Development of a Mode Choice Model Considering Heterogeneous Traffic of Dhaka City

by

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It is hereby declared that the thesis contains no material previously published or written by another person except where due reference is made. No part of it has been submitted elsewhere for the award of any degree or diploma.

August, 2010 **Dibakar Saha**

DEDICATION

To My Parents

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ABSTRACT

Mode choice analysis is one of the most important and challenging components of the conventional four step travel demand modeling process. However, analysis of mode choice behavior seems to have been considered as a neglected component of the planning of cities in the developing world. Although several transport related studies have been conducted for Dhaka city, none has achieved the desired success in the planning of the transportation system; which is clearly reflected by the inadequately planned and developed transportation system of the city.

The presence of motorized and non-motorized vehicles in the same right of way, slow moving and fast moving vehicles in non-lane based road network makes the transportation system of Dhaka city heterogeneous in nature. Moreover, recently the Government of Bangladesh has taken initiatives to introduce metro, or bus rapid transit, or elevated express way which requires huge investment and infrastructure development. Therefore, a proper understanding of the factors acting behind the choice of travel mode of individuals is imperative for the decision-makers. In this regard, the study has two major objectives: the identification of the factors that influence mode choice behavior of the city dwellers and the formulation of a representative mode choice model.

The study area covers Dhaka City Corporation (DCC) and its surrounding areas comprising of 168 sq km. This area is divided into 94 Traffic Analysis Zones (TAZs) and the road network is comprised of 534.72 km with 1,068 nodes and 1,565, links. The data set used for this study is extracted from the Household Interview Survey (HIS) carried out for Strategic Transport Plan (STP) in 2004. The mode choice model is estimated using JICA STRADA 3.0 software package developed as a tool for the technical assistance program of JICA in the transport sector for developing countries.

Personal attributes such as sex, age, household size and income, etc. and travel attributes such as mode selection, trip purpose, zone type, etc. of 4,825 relevant household records representing 19,792 people making 40,138 trips are analyzed to reveal the mode choice behavior in the study area. Rickshaw is found to dominate with 36% share followed by public bus with 32% share for all trips. Major portion of Home Based Education (HBE)

and Home Based Other (HBO) trips share rickshaw; while major portion of Home Based Work (HBW) and Non Home Based (NHB) trips share public bus. Multinomial logistic regression using SPSS 17.0 is performed to analytically determine the effects of the attributes or factors on choice of travel mode. Household income is found to be the most important factor in determining choice of travel mode; gender being the next significant factor.

Disaggregate approach using 32,422 individual level inter zonal trips are used to develop the mode choice model. With consideration of random utility maximization principle, multinomial logit (MNL) model is estimated for HBW, HBE, HBO and NHB trips. Alternative specific constant for each mode with variables travel time and travel cost/income are found statistically significant for HBW and HBO trips. For HBE trips, alternative specific constant for each mode with variables travel time, travel cost/Ln(income) and income specific to alternative modes are found statistically significant. For NHB trips, alternative specific constant for each mode with variables travel time, travel cost/ income and income specific to alternative modes are found statistically significant. A market segmentation test on gender is executed and found significant for HBW, HBE and HBO trips. In order to overcome the restrictive independence from irrelevance property of MNL model, nested logit (NL) approach is tested with different tree structures. Nested structure consisting Private transport (with walk, private bus, motor cycle, car/jeep in the first level), Para transit (with rickshaw, taxi, CNG in the first level), Public transit (with public bus only in the first level) in the second level is more explicable over MNL model in determining utility of modes for HBW, HBE and HBO trips. However, the NL model is not significant for NHB trips.

Finally, an additional analysis for model estimation with BIOGEME is carried out to check the reasonableness of the model output in JICA STRADA.

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LIST OF ACRONYMS

BBS	Bangladesh Bureau of Statistics
BRT	Bus Rapid Transit
BRTA	Bangladesh Road Transport Authority
BUET	Bangladesh University of Engineering and Technology
CNG	Compressed Natural Gas (here CNG Auto-rickshaw too)
DCC	Dhaka City Corporation
DHUTS	Dhaka Urban Transport Network Development Study
DIT	Dhaka Improvement Trust
DITS	Greater Dhaka Metropolitan Area Integrated Transport Study
DMA	Dhaka Metropolitan Area
DMAIUDP	Dhaka Metropolitan Area Integrated Urban Development Plan
DMDP	Dhaka Metropolitan Development Plan
DSMA	Dhaka Statistical Metropolitan Area
DTCB	Dhaka Transport Coordination Board
DUTP	Dhaka Urban Transport Project
EPTRI	Environment Protection Training and Research Institute
GDP	Gross Domestic Product
GOB	Government of Bangladesh
HBE	Home Based Education
HBO	Home Based Other
HBW	Home Based Work
HH	Household
HIG	Household Income Group
HIS	Household Interview Survey
IIA	Independence from Irrelevance Alternatives
JICA	Japan International Cooperation Agency
LIG	Low Income Group
MIG	Middle Income Group
MNL	Multinomial Logit
MNLR	Multinomial Logistic Regression Analysis
MNP	Multinomial Probit

MV/MT	Motorized Vehicle/ Motorized Traffic
NHB	Non Home Based
NHBB	Non Home Based Business
NL	Nested Logit
NMV/NMT	Non-motorized vehicle/ Non-motorized Traffic
NNNL	Non-normalized Nested Logit
RAJUK	Rajdhani Unnayan Kartipakkha
RP	Revealed Preference
RUM	Random Utility Model
SP	Stated Preference
STP	Strategic Transport Plan
STRADA	System for Traffic Demand Analysis
TAZ	Traffic Analysis Zone
TRB	Transportation Research Board
UMNL	Utility Maximization Nested Logit
UN	United Nations
UNDP	United Nations Development Programme
UTP	Urban Transport Planning
WB	World Bank

CHAPTER 1

INTRODUCTION

1.1 General

Urbanization has been one of the dominant contemporary processes as a growing share of the global population lives in cities. Considering this trend, urban transportation issues are of foremost importance to support the passengers and freight mobility requirements of large urban agglomerations. Transportation in urban areas is highly complex because of the modes involved, the multitude of origins and destinations, and the amount and variety of traffic. Moreover, rapid and expanded urbanization occurring around the world involves an increased numbers of trips in urban areas. Traditionally, the focus of urban transportation has been on passengers as cities were viewed as locations of utmost human interