	0.53	1.00	0.94	1.00	0.95	0.96	0.95	0.59	0.80	0.66	0.78	0.80	0.44	0.80	1.00	0.33	0.71
KST	0.80	0.88	0.80	0.38	0.70	0.80	1.00	0.78	0.75	0.60	0.62	0.80	0.69	0.81	0.80	0.80	1.00	1.00	0.71	0.33

Table A-11: Probability of Using Rail, $P_{rail} = \dfrac{e^{t_{rail}}}{e^{t_{road}} + e^{t_{rail}} + e^{t_{water}}}$

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0.33	0.36	0.30	0.15	0.01	0.15	0.20	0.20	0.15	0.24	0.20	0.20	0.06	0.03	0.20	0.05	0.00	0.00	0.07	0.20
MYM	0.36	0.33	0.42	0.14	0.00	0.40	0.54	0.54	0.66	0.08	0.05	0.10	0.05	0.01	0.25	0.13	0.00	0.00	0.10	0.12
JAM	0.30	0.42	0.33	0.01	0.00	0.44	0.24	0.24	0.34	0.06	0.00	0.40	0.04	0.01	0.20	0.01	0.00	0.00	0.08	0.20
TAN	0.15	0.14	0.01	0.33	0.00	0.12	0.20	0.20	0.20	0.44	0.39	0.20	0.04	0.01	0.20	0.10	0.00	0.00	0.47	0.62
FAR	0.01	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.21	0.20	0.10	0.04	0.31	0.01	0.00	0.00	0.00	0.30
CTG	0.15	0.40	0.44	0.12	0.00	0.33	0.20	0.20	0.20	0.35	0.40	0.40	0.09	0.05	0.90	0.01	0.00	0.00	0.06	0.20
CHT	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NKL	0.20	0.54	0.24	0.20	0.00	0.20	0.00	0.33	0.20	0.20	0.39	0.20	0.04	0.02	0.20	0.00	0.00	0.00	0.05	0.22
COM	0.15	0.66	0.34	0.20	0.00	0.20	0.00	0.20	0.33	0.15	0.20	0.20	0.06	0.03	0.20	0.01	0.00	0.00	0.04	0.25
SYL	0.24	0.08	0.06	0.44	0.00	0.35	0.00	0.20	0.15	0.33	0.33	0.49	0.03	0.01	0.20	0.02	0.00	0.00	0.05	0.40
RAJ	0.20	0.05	0.00	0.39	0.21	0.40	0.00	0.39	0.20	0.33	0.33	0.40	0.15	0.08	0.20	0.46	0.00	0.00	0.41	0.38
DIN	0.20	0.10	0.40	0.20	0.20	0.40	0.00	0.20	0.20	0.49	0.40	0.33	0.43	0.15	0.20	0.20	0.00	0.00	0.20	0.20
RAN	0.06	0.05	0.04	0.04	0.10	0.09	0.00	0.04	0.06	0.03	0.15	0.43	0.33	0.04	0.20	0.40	0.00	0.00	0.34	0.31
BGR	0.03	0.01	0.01	0.01	0.04	0.05	0.00	0.02	0.03	0.01	0.08	0.15	0.04	0.33	0.20	0.26	0.00	0.00	0.22	0.19
PBN	0.20	0.25	0.20	0.20	0.31	0.90	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.33	0.60	0.00	0.00	0.20	0.20
KHL	0.05	0.13	0.01	0.10	0.01	0.01	0.00	0.00	0.01	0.02	0.46	0.20	0.40	0.26	0.60	0.33	0.00	0.00	0.56	0.20
BAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.20	0.00
PAT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00
JSR	0.07	0.10	0.08	0.47	0.00	0.06	0.00	0.05	0.04	0.05	0.41	0.20	0.34	0.22	0.20	0.56	0.20	0.00	0.33	0.29
KST	0.20	0.12	0.20	0.62	0.30	0.20	0.00	0.22	0.25	0.40	0.38	0.20	0.31	0.19	0.20	0.20	0.00	0.00	0.29	0.33

Table A-12: Probability of Using Waterway, $P_{water} = \dfrac{e^{t_{water}}}{e^{t_{road}} + e^{t_{rail}} + e^{t_{water}}}$

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0.33	0.00	0.11	0.05	0.04	0.06	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.00	0.03	0.60	0.60	0.00	0.00
MYM	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.00	0.00
JAM	0.11	0.00	0.33	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.19	0.00	0.19	0.20	0.20	0.00	0.00
TAN	0.05	0.00	0.02	0.33	0.42	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.10	0.40	0.40	0.00	0.00
FAR	0.04	0.00	0.02	0.42	0.33	0.02	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.20	0.20	0.00	0.00
CTG	0.06	0.00	0.00	0.03	0.02	0.33	0.02	0.02	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.19	0.25	0.25	0.00	0.00
CHT	0.00	0.00	0.00	0.00	0.00	0.02	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
NKL	0.00	0.00	0.00	0.00	0.40	0.02	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.40	0.40	0.00	0.00
COM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.05	0.00	0.00	0.00	0.00	0.00	0.19	0.35	0.25	0.00	0.00
SYL	0.01	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00
RAJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.05	0.00	0.00	0.20	0.20	0.00	0.00
RAN	0.02	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.01	0.00	0.00	0.20	0.20	0.00	0.00
BGR	0.01	0.00	0.19	0.26	0.19	0.00	0.00	0.01	0.00	0.00	0.00	0.05	0.01	0.33	0.00	0.00	0.20	0.20	0.00	0.00
PBN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.20	0.20	0.00	0.00
KHL	0.03	0.00	0.19	0.10	0.00	0.19	0.00	0.05	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.55	0.55	0.00	0.00
BAR	0.60	0.40	0.20	0.40	0.20	0.25	0.04	0.40	0.35	0.25	0.00	0.20	0.20	0.20	0.20	0.55	0.33	0.60	0.00	0.00
PAT	0.60	0.40	0.20	0.40	0.20	0.25	0.00	0.40	0.25	0.25	0.00	0.20	0.20	0.20	0.20	0.55	0.60	0.33	0.00	0.00
JSR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
KST	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33

Table A-13: Composite Time (in hr), $t_{ij} = \frac{-1}{\lambda_{ij}} \ln \sum_{m} P_{ijm} \exp(-\lambda_{ij}\, t_{ijm})$

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0	3.785	6.033	2.965	4.040	7.868	9.429	5.794	3.317	7.511	8.194	11.317	9.713	6.282	5.896	7.338	7.518	9.029	6.929	6.562
MYM	3.785	0	2.925	3.098	6.946	11.289	13.306	9.631	6.729	8.236	7.582	10.697	9.085	5.662	6.600	10.702	10.807	12.157	9.646	7.456
JAM	6.033	2.925	0	2.796	7.236	13.606	15.094	11.467	9.069	10.368	7.333	10.781	7.279	3.666	6.411	11.228	11.432	12.782	9.422	7.359
TAN	2.965	3.098	2.796	0	4.582	10.648	12.354	8.658	6.166	9.835	5.380	8.440	6.780	3.543	3.740	8.648	8.951	10.302	7.043	4.755
FAR	4.040	6.946	7.236	4.582	0	11.311	13.060	8.300	7.093	11.210	7.253	11.665	10.042	6.815	4.560	4.624	4.342	5.692	3.057	3.625
CTG	7.868	11.289	13.606	10.648	11.311	0	2.107	4.738	4.777	11.560	16.020	18.956	17.381	13.951	13.766	14.025	12.383	14.267	14.225	14.249
CHT	9.429	13.306	15.094	12.354	13.060	2.107	0	6.301	6.662	13.646	17.556	20.674	19.062	15.671	15.350	15.567	14.459	15.768	15.928	15.853
NKL	5.794	9.631	11.467	8.658	8.300	4.738	6.301	0	2.886	9.820	14.025	16.968	15.259	11.862	11.540	11.064	5.710	10.067	11.428	11.623
COM	3.317	6.729	9.069	6.166	7.093	4.777	6.662	2.886	0	7.297	11.426	14.465	12.873	9.455	9.154	10.248	9.306	10.513	10.001	9.819
SYL	7.511	8.236	10.368	9.835	11.210	11.560	13.646	9.820	7.297	0	14.730	17.874	15.983	12.577	13.065	14.499	14.228	15.578	14.125	13.889
RAJ	8.194	7.582	7.333	5.380	7.253	16.020	17.556	14.025	11.426	14.730	0	8.110	7.078	3.702	3.174	8.788	11.044	12.394	6.897	4.035
DIN	11.317	10.697	10.781	8.440	11.665	18.956	20.674	16.968	14.465	17.874	8.110	0	2.586	5.137	7.400	13.379	15.757	17.107	11.571	8.766
RAN	9.713	9.085	7.279	6.780	10.042	17.381	19.062	15.259	12.873	15.983	7.078	2.586	0	3.447	7.249	12.880	14.144	15.494	10.950	8.071
BGR	6.282	5.662	3.666	3.543	6.815	13.951	15.671	11.862	9.455	12.577	3.702	5.137	3.447	0	4.022	9.595	10.778	12.128	7.617	4.719
PBN	5.896	6.600	6.411	3.740	4.560	13.766	15.350	11.540	9.154	13.065	3.174	7.400	7.249	4.022	0	6.269	8.446	9.796	4.496	1.636
KHL	7.338	10.702	11.228	8.648	4.624	14.025	15.567	11.064	10.248	14.499	8.788	13.379	12.880	9.595	6.269	0	6.105	7.392	1.828	4.955
BAR	7.518	10.807	11.432	8.951	4.342	12.383	14.459	5.710	9.306	14.228	11.044	15.757	14.144	10.778	8.446	6.105	0	2.362	6.444	7.360
PAT	9.029	12.157	12.782	10.302	5.692	14.267	15.768	10.067	10.513	15.578	12.394	17.107	15.494	12.128	9.796	7.392	2.362	0	7.521	8.710
JSR	6.929	9.646	9.422	7.043	3.057	14.225	15.928	11.428	10.001	14.125	6.897	11.571	10.950	7.617	4.496	1.828	6.444	7.521	0	3.075
KST	6.562	7.456	7.359	4.755	3.625	14.249	15.853	11.623	9.819	13.889	4.035	8.766	8.071	4.719	1.636	4.955	7.360	8.710	3.075	0

Table A-14: Measure of Attarction Zone (product of population percentage of origin and destination), $E_j = \frac{P_i P_j}{\sum P_i \sum P_j}$

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST
DHK	0.02134	0.01053	0.00396	0.00384	0.00698	0.00993	0.00159	0.00616	0.01074	0.00920	0.00896	0.00552	0.01067	0.00457	0.00567	0.00662	0.00677	0.00264	0.00649	0.00390
MYM	0.01053	0.00520	0.00196	0.00189	0.00344	0.00490	0.00078	0.00304	0.00530	0.00454	0.00442	0.00273	0.00527	0.00226	0.00280	0.00327	0.00334	0.00130	0.00320	0.00192
JAM	0.00396	0.00196	0.00074	0.00071	0.00130	0.00184	0.00029	0.00114	0.00199	0.00171	0.00166	0.00103	0.00198	0.00085	0.00105	0.00123	0.00126	0.00049	0.00120	0.00072
TAN	0.00384	0.00189	0.00071	0.00069	0.00125	0.00179	0.00029	0.00111	0.00193	0.00166	0.00161	0.00099	0.00192	0.00082	0.00102	0.00119	0.00122	0.00048	0.00117	0.00070
FAR	0.00698	0.00344	0.00130	0.00125	0.00228	0.00325	0.00052	0.00201	0.00351	0.00301	0.00293	0.00181	0.00349	0.00150	0.00185	0.00217	0.00221	0.00086	0.00212	0.00128
CTG	0.00993	0.00490	0.00184	0.00179	0.00325	0.00462	0.00074	0.00287	0.00500	0.00428	0.00417	0.00257	0.00497	0.00213	0.00264	0.00308	0.00315	0.00123	0.00302	0.00182
CHT	0.00159	0.00078	0.00029	0.00029	0.00052	0.00074	0.00012	0.00046	0.00080	0.00068	0.00067	0.00041	0.00079	0.00034	0.00042	0.00049	0.00050	0.00020	0.00048	0.00029
NKL	0.00616	0.00304	0.00114	0.00111	0.00201	0.00287	0.00046	0.00178	0.00310	0.00266	0.00259	0.00159	0.00308	0.00132	0.00164	0.00191	0.00195	0.00076	0.00187	0.00113
COM	0.01074	0.00530	0.00199	0.00193	0.00351	0.00500	0.00080	0.00310	0.00540	0.00463	0.00451	0.00278	0.00537	0.00230	0.00285	0.00333	0.00340	0.00133	0.00326	0.00196
SYL	0.00920	0.00454	0.00171	0.00166	0.00301	0.00428	0.00068	0.00266	0.00463	0.00397	0.00386	0.00238	0.00460	0.00197	0.00244	0.00286	0.00292	0.00114	0.00280	0.00168
RAJ	0.00896	0.00442	0.00166	0.00161	0.00293	0.00417	0.00067	0.00259	0.00451	0.00386	0.00376	0.00232	0.00448	0.00192	0.00238	0.00278	0.00284	0.00111	0.00272	0.00164
DIN	0.00552	0.00273	0.00103	0.00099	0.00181	0.00257	0.00041	0.00159	0.00278	0.00238	0.00232	0.00143	0.00276	0.00118	0.00147	0.00171	0.00175	0.00068	0.00168	0.00101
RAN	0.01067	0.00527	0.00198	0.00192	0.00349	0.00497	0.00079	0.00308	0.00537	0.00460	0.00448	0.00276	0.00534	0.00229	0.00283	0.00331	0.00338	0.00132	0.00325	0.00195
BGR	0.00457	0.00226	0.00085	0.00082	0.00150	0.00213	0.00034	0.00132	0.00230	0.00197	0.00192	0.00118	0.00229	0.00098	0.00121	0.00142	0.00145	0.00057	0.00139	0.00084
PBN	0.00567	0.00280	0.00105	0.00102	0.00185	0.00264	0.00042	0.00164	0.00285	0.00244	0.00238	0.00147	0.00283	0.00121	0.00150	0.00176	0.00180	0.00070	0.00172	0.00104
KHL	0.00662	0.00327	0.00123	0.00119	0.00217	0.00308	0.00049	0.00191	0.00333	0.00286	0.00278	0.00171	0.00331	0.00142	0.00176	0.00206	0.00210	0.00082	0.00201	0.00121
BAR	0.00677	0.00334	0.00126	0.00122	0.00221	0.00315	0.00050	0.00195	0.00340	0.00292	0.00284	0.00175	0.00338	0.00145	0.00180	0.00210	0.00215	0.00084	0.00206	0.00124
PAT	0.00264	0.00130	0.00049	0.00048	0.00086	0.00123	0.00020	0.00076	0.00133	0.00114	0.00111	0.00068	0.00132	0.00057	0.00070	0.00082	0.00084	0.00033	0.00080	0.00048
JSR	0.00649	0.00320	0.00120	0.00117	0.00212	0.00302	0.00048	0.00187	0.00326	0.00280	0.00272	0.00168	0.00325	0.00139	0.00172	0.00201	0.00206	0.00080	0.00197	0.00119
KST	0.00390	0.00192	0.00072	0.00070	0.00128	0.00182	0.00029	0.00113	0.00196	0.00168	0.00164	0.00101	0.00195	0.00084	0.00104	0.00121	0.00124	0.00048	0.00119	0.00071

Table A-15: Accessibility Index Calculation, $A_i = \sum_i E_j \exp(-\mu\, t_{ij})$

O-D	DHK	MYM	JAM	TAN	FAR	CTG	CHT	NKL	COM	SYL	RAJ	DIN	RAN	BGR	PBN	KHL	BAR	PAT	JSR	KST	A_i
DHK	1.564	0.569	0.183	0.232	0.294	0.383	0.043	0.314	0.700	0.410	0.335	0.147	0.359	0.202	0.227	0.228	0.287	0.094	0.254	0.143	**6.969**
MYM	0.569	0.561	0.159	0.158	0.158	0.147	0.017	0.120	0.270	0.183	0.242	0.106	0.260	0.146	0.162	0.127	0.138	0.046	0.142	0.103	**3.814**
JAM	0.183	0.159	0.079	0.060	0.055	0.048	0.005	0.039	0.087	0.059	0.093	0.040	0.101	0.060	0.062	0.048	0.048	0.016	0.054	0.039	**1.336**
TAN	1.026	0.158	0.060	0.080	0.069	0.060	0.007	0.049	0.110	0.074	0.110	0.048	0.118	0.067	0.074	0.058	0.060	0.020	0.064	0.047	**2.358**
FAR	0.294	0.158	0.055	0.069	0.179	0.077	0.009	0.063	0.141	0.090	0.134	0.048	0.118	0.066	0.101	0.128	0.146	0.048	0.143	0.077	**2.144**
CTG	0.383	0.147	0.048	0.060	0.077	0.430	0.045	0.178	0.306	0.143	0.088	0.038	0.094	0.053	0.059	0.061	0.079	0.026	0.066	0.037	**2.418**
CHT	0.043	0.017	0.005	0.007	0.009	0.045	0.009	0.020	0.034	0.016	0.010	0.004	0.011	0.006	0.007	0.007	0.009	0.003	0.008	0.004	**0.275**
NKL	0.314	0.120	0.039	0.049	0.063	0.178	0.020	0.196	0.248	0.116	0.071	0.031	0.077	0.043	0.048	0.051	0.085	0.025	0.054	0.030	**1.859**
COM	0.700	0.270	0.087	0.110	0.141	0.306	0.034	0.248	0.617	0.261	0.160	0.070	0.171	0.097	0.108	0.111	0.143	0.047	0.120	0.068	**3.871**
SYL	0.410	0.183	0.059	0.074	0.090	0.143	0.016	0.116	0.261	0.418	0.109	0.048	0.117	0.066	0.073	0.070	0.084	0.028	0.078	0.046	**2.490**
RAJ	0.335	0.242	0.093	0.110	0.134	0.088	0.010	0.071	0.160	0.109	0.393	0.106	0.258	0.144	0.181	0.141	0.117	0.039	0.157	0.115	**3.003**
DIN	0.147	0.106	0.040	0.048	0.048	0.038	0.004	0.031	0.070	0.048	0.106	0.143	0.223	0.071	0.066	0.051	0.042	0.014	0.057	0.041	**1.393**
RAN	0.359	0.260	0.101	0.118	0.118	0.094	0.011	0.077	0.171	0.117	0.258	0.223	0.579	0.174	0.159	0.124	0.103	0.034	0.139	0.101	**3.318**
BGR	0.202	0.146	0.060	0.067	0.066	0.053	0.006	0.043	0.097	0.066	0.144	0.071	0.174	0.106	0.089	0.069	0.058	0.019	0.077	0.056	**1.669**
PBN	0.227	0.162	0.062	0.074	0.101	0.059	0.007	0.048	0.108	0.073	0.181	0.066	0.159	0.089	0.158	0.106	0.088	0.029	0.119	0.087	**2.002**
KHL	0.228	0.127	0.048	0.058	0.128	0.061	0.007	0.051	0.111	0.070	0.141	0.051	0.124	0.069	0.106	0.228	0.122	0.041	0.177	0.081	**2.029**
BAR	0.287	0.138	0.048	0.060	0.146	0.079	0.009	0.085	0.143	0.084	0.117	0.042	0.103	0.058	0.088	0.122	0.259	0.080	0.125	0.067	**2.140**
PAT	0.094	0.046	0.016	0.020	0.048	0.026	0.003	0.025	0.047	0.028	0.039	0.014	0.034	0.019	0.029	0.041	0.080	0.037	0.041	0.022	**0.707**
JSR	0.254	0.142	0.054	0.064	0.143	0.066	0.008	0.054	0.120	0.078	0.157	0.057	0.139	0.077	0.119	0.177	0.125	0.041	0.208	0.091	**2.175**
KST	0.143	0.103	0.039	0.047	0.077	0.037	0.004	0.030	0.068	0.046	0.115	0.041	0.101	0.056	0.087	0.081	0.067	0.022	0.091	0.070	**1.327**

APPENDIX-B

Input and Output of SDEM Analysis in BIOGEME Statistical Software

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]

Author: Michel Bierlaire, EPFL (2001-2005)

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08/26/07 14:43:51

Example of a model specification file for Stochastic DEA in multinomial logit Framework

Model:	Multinomial Logit
Number of estimated parameters:	5
Number of observations:	100
Number of individuals:	100
Null log-likelihood:	-109.861
Init log-likelihood:	-109.861
Final log-likelihood:	-52.0454
Likelihood ratio test:	115.632
Rho-square:	0.526262
Adjusted rho-square:	0.48075
Final gradient norm:	7.37051e-005
Variance-covariance:	from finite difference hessian

Utility parameters

Name	Value	Std err	t-test		Robust Std err	Robust t-test
A1	+8.6744777e+000	+1.5742699e+000	+5.5069832e+000		+1.9064082e+000	+4.5475453e+000
A2	-4.5286024e+000	+1.0901690e+000	-4.1522025e+000		+1.0812370e+000	-4.1865034e+000
A3	-1.7261397e+000	+3.9394440e-001	-4.3816837e+000		+3.0775185e-001	-5.6088687e+000
A4	-2.9309228e+000	+5.2605402e-001	-5.5715244e+000		+6.4763557e-001	-4.5255742e+000
A5	-1.0833903e+000	+5.2270825e-001	-2.0726483e+000		+3.4069139e-001	-3.1799757e+000

Scale parameters

Name	Value	Std err	t-test 1		Robust Std err	Robust t-test 1	
Scale1	+1.0000000e+000	fixed					

Utility functions

1	Alt1	av1	A1 * GDP1 + A2 * ARE1 + A3 * POP1 + A4 * CAP1 + A5 * ACC1
2	Alt2	av2	A1 * GDP2 + A2 * ARE2 + A3 * POP2 + A4 * CAP2 + A5 * ACC2
3	Alt3	av3	A1 * GDP3 + A2 * ARE3 + A3 * POP3 + A4 * CAP3 + A5 * ACC3

Correlation of coefficients

Coefficient1	Coefficient2	Covariance	Correlation	t-test		Rob. cov.	Rob. corr.	Rob. t-test
A3	A5	-4.9919415e-002	-2.4242378e-001	-8.8434128e-001	*	-6.8552511e-003	-6.5382502e-002	-1.3565660e+000
A2	A4	2.4575668e-001	4.2852994e-001	-1.6170960e+000	*	3.5747288e-001	5.1049502e-001	-1.7072591e+000
A2	A3	-2.9275117e-002	-6.8166327e-002	-2.3649563e+000		1.2257140e-001	3.6835585e-001	-2.7747191e+000
A3	A4	1.0332098e-001	4.9856668e-001	2.5383096e+000		1.6804146e-001	8.4311161e-001	2.8551277e+000
A4	A5	2.8985548e-002	1.0541243e-001	-2.6340006e+000		5.9143819e-003	2.6805105e-002	-2.5530640e+000
A2	A5	2.0270944e-001	3.5573026e-001	-3.3502375e+000		1.2709871e-001	3.4503177e-001	-3.3911396e+000
A1	A5	-3.9301744e-001	-4.7760986e-001	5.1853603e+000		-2.6677936e-001	-4.1074773e-001	4.7120134e+000
A1	A2	-1.1377453e+000	-6.6293665e-001	5.4133763e+000		-1.5368151e+000	-7.4556381e-001	4.7017754e+000
A1	A4	-6.7507191e-001	-8.1515558e-001	5.7253983e+000		-1.0739252e+000	-8.6981611e-001	4.6582039e+000
A1	A3	-2.3277139e-001	-3.7533191e-001	5.9052087e+000		-4.1609860e-001	-7.0921789e-001	4.8674997e+000

Smallest singular value of the hessian: 2.9581397e-001

Appendix-C

Transport Sector Issues and Concerns

TRANSPORT SECTOR ISSUES AND CONCERNS

The issues and concerns the transport sector is confronted with can be grouped into four (4), namely, structural, natural, institutional and others.

1. Structural

The structural change that took place in the transport sector particularly over the last twenty (20) years or so can be largely explained by the Government's shifting priority, heavily biased to road transport development. The trend is still continued. Prior to independence in 1971, there were hardly any rural roads but national roads less than 3800 km - 65% paved and 35% unpaved (BTS, 1978). In the last ten years, the growth of the rural roads has been phenomenal. The current roads network is 290,000 km, comprising more than 21,000 km national, about 250,000 rural and estimated 19,000 km urban. The phenomenal growth of roads has been achieved at the cost of degeneration of the railway and naturally advantaged inland water transport (IWT) systems.

Railway route network, although decreased marginally in the nineties increased again to pre-1971 level at 2,880 km in 2003 (BR, 2005). The track-kilometer has also remained almost at the same at 4,443 km. Railway used to be an extensive network linking Dhaka with 19 (out of 21) the then districts. The service network was extensive (compared to paved roads) and it was functionally efficient prior to independence in 1971. However, it has suffered over the past years due to lack of funding for maintenance of the tracks, bridges, signals and stations; and, procurement of rolling stock - to replace the age old engines, carriages, wagons, etc. Once thriving railway has been now reduced to subsistence survival.

IWT suffered most due to over emphasis on roads. In 1971, the IWT network navigable round the year was 12,000 km. In both rural and urban areas, majority of the economic activities and administrative centers used to be located around the IWT stations/ports, each provided with un/paved or unclassified roads depending on the location. The network has been now reduced to less than 6,000 km (of which 2,400 km are not navigable during dry season), due to withdrawal of water from the upstream and silt accumulated over the past years due to lack of dredging. On the other hand, inadequately planned roads have been constructed in rural areas, obstructing free flow of water to provide road connectivity to the new growth centers - many of which have been developed away from the IWT stations. All these factors contributed to disintegration and degeneration of the naturally advantaged IWT to make room for expensive road transport, maintenance of which is also more expensive than maintaining the waterways.

The Government's shifting priority to roads development has been demonstrated by programming resources. The first five-year plan (1973 - 1978) allocated Tk. 4,149 million to the transport sector (excluding international shipping and ports), of which 36% was for road, 30% for rail, 18% for IWT and 16% for air or civil aviation. Sub-sector allocations changed noticeably in the third five-year plan (1985 - 1990). The plan allocated more than 54% to road, about 33% to rail, 8% to civil aviation, and less than 5% to IWT. The fourth five-year plan (1990 - 1995) allocated about 76% and the fifth five year plan (1997 - 2002) more than 66% to the road sub-sector. The higher allocation for the road sub-sector resulted partly from the construction of Jamuna bridge, which accounted for 14% of the third plan, 22% in the fourth plan, 53% of the two-year plan (1995-1997) and 15% of the fifth plan (1997-2002) allocations for the road sub-sector. The Jamuna Bridge was completed by the beginning of the fifth plan; however, out of the total allocation for the transport sector, 21% was made to railway and only 7% to IWT.

Five-year plan allocations are indicative and subject to revision(s). The actual allocations are reflected in annual development programmes (ADPs). An examination of recent ADP allocations for FY2000 to FY 2005 reveals the same bias toward the road sub-sector depriving railway and IWT. ADP allocations to IWT including BIWTA and BIWTC have been less than 1% since 2001. The higher 4% allocation in 2000 resulted from the procurement of dredgers by BIWTA.

The FY 2005 allocations, including both ADP and Revenue budget for roads and bridges amounted to Tk. 52,516 million, of which 14% was distributed for construction, 22% for maintenance, and 64% for rehabilitation & improvement.

2. Natural

Bangladesh is a low-income country, characterized by high population density, low resource base and high incidence of natural disasters resulting in poverty and malnutrition (I-PRSP, 2003).

a. High population density

Population in Bangladesh almost doubled from less than 65 million in 1970 to about 129 million 2000. During 2001-2005 five-year period, population is estimated to have grown by more than 10%; and over the next twenty years, it is projected to grow further by 37% to about 194 million.

Poverty and population density cannot be considered independently in Bangladesh. Sustained population growth has pushed the population density from 440 to 961 persons per square kilometer between 1970 and 2005 (actually end-2004). Population density is projected to increase to 1,313 persons per sq. km by 2025.

Table C.1: Bangladesh at a glance, 2005

Land area	**147,570 sq. km**
Population	**142 million (est.)**
Population density	**961 persons/sq. km**
Population below poverty line	**40% (2004)**
Life expectancy	**64.9 years (2002)**
Literacy rate	**62.66% (2002)**
Labor force participation rate	**44.3 million (2003)**
Male	34.5 million
Female	9.8 million
GDP per capita	**US$ 445**
GDP	**Tk. 3684.76 billion**
Industry	17.08%
Agriculture	33.21%
Services	49.72 %
(Transport)	(8.28%)

***Source:** BCS, 2005*

b. Low resource base

Bangladesh is bestowed with fertile land and abundant water; and, few commercially viable mineral resources.

Table C.2: Population, 1970 - 2025

In millions

Year	Medium variant	High variant	Low variant	Constant-Fertility variant	TFR=2.1 By 2011	TFR=2.1 by 2016	TFR=2.1 by 2021
	Source: UN DESD				Source: BBS		
1970	64.907	64.907	64.907	64.907	64.907	64.907	64.907
1975	73.178	73.178	73.178	73.178	73.178	73.178	73.178
1980	82.185	82.185	82.185	82.185	82.185	82.185	82.185
1985	92.818	92.818	92.818	92.818	92.818	92.818	92.818
1990	104.047	104.047	104.047	104.047	104.047	104.047	104.047
1995	116.455	116.455	116.455	116.455	116.455	116.455	116.455
2000	128.916	128.916	128.916	128.916	128.916	128.916	128.916
2005est.	141.822	141.822	141.822	141.822	139.76	139.82	139.84
2010proj	154.960	156.492	153.432	156.726	149.69	150.52	151.48
2015proj	168.158	172.346	163.98	173.352	158.96	161.59	163.35
2020proj	181.18	188.907	173.459	191.304	169 54	172.16	174.97
2025proj	193.752	205.409	182.201	210.471	180.2	182.86	185.67

Source: *BBS Unpublished data; and World Population Prospects: The 2004 Revision; UN Department of Economic and Social Development (UNDESD); 24 February 2005*

Natural resources

Land area is limited to only 147,570 sq. km., of which is 58% is under cultivation, 23% not available for cultivation (includes urban, housing, industry and services) and the remaining 9% forest and mountainous. The land is highly fertile, but salinity and excessive use of fertilizer is reducing the soil nutrients. Construction of huge rural roads network over the past twenty years or so claimed a vast land area and also, necessitated resettlement of many people

Water is scarce during the lean season, but abundant enough to cause flooding during monsoon every year. The situation has been further compounded by the indiscriminate construction of rural roads without adequate discharge structures, which cause water logging. Water resources management in Bangladesh faces immense challenge for resolving many diverse problems and issues. The most critical of these are alternating flood and water scarcity during wet and lean seasons respectively, ever-expanding water needs of a growing economy and population, and massive river sedimentation and bank erosion.

Mineral resources

The mineral resource base includes gas, ngl & crude oil, coal and limestone; of which, only the proven reserve of gas is significant – currently estimated at about 35 TCF (BBS, 2001). The present annual consumption of gas is estimated at 10 BCF (EIU, 2005), of which power sector alone consumes 50%, fertilizer 25%, industry 14%, domestic (household) 10%, and commercial services only1%.

c. High incidence of natural disasters

Bangladesh is vulnerable to natural disasters, mainly, flood, cyclone & tidal surges, and drought which affects and sometimes devastates the country. Amongst these flood is a regular phenomenon.

Flood. Bangladesh is the most flood-prone country in the world. More than 80% of the country's land is floodplain. Normal flooding (monsoon) affects about 25% of the country's total land area every year, and serious floods can affect 90% or more of the country. The 1988 flood affected 92.5% of total land area. The flood affected the country's total transport system networks. For example, within the road transport sub-sector, 3,000 km of highway, 11,000 km of rural roads, 85 bridges on highway, 600 bridges & culverts on secondary roads, and 213 bridges on rural roads were damaged (RHD, 2004). The 2004 flash flood, which lasted about 40 days, inundated 34,583 sq. km in 42 districts. The flood caused extensive damage to transport infrastructure. About 1,000 km of national road network; and 2,350 km of roads and 1,560 meter of bridges & culverts in the rural areas were damaged. The damage was estimated at more than Tk. 3,000 million for the national roads network and about Tk. 3,100 million for the rural roads network (RHD, 2004).

Cyclone. Due to the geographic location of Bangladesh, severe cyclone and tidal surges are common in the 710 km long coastal belt areas. In April 1991, 4-8 meter tidal surges generated by tornado in the Bay of Bengal caused death of approximately 150,000 people and 70,000 animals, and damage to several thousand hectares of crops and property. The cyclone also caused serious damage to the transport infrastructure in the coastal areas of the country.

Drought. Mild to medium level droughts are common, particularly in the northern region of the country. In comparison with floods and especially cyclones, droughts are slow to manifest themselves but relatively more pervasive. The severe drought of 1979 affected more than 42% of the country's total land area and some 44 percent of the population. An investigation should be made to identify if any additional/special transport intervention would make any change in the conditions of vulnerability of the people in the drought affected region(s) of the country.

3. Institutional

Institutional issues concern lack of policy, planning and coordination between the ministries and agencies concerned; and also, their capacity to respond to the transport needs under the new PRS/IMTP regime. The ministries and the agencies under their administrative control give priority to new construction, which leads to deterioration of the existing (road) infrastructure beyond maintenance. In addition to non-maintenance, inadequately planned new (road) construction contributed to disadvantaging the other modes, water logging and deterioration of the environment. On the other hand, demand management and least-cost supply options, i.e. alternative mode(s) and multi-modal integration opportunities are not necessarily considered during planning for new construction. This can be largely explained by the absence of any effective policy, providing guidelines for the ministries and agencies to follow.

a. Policy

There has been no policy for a balanced and integrated development of the transport sector in the country. The Government has recently approved a National Land Transport Policy (NLTP), the first of its kind in the country. In addition, an Integrated Multi-modal Transport Policy (IMTP) is expected to be approved soon.

Roads

Too many roads have been constructed and the trend is continued. Instead of "building on past achievements", what is being experienced across the sector is "de-building the past achievements" due to lack of policy, planning, and strategy for programming scarce resources

1. New roads are being constructed while the existing roads are not adequately maintained causing deterioration to require re/construction.

2. Majority of the roads and bridges have been constructed with foreign aid. Foreign aid is also used for maintenance and rehabilitation & improvement. This is an acquired dependency syndrome, (already) risking the key PRS task "building on past achievements".
3. The rush to claim foreign aid led to construction of uncoordinated and unplanned roads to compromise the efficiency and equity conditions:
   - National and rural roads in particular constructed with inadequate water discharge facilities which has been identified as the key reason for water logging (re: prolonged flood);
   - National roads constructed with faulty intersection and turning design; and inadequate (or, no) traffic signs & signals, medians, bus/truck bays, parking, NMT segregation, pedestrian crossing, rumble strips, etc. - causing road traffic accidents;
   - Rural roads constructed with highly inadequate drainage structures which cause water logging up to 9 months a year in many places;
   - Rural road structures constructed with inadequate clearance which obstruct movement of country boats;
   - Rural roads constructed often with no connectivity with the IWT stations;
   - Village roads, mostly unpaved and often influenced by reasons other than efficiency and equity have been apparently abandoned by LGED, in expectation that these would be handed over to the Union Parishad (UP). These roads are not maintained and also given the flood factor, it is likely that many of these roads will disappear within next few years.
4. There have been too many slippages in past interventions for which neither the (economic) efficiency objective nor the (social) equity objective could be fully achieved. For example, highway constructed without parking, NMT segregation and pedestrian facilities.
5. There is no system in place for maintenance of the roads. Many have already deteriorated beyond maintenance. The backlog maintenance is accumulating to increasingly demand rehabilitation & improvement and re-construction. The cost of non-maintenance is significantly high. Bangladesh can ill afford it.
6. It is unlikely that foreign aid will be available for incremental maintenance of the expanding road networks. The Government should make arrangements for maintenance from revenue budget prior to committing new construction funded by the donor agencies. The proposed Road Maintenance Fund is a best practice example, demonstrated in many countries.

Railways

7. The comparative advantage of the rail transport has been defeated. Railway needs a complete rehabilitation & improvement of the tracks, reconstruction of the signals and structures, and replacement of the majority rolling stock - to regain competitiveness.
8. Selected Re/construction of railway stations and signals without rehabilitation of the tracks is a demonstration of inefficiency in programming scarce resources.
9. Corridor specific interventions for development of the rail transport never considered. For example, could a second rail track and/or the loop line provide a cheaper and faster mode of transport than a new road lane between Dhaka and Chittagong - has never been considered from an integrated multi-modal transport network perspective.
10. Railway clearly enjoys a comparative advantage in inter-city passenger transport and cargo/container handling. This has not been adequately addressed in the context of recent changes and emerging prospects.

Waterways

11. IWT, the traditionally least cost and most extensive network in the country has been marginalized to a subsistence sub-sector due to lack of bare minimum investment over the past years. If the present trend is continued, i.e., dredging not performed adequately - there would be no IWT except the coastal areas within next few years.
12. IWT port and workshop facilities and navigational aids need major improvement.
13. There is no policy or planning for sustaining the natural waterways in the country. The last condition survey was conducted in 1984!
14. Regeneration of IWT to the extent possible is desired for economic, social, environmental and strategic reasons. It can also become a major source of revenue income for the government.
15. IWT policy must be integrated with the flood control actions.

b. Planning

National roads

National roads have been built without adequate roadside services, e.g., bus bays, hard shoulders, NMT and pedestrian facilities. In addition to this, the entrance to the roads from the neighboring residential areas are not adequately designed. The "slippages" are being repeated in most new constructions. In some places, bus bays are created but occupying a portion of the highway crest, thereby inducing bottlenecks. Besides, it was observed that these services are not utilized and enforced properly. Buses do not use the bus bays, since these have been constructed without proper needs survey. The bus bays are also occupied by hawkers.

RHD operates two types of maintenance works, routine and periodic. Routine maintenance is benignly neglected. RHD actually performs periodic maintenance, which is designed to maintain the network from minor deterioration due to traffic. The Periodic Maintenance Programme (PMP) is prepared following an HDM-run analysis to identify and prioritize the network portions requiring maintenance. But there are anomalies found in different parts of this process. Because relatively short road sections (3 km) are analyzed, grouping the highest priority sections may not produce reasonable contract packages and the inclusion of other factors are not included in the analysis it has been common practice for the final list of projects to include sections of roads which had a much lower priority rating. In some instances, the preferred section was selected but the treatment indicated by the analysis was changed. This also results in a loss of benefits since the preferred treatment is selected to give the highest benefit ratio and any other treatment gives a smaller return. It may be appropriate to include a lower rated section to create a justifiable contract package with other high rated sections to a safer consistent standard over its entire length. Besides, allowing verbal undocumented instructions to be given to a contractor permits variations in the contract extent to be made locally. Thus contract works may be carried out on different sections of the same road or on completely different roads with no advice being given to other offices. Planning and implementation of the PMP is constrained by a number of factors including but not necessarily limited to the followings:

1. Poor or no design
2. Lack of documentation
3. Inadequate material and construction testing
4. Poor execution of work

RHD maintenance criteria does not include socio-economic indicators for prioritizing its maintenance schedules which leads to the fact that Zilla roads are not getting priority. The current practice is completely based on only economic analysis.

Road maintenance is constrained by lack of funding. For instance, in FY2005 maintenance program HDM analysis suggests that the average unconstrained maintenance budget should be approximately Tk. 14,000 Million. However, allocation for the year was Tk. 6,676 million out of which only Tk. 2,920 million, i.e. about 21% committed for actual maintenance works.

RHD's current estimated annual requirement for routine maintenance is Tk. 330 million, against which it receives about Tk. 110 million, i.e. only one-third of the requirement. The allocated amount is not also available in time. The demand for periodic maintenance could be significantly reduced had the routine maintenance been adequate. On the other hand, the demand for rehabilitation could be avoided had the periodic maintenance been adequate.

Ferries are maintained by RHD while contractors are operating most of these. The revenue generated by ferries is higher than the cost of maintenance. However, the ferries are not maintained. Also, the private contractors do not want to stop operations until it gets completely defunct, thereby elevating the maintenance cost for ferries.

Bridges & culverts (88) are identified as narrow bridges, majority of which are on regional and Zilla roads, and almost all are on a particular road. The Government currently rehabilitating 25 bridges with donor assistance to reduce bottlenecks in the network. There is no established schedule for repair and maintenance of these bridges and culverts.

Connectivity and coordination with other agencies is not adequately considered. There are examples that that development works are undertaken without considering the connectivity of the service, e.g. Chandpur-Shariyatpur ferry service. BIWTA completed 90% of the infrastructure development on their part; however, the 36 km road in Shariatpur yet remains to be completed by RHD. If constructed, much of the traffic to and from greater Barisal, Faridpur, Jessore and Khulna districts could be diverted to this road (releasing pressure on Aricha and Mawa), since it would shorten the distance between Mongla and Chittagong ports by 135 km.

Road safety is inadequately addressed. The key issues include, amongst others road alignment, intersection design, rumble strips (instead of humps), service lane, lane segregation, etc. Although it is not expected, but the planners can not ignore the fact that the national and regional highways are also used by pedestrian and NMT traffic. Though guidance is provided in the design manual for highways, RHD is yet to plan to segregate NMT from MT on the highways. The Nalka - Hatikamrul road is a good practice example. For safety, as well as efficiency reasons, RHD should consider re/constructing double-carriage highways.

Rural roads

A huge network of 249,830 km rural roads, including 36,166 km Upazilla roads; 42,329 km Union roads; 94,059 km Village road type-A and 77,276 km Village roads type-B has been built over the past years. However, more than 86% of these roads are earthen: 50% of Upazilla roads, 80% of Union roads, 91% of Village roads type-A and 99% of Village roads type-B. In other words, less than 14% of rural roads are paved including both bituminous and rigid; and, LGED's maintenance programme is limited to these paved roads only. The vast 86% of the rural roads are vulnerable to flooding and many have already become unworthy and/or near non-existence due to lack of maintenance.

Rural roads maintenance program is constrained by both lack of adequate funding and more importantly, the decision-making process through which priority needs identification is performed. LGED is currently formulating policy to hand over its village roads (68.5% of its network) to District/Union Parishad for maintenance.

In addition to non-maintenance and missing links, inadequate height and significant structural gaps still prevail in the rural roads network. Height should have been at least 1 meter above the ground level to insulate many road portions from being washed away by flood.

At present, the average structure length per kilometer of rural roads is as followings (RRMP, 2005):

1. 7.46 meter/km on Upazila road
2. 4.85 meter/km on Union road; and
3. 1.85 meter/km on Village road

compared to the minimum need as followings:

1. 10.56 meter/km on Upazila road
2. 7.80 meter/km on Union road; and
3. 4.06 meter/km on Village road

This inadequate drainage has contributed to prolong the period of flooding, which causes human sufferings and loss of income.

Indiscriminate construction of rural roads with inadequate water discharge facility contributed to water logging and on the other hand, low clearance created obstruction for navigation of country boats. In many cases, the rural roads also did not provide connectivity with IWT landing stations in the rural areas.

Local Government Engineering Department (LGED) has recently prepared an ambitious Rural Roads Master Plan (RRMP), 2006-2025. The Plan envisages an investment of Tk 1,722,110 million (excluding buildings). The RRMP makes reference to PRSP and also, targeted interventions for poverty reduction. However, the stated policy objective has not been adequately demonstrated in the design of the Plan. The Plan is not fully on the PRSP track. PRSP requires: (a) consolidating the past achievements, (b) fixing the slippages of past interventions (and, avoiding repetitions), and (c) addressing the implementation by freeing ADPs of under-funded projects.

Urban roads

It is estimated that one-third of the country's population, i.e. 46 million live in urban areas of which greater Dhaka alone accounts for more than 30%. The country's urban road networks length is not known. However, in Dhaka city, the roads network length is reportedly 3,000 km:

1. 60% is paved and yet, majority of the paved roads are narrow.
2. Less than 150 km, i.e. 5% of the roads network is considered as "arterial" - suitable for public bus transport service operations.
3. The arterial roads are provided with highly inadequate bus bays and parking facilities.
4. The road construction geometric design (and, standards) is faulty. For example, the recently improved geometric design on few arterial roads under DUTP significantly contributed to discipline traffic movements.
5. There is no city bus terminal.
6. Dhaka does not have any good public transport service. Currently, there are about 2,000 large and 3,500 mini buses, which operate city and sub-urban services respectively. Public bus transport service is highly in-disciplined.

7. More than half of the daily individual walk trips is performed on foot. However, pedestrian facilities are highly inadequate. For example, only 13% of the roads have footpaths. These are narrow, compared to demand and yet, not fully available for use by the pedestrians. For example, DCC established garbage collection bins and constructed foot over-bridges (rarely used by pedestrians) on many important footpaths. The worse sufferers are the elderly, women and children.
8. There are about half a million slow-moving non-motorized transport (NMT), namely, rickshaws. The slow-moving NMT is not segregated except few arterial road sections. NMT occupies about 70% of the road space.
9. Majority of accident casualties are the pedestrians and NMT passengers. Numerous humps - without any design or technical standard have been constructed on the roads, which has been identified as one of the key reasons for road accident.
10. Majority of the private transport is registered in Dhaka. For example, 74% of all private transport and taxis; 40% of all trucks; 37% of all auto 3-wheelers; and 17% of all buses are registered in Dhaka.
11. There is no duct, in-built with road construction to accommodate telephone and electricity cables, gas and water pipes and drainage. As a result, the utility agencies continuously dig roads for repair & maintenance or replacement. These agency activities are not coordinated. In addition to traffic congestion and immense sufferings by the people, this causes wastage of scarce resources.
12. The roads are not adequately maintained. Every year, DCC allocates limited funds for (annual) periodic maintenance of the secondary roads (other than the primary/arterial roads) by the Ward Commissioners. There is no quality control. Also, there is no established standard for maintenance of the roads.
13. Flood does not affect Dhaka city, unless it is of serious magnitude as it was in 1988 and 1994. However, due to low quality construction and maintenance, the roads are damaged by monsoon rain every year.

Railways

Although damaged during liberation war, Bangladesh inherited a relatively well-developed and functionally efficient rail transport system which connected 19 out of 21 the greater districts. The 2 districts in the south could not be provided with rail connectivity due to remoteness caused by many rivers. Railway was rehabilitated to restore service in the post liberation period. Further rehabilitation and maintenance has been limited to "rescuing" only. No significant investment has been made other than providing access to Jamuna Bridge. There was no provision for railway on the Jamuna Bridge in the original design. It was added in the last minute when the bridge was nearing completion.

Majority of the railway tracks has never been in the last 35 years (or, more) – allowing it to erode beyond regular maintenance. BR has identified urgent need for rehabilitation of more than 2,300 km, i.e.52% of the existing 4443 km route track network. Condition of most of the 3,545 railway bridges has deteriorated to a high-risk level. In order to avoid accidents, speed for crossing the bridges is limited on average to only 5 km/hr.

BR has 458 stations, 248 in the East and 210 in the West. Majority of these are age-old stations constructed before 1971. BR has initiated actions for rehabilitation/ improvement of few. However, it is worth mentioning that the recently reconstructed few stations, e.g., Sylhet station has not been maintained since reconstruction in 2002. The number of passenger carriages increased by 9% while locomotive and wagon numbers decreased by 43% and 37% respectively in the last 35 years. A large majority of this rolling stock has expired economic life. The number of passengers carried every year by BR almost halved in the last 35 years. However, during the period, passenger kilometers increased by 17.6%, i.e. only little more than 0.5 percentage points per annum. The only significant change in the railway passenger traffic has been the travel pattern. The average passenger kilometers increased from less than 46 km in 1970 to about 103 km in 2003, reflecting demand for intercity services, which carried 45% of all passenger traffic but contributed more than 76% of earnings in 2003.

BR lost freight ton volume by about 25% from about 49 million tons in 1970 to about 37 million tons in 2003. Freight ton kilometers also decreased by about 25%; but average freight ton kilometers remained static at 260 km over the same period. The most recent development in freight movement has been the addition of container traffic between Dhaka ICD and Chittagong. The constrained railway currently carries 11% of all containers originating/terminating at Chittagong port.

A significant portion of trade and transit is performed by railway. The effectiveness of Bangladesh Railway (BR), the only agency which is responsible for both infrastructure and services has been marginalized largely due to benign negligence of the government. Inadequate financing has resulted in deterioration of the tracks, signals, structures and rolling stock – beyond maintenance. All the infrastructure components now require rehabilitation, if not complete reconstruction while majority of rolling stock items, which expired economic life, require replacement - to improve the conditions for remaining in business.

BR has also demonstrated inadequacy in planning for targeted interventions. For example, rehabilitation of tracks should have received priority over reconstruction of stations and replacing the signals. BR clearly enjoys comparative advantages in transporting container & bulk cargo and inter-city passengers. Dhaka-Chittagong, Dhaka – Sylhet and Dhaka – Rajshahi, Rangpur and Dinajpur national transport sectors could be the priorities. A further potential corridor could be Dhaka - Faridpur, Jessore and Khulna if the bridge over Padma would be constructed.

In addition to the above, BR has to address the emerging new demand for carrying additional containers, coal from north Bengal (re: TATA and Asia Energy), and regional and international trade & transit services. Also, BR has to develop commuter rail services particularly linking Dhaka and Chittagong with the sub-urban areas and neighbouring townships. BR should learn lessons from Kolkata and Mumbai in India.

Private sector participation in BR has been insignificant. There are ways and means to encourage inter/national private sector not only in the operations & management but also in the provision of infrastructure and rolling stock supplies.

Waterways

The IWT suffered most due to continued over emphasis on roads. The advantaged waterways, crisscrossing the country has largely silted over the past years due to lack of dredging. In 1994, the length of navigable waterways was 8,400km during the monsoon and 5,200km during the dry season, which at present has declined to 5,968km and 3,568km respectively. Due to increased obstruction of surface water and ground water in low flow season, stream flow in tributaries and connecting rivers has also declined. Also, implementation of flood control, drainage and numerous road projects has contributed to reduced tidal volume. On the other hand, withdrawal of cross-boundary flows from upstream in India has further aggravated the situation. Siltation rate has increased and it has consequently reduced the navigability of waterways.

BIWTA dredging has been concentrated at strategic ferry locations, Aricha in particular – to actually serve the road transport; and yet, it has been inadequate. Aricha ferry channel requires capital dredging to maintain navigability round the year while there has been no maintenance since 1988 at Mawa, which is an alternative to Aricha for districts in the south-west region of the country. In addition to disruption of service due to siltation, ferry service distance between Mawa and Tarakandi has increased fourfold. BWDB also performs dredging, but it is not coordinated with dredging by BIWTA.

There has not been any condition survey of the waterways since 1984. BIWTA, with limited capacity responds to emergency dredging needs to keep the class-I routes navigable. However, siltation has accumulated over the past years to such an extent that navigation is disrupted at locations of class-I routes even during monsoon. A condition survey of the waterways should be conducted without any further delay. A dredging plan, integrated with the flood control is urgently required.

Inadequate infrastructure, lack of un/loading equipment and navigational aids are common features of IWT ports (11). Modern technology is absent in the infrastructure and super structure facilities in almost all the ports. None of the ports has been also provided with any proper modern cargo handling equipment. Only Dhaka and Narayangonj ports have one crane each outlived with 1-2 ton capacity. Ships wait for days for lack of berthing and cargo handling facilities and also, they do not always make overnight journeys in the night due to non-availability of navigation aids. BIWTA achieved some success in providing navigation aids over the past few years though not sufficient. On average about 18% of the navigational aids remain out of order. Due to inadequate navigation aids, night navigation is restricted for all kinds of vessels.

Against all odds, IWT's share in the passenger market increased from 8% in 1999 to 9% in 2003; although it carried 38% more tonne kilometers. In 2003, IWT accounted for 20% of the freight market, which is still significantly high considering limited investments in this sub-sector. Trade & transit services can become a major source of income, if navigability of the protocol routes, port & equipment facilities, and navigational aids are maintained. Also, the recently proposed reopening of Kolkata - Dhaka/Narayngang route should be actively considered.

More than half the country's land area and three quarters of commercial activities are within 10 km to navigable waterways in all seasons. The role of IWT in the national economy, particularly in terms of transportation and employment is highly significant. In FY 1991, 16% of all passengers and 35% of all goods were transported by IWT. The relative modal share of IWT has decreased over the past years largely due to development of road transport network; however, both passenger and cargo volumes carried by IWT is likely to increase in absolute terms in the coming years largely because of GDP growth and mechanization of the country boats. IWT currently employs more than 3 million people, mostly unskilled laborers. Growth of the sub-sector has been constrained by sheer negligence; and also, shrinking of waterways due to both siltation and reduction in the amount of water available during the dry season.

IWT accidents typically claim more lives than road accidents. Construction design fault and over-crowding have been identified as the two key reasons.

Dredging, navigational aids, ports (19), and landing stations on four (4) trunk routes (683 km) and seven (7) transit/link routes (1,000 km) - if improved, maintained, and connected with road/rail as applicable can become a least-cost response to new demand. For example, IWT is comparatively advantaged to carry a huge quantity of container and bulk cargo to and from Chittagong port. Investment required is much less than adding new lanes to the existing Dhaka-Chittagong highway. Maintenance of IWT is less. Also, it does not require any land acquisition and resettlement.

c. *Coordination*

There are as many as eleven ministries, which are in/directly involved in the transport sector. The situation has been further complicated in absence of any policy to provide guidance and require coordination between the ministries and agencies concerned. On the other hand, the ministries responsible for planning and finance do not necessarily follow any policy to programming resources for targeted interventions – which have had been mostly decided on ad-hoc basis. The lack of coordination, reflected by lack of policy guidance and fragmentation of responsibilities contributed to compromise the conditions of efficiency and equity toward achieving targeted interventions. Lack of coordination is also demonstrated by the fact that resources for re/construction is provided by the Planning commission; but, for maintenance, it is provided by the ministry on concerned.

National

1. Ministry of Planning - proposes projects for approval by ECNEC
   (Planning Commission)
2. Ministry of Finance - allocates resources to projects approved by ECNEC

Sector

3. Ministry of Communication (MOC) – forwards project proposals to Planning Commission;
   (RHD, BR, BRTA and BRTC)
4. Ministry of Local Government, Rural Development & Cooperatives - forwards project proposals to Planning Commission
   (LGED, city corporations and municipalities)
5. Ministry of Shipping (MOS) - forwards project proposals to Planning Commission;
   (Department of Shipping, BIWTA and BIWTC)
6. Ministry of Works (MOW) - forwards project proposals to Planning Commission;
   (City Development Authorities)
7. Ministry of Civil Aviation and Tourism (MOCA) - forwards project proposals to Planning Commission
   (Biman, Bangladesh Airlines; and Civil Aviation Authority of Bangladesh, CAAB)

In addition to the above, there are other ministries which affect functioning of the transport sector in the country:

8. Ministry of Home Affairs (MOH)
   Department of Police (Traffic) – Enforcement of traffic rules & regulations
9. Ministry of Water Resources (MWR);
   Bangladesh Water Development Board (BWDB) - dredging
   Water and Sewerage Authority (WASA) – road digging
10. Ministry of T&T;
    Bangladesh Telephone and Telegraph Board (BTTB) – road digging
11. Ministry of Energy and Mineral Resources (MEMR)
    Gas distribution companies – road digging
    Bangladesh Power Development Board – road digging
    Rural Electrification Board (REB) – road digging

There is no established policy and/or mechanism, which require effective coordination between the ministries and agencies concerned.

Ministry of Home plays a strategic role, by enforcing traffic rules and regulations that is essential for efficiency in functioning of the road sub-sector. The three ministries, namely, Water, T&T and Energy actually impact negatively on functional efficiency and maintenance of the roads, in urban areas in particular. The government would save millions every year, only if such diggings could be coordinated. This problem can be also completely eliminated by providing simple infrastructure facility, e.g. duck system.

d. Capacity

The key issue is how to change/improve performance efficiency of the ministries and agencies concerned to translate transport outcomes into poverty outcomes. This is conceptually new to the policy makers, as well as the planners. The ministries and agencies concerned require to bring-in a qualitative change in their respective policy and planning approaches by institutionalizing a system based on efficiency and equity principles toward achieving an integrated multi-modal transport, which is socially, economically, technologically and environmentally sustainable.

Planning Commission. in the Ministry of Planning should play its due role in providing guidance and requiring compliance with PRS/IMTP by the development ministries and agencies in the preparation and implementation of plans, programmes and projects. They must exercise their role in planning & coordination at the national level and also, processing the projects submitted by the development ministries. The recently established Transport Sector Coordination (TSC) Wing is in a unique position to perform this responsibility. However, it should be further strengthened, also as the secretariat of the Cabinet Committee (re: IMTP) to perform effectively.

Roads and Highways Department (RHD), under the administrative control of the Ministry of Communications has initiated the preparations for formulation of a national Roads Master Plan, with technical assistance (TA) support from the Asian Development Bank (ADB). RHD should be required to follow the Guidelines (and, the strategic planning framework to be provided in the next report) in order to ensure that the plan is prepared within the broader framework of PRS/IMTP. RHD's capacity should be also strengthened for identification of priorities in coordination with LGED, BR and BIWTC; maintenance; and monitoring & evaluation - for providing feedback to improvements.

Dhaka Transport Coordination Board (DTCB), under the administrative control of the Ministry of Communications was established in 1997, (actually) to qualify for a US$ 177 million IDA loan for Dhaka Urban Transport Project (DUTP). Given that it is a technical organization and the required skills are not available in the Government, the legislated DTCB Bill made provision for recruitment of professional staff from outside the Government. However, the Government fielded staff on secondment – defeating the purpose of DTCB. It should be reformed into a Metropolitan Transport Authority (MTA) as required by IMTP, and strengthened by recruiting professional staff including the Executive Director and empowered to facilitate coordination between the agencies concerned. MTA should be also established in Chittagong, Khulna and Rajshahi.

Local Government Engineering Department (LGED), under the administrative control of the Local Government Division of the Ministry of LGRD & Cooperatives has recently prepared a Rural Roads Master Plan for the next twenty years. It is ambitious and also, poorly rationalizes the activities (and, allocations) proposed under maintenance, rehabilitation & improvement and development. The Plan should be redone, following the PRS tasks, namely, consolidating the past achievements, avoiding slippages (re: past mistakes/oversights and not repeating the same), and addressing implementation (re: efficiency and equity). LGED should be required to follow the Guidelines and coordinate with BIWTA and BIWTC.

Union Parishad (UP), under administrative control of the Local Government Division of the Ministry of LGRD & Cooperatives is responsible for local governance including rural development. However, the UP is constrained by lack of capacity and resources. LGED's handing over the responsibility of village roads to the UP would expedite degeneration of the extensive network constructed over the past years. The mostly unpaved village roads, both type A and B are extremely vulnerable to flood and non-maintenance. The Government should immediately consider strengthening the UP in terms of both capacity and resources, prior to handing over the responsibility for maintenance and rehabilitation & improvement.

City corporations, under the administrative control of the Local Government Division of the Ministry of LGRD & Cooperatives are responsible for construction and maintenance of roads including those constructed by the city development authorities. This is a major task; however, none but Dhaka City Corporation (DCC) only has a transport/traffic engineering department. A small Traffic Engineering Department (TED) was established by DCC in 1997 to (actually) qualify for the IDA loan components of DUTP. The TED is not functioning toward achieving the objectives for which it was established.

Municipalities, also under the administrative control of the Ministry of Local Government Rural Development & Cooperatives do not have any transport/traffic engineering department or unit.

Bangladesh Railways (BR), under the Ministry of Communications is the exclusive owner of the infrastructure & rolling stock and also, the lone service provider. BR is currently surviving on in/direct subsidy, selling and leasing out properties. On the other hand, in addition to lack of skills, BR virtually does not have any administrative or financial authority – constraining its operations management. BR is currently implementing the third phase of its reorganization at a cost of Tk. 50 million within the overall framework of Railway Recovery Programme (RRP). The major successes achieved to date include downsizing the staff and limited private sector participation. Last five to ten years' data analyses suggest that BR is most unlikely to achieve the targets required for its regaining competitiveness. On the contrary, it is likely to shrink in terms of its share in the transport sector.

The World Bank and ADB committed a US$ 500 million loan to regenerate rail transport, subject to BR's corporatization. BR should reconsider reform more from a competitive, i.e. sustainability perspective rather than trying to qualify for the loan.

Bangladesh Inland Water Transport Authority (BIWTA), under the administrative control of the Ministry of Shipping is responsible for maintaining navigability of the waterways. The task is inadequately performed due to lack of capacity and resources. There is no plan for dredging and also, there has been no survey of the waterways since many years. BIWTA currently maintains 11 inland ports, none of which has adequate berthing, storage and equipment facility. Total amount they expend for maintenance of the ports, coastal and landing stations is negligible - less than 5% of the agency's income. On the other hand, navigational aids on the waterway routes is inadequate and poor.

4. Other strategic

There are a number of other strategic issues and concerns, namely, safety, urbanization, trade & transport services and private sector participation which the policy-makers and planners cannot ignore for future development of the transport sector.

a. Safety

Road accident fatality rate in Bangladesh is considered to be the highest in the world. Given the number (and, growth rate) of motorized vehicles in the country, there is no rationale why the number of people who died in road traffic accidents on the spot should increase by about 150% from 1,653 in 1995 to 4,046 in 2000. The actual number of deaths is even higher, since there is no systematic follow-up to report the number of grievously injured people who succumbed to death at a later stage. According to the Bangladesh Labor Research Institute, 452 deaths and about 1,583 injuries were recorded in the traffic month observed in October, 2005. Traffic rules & regulations are enforced during traffic month observed every year. Accidental deaths numbering 452 during this month suggest that actual deaths in other months must be higher. Taking this into account, the current number of deaths in road accidents is estimated at more than 10,000 per year. Road accidents currently cost the nation an estimated Tk. 24,000 million per year.

Road accidents affect the rural poor more than any other social group. About 60 % accidents occur on National and Regional Highways and 40% on city roads. Accident on national highways is more severe –about 73% fatal and city roads 42% accidents are fatal. A recent accident analysis shows that out of the total no. of victims, about 53% are pedestrians, a large majority of which are children of age less than 10. Also, one-third of the victims are adult males of age between 21-40 years.

The identified major causes of road traffic accidents are as follows:

1. Driving with fake license, without license, short time training or without training,
2. Exceeding the safe and legal speed limit,
3. Dangerous overtaking tendency,
4. Overloading violating the laws and unauthorized carrying the passenger with the trucks and carrying passenger on the roof of the bus,
5. Careless movement by the pedestrian,
6. Driving with the expired and faulty vehicles,
7. Lack of awareness and knowledge about the safer road,
8. Lack of enforcement of traffic regulations & regulations,
9. Lack of pedestrian facilities,
10. Non-segregation of MT and NMT,
11. Inadequate infrastructure (and, design), and
12. Road infrastructure surface without proper maintenance.

Over the past twenty years or so, the relevant government agencies and some NGOs with support from various donor agencies implemented numerous activities, including conferences, seminars, workshops, awareness campaigns and community activities to reduce the incidence of road traffic accidents. However, these activities were never coordinated, nor followed-up for continuation at the national level. The Government established the National Road Safety Council (NRSC) and also, the secretariat Road Safety Cell (RSC) at BRTA, Ministry of Communications. RSC prepared three consecutive strategic plans for implementation of various actions. However, results achieved on the ground has been frustrating.

RHD allocates 30% of its maintenance budget to Road Safety Division to ensure highway safety. It is not known how much was actually expended, and if it made any impact on road safety. However, it is worth noting that the recently re/constructed highways, e,g, Nalka – Hati kamrul, Dhaka – Sylhet and Dhaka-Chittagong highways have included some (physical) road safety measures which are not necessarily fully adequate or efficient.

Railway accidents are frequent but rarely fatal. This can be largely explained by low speed due to poor track and signal conditions. However, accidents occur at level crossings since many are located at densely populated settlement areas and also given that many slums and markets have been illegally developed along the rail tracks.

IWT accidents are few but fatal. Most of the private sector passenger vessels (7,000), many unregistered have been constructed with faulty design. Also they carry far more no. of passengers than the capacity. These vessels are extremely vulnerable to overloading and bad weather conditions. A typical accident claims more than 100 deaths. Majority of the fatal accidents occur during Eid holidays and April-May period when storms are frequent. The situation has recently improved. There has not been any major accident in the last two years or so, since the law enforcing authorities (physically) did not allow sailing in bad weather conditions and overloading during Eid holidays.

b. Urbanization

Although relatively small, the importance of urban road networks and its connectivity with the national and rural roads, as well as rail and IWT cannot be ignored for greater national economic and strategic reasons. Currently a quarter of the population live in urban areas. By 2025, between 36 (medium variant) and more than 40% (high variant) of the population will be living in urban areas. This transformation might bring prosperity or decline, depending largely on the degree to which the two mega cities, Dhaka and Chittagong; the existing metropolitan areas of Rajshahi and Khulna; and the strategically located secondary towns manage the sprawl and integrate with the national transport network systems.

Table C.3: Motorized vehicles, 1996-2004

No.	Type of vehicle	1996		2000		2004	
		Bangladesh	Dhaka	Bangladesh	Dhaka	Bangladesh	Dhaka
1	Motor Car	72504	52307 (72.14%)	95807	70601 (73.69%)	121606	92600 (76.15%)
2	Jeep/St.Wagon/Microbus	32319	20880 (64.61%)	40269	26091 (64.79%)	51878	34505 (66.51%)
3	Taxi	1995	847 (42.46%)	2908	1526 (52.48%)	11472	9892 (86.23%)
4	Bus	27873	487 (1.75%)	28862	1155 (4.00%)	31474	3393 (10.78%)
5	Minibus	25887	2500 (9.66%)	28238	3654 (12.94%)	33986	7828 (23.03%)
6	Truck	34870	11192 (32.10%)	43628	16197 (37.13%)	53958	21779 (40.36%)
7	Auto-rick./Tempo	62523	20275 (32.43%)	78747	26429 (33.56%)	107453	39460 (36.72%)
8	Human Hauler	0	0.00%	0	0.00%	1252	809 (64.62%)
9	Covered Van	0	0.00%	0	0.00%	581	527 (90.71%)
10	Motor-Cycle	189065	69932 (36.99%)	246795	94368 (38.24%)	346288	127171 (36.72%)
11	Others	8698	3769 (43.33%)	15511	6420 (41.39%)	26654	13814 (51.83%)

Source: *BRTA, 2005*

Urbanization has never been planned or managed; and so, the urban road networks. The urban sprawl is best demonstrated by the growth and development of Dhaka city. In 2001, as many as many 8.4 million people lived in Dhaka city corporation (DCC) area of 360 sq. km. Population density in Dhaka in 2001 was 23,333 per sq. km. which is estimated to have increased by 5%/year (compared to urban population growth of 3.8%/year) to more than 28,000/sq.km (compared to national population density of 985/sq. km) in 2005.

In Bangladesh, the number of private transport increased by more than 65% from 104,823 in 1996 to 173,484 in 2004. During the last eight-year period, the number of private transport increased by 68,661 nos. of which 53,922 nos., i.e. about 79% were registered in Dhaka alone.

The urban sprawl is unlikely to decelerate in the coming years. River erosion, landlessness and shrinking job opportunities in the agriculture sector, and continued under emphasis on secondary towns will encourage migration to Dhaka and Chittagong where most economic activities are located. The test of an urban transport policy in the face of such challenges and opportunities will be how well it responds to the needs by a combination of demand management and least-cost supply options.

c. ***Trade and transport services***

Roads

There are currently thirteen (13) established land ports under the recently established Bangladesh Land Ports Authority (Bangladesh Sthala Bandar Kartipaksha/BSBK). All the ports have been leased out to the private sector on build own and operate (BOT) basis, but Benapole which is the single largest land port in the country. It is directly operated by BSBK. Benapole and Taknaf land ports have been provided with infrastructure and superstructure facilities. In addition to road infrastructure, all the remaining ports lack adequate un/loading facilities, warehouse, testing and banking facilities.

Two land ports, namely, Tamabil in Sylhet and Teknaf in Cox's Bazar are of critical importance. Majority of the trade performed through Tamabil is with the NE/W India while Teknaf is the only land port through which trade with Mynmar is performed.

The proposed transit route between East India and North-east India through Bangladesh will reduce transport distance by more than 60 per cent in comparison to the current route around Bangladesh through Shiliguri in India.

Road is the dominant transport mode in the inland distribution network with a market share of about 70% of freight tonnage movements. However, apart from localized operation in Chittagong and Dhaka, the distribution of containers by road is currently very low. On the other hand, there is hardly any facility for container handling, other than the EPZs. In FY2004, Chittagong EPZ alone handled 10% of the total container traffic at Chittagong while the EPZ in Dhaka handled 28% of the total at the ICD.

The road network in the country is not designed to meet the needs of modern freight transport systems. The roads are unsuitable for movement of heavy goods vehicles (HGVs) with containers due to flow capacity, road width and axle load constraints.

Railways

Currently export and import is performed through three (3) ports, namely, Benapole, Darshana and Rohanpur. More than 600 wagons enter/exit Bangladesh everyday. The volume is likely to increase after reopening Birol, the fourth port.

There are currently twelve inland container depots (ICDs) in the country, one in Dhaka operated by BR in coordination with the Chittagong Port Authority, and 11 recently established private sector ICDs in Chittagong. However, the private sector ICDs can not be considered as fully functional; since, under the present regulations they are permitted only to stuff export and store empty containers. They are not allowed to handle import containers. During the recently concluded SAARC summit in Dhaka, India requested for transit and transshipment by rail through Bangladesh.

Waterways

Under the name of title "Protocol On Inland Water Transit and Trade" India uses five (5) in-transit inland waterways to transport cargo to and from its North-Eastern region. A portion of trade between the two countries also follows the same waterways.

Table C.4: Waterway Transit and Trade Routes, 2005

No	Route description	Length (km)
	Established Route	
1.	Kolkata - Dhubri	1055.8
2.	Dhubri - Kolkata	1055.8
3.	Kolkata - Karimganj	1086
4.	Karimganj - Kolkata	1086
5.	Dhubri - Karimgonj	832.3
	Proposed Routes	
6.	Rajshahi - Dhulian	>100km
7.	Kolkata - Dhaka and Narayanganj	

***Source:** BIWTA and Kolkata Port Authority (KPA)*

None of the routes is provided infrastructure that could be considered fast and reliable, though some of them are functionally more efficient than others. International markets are increasingly demanding tighter and more reliable deliveries. Improved infrastructure and service facilities are essential to become competitive.

The growth of inter country trade will not increase much due to decrease of draft and navigability while in-transit of cargo is unlikely to grow also due to distance and time constraints. India has proposed a new route via Rajshahi (or, Dhulian in West Bengal), one of the 8 routes originally agreed in the Protocol. This proposed route needs major dredging to keep it navigable round the year. It will significantly reduce the distance and travel time. It has the potential to increase the in-transit cargo volume by 1000 MT/day. More recently, Kolkata Port Authority has expressed interest to reopen the Kolkata - Dhaka - Narayanganj route.

d. Private sector participation

The private sector emerged dramatically as the single largest provider of road and IWT in the country. Prior to independence in 1971, the road transport service operations used to be dominated by BRTC and inland water transport by BIWTC. Over the past years, the private sector – with little support from the Government gradually made its way to fill-up the service supply gaps, increasingly unmet by BRTC and BIWTC. However, in absence of any transparent and accountable system in place, performance of the private sector has been in-disciplined and of low quality. On the other hand, Bangladesh Railways (BR) – the only agency which owns the infrastructure (and, rolling stock) and also operates services recently allowed limited private sector participation. However, due to various constraints, the private sector is unlikely to grow, if not cease functioning.

The benefits obtainable from competitive private sector provision in transport infrastructure are well established. The Government has recently approved the Guidelines; however, it is not happening yet. This is either because it is positively resisted by the government, or because the conditions under which entry is possible are not attractive to the private sector:

1. Government resistance appears when it is believed that either:
   - strategic issues are at stake (ownership of basic infrastructure or basic movement capacity);

- ownership is necessary to control social impacts (un-remunerative service for social or distributional reasons); or
- private monopoly would exploit users.

2. Private sector finds entry unattractive:
   - where there is no apparent revenue flow (un-tolled roads);
   - where there is perceived to be a high probability of damaging government interference (social services); or
   - where sunk capital will not be recoverable.

The incidence of the above impediments to private sector participation varies substantially by sub-mode. For example, it is inherently very difficult to attract private participation in rural road finance, but relatively straightforward for much rail and port infrastructure.

However, when operations are taken into consideration there appears to be a very large proportion of transport supply, which is suitable for private sector involvement under competitive market conditions. The key challenge here is to devise an arrangement, which effectively reconcile the commercial objective of the private sector with the non-commercial objectives of the government.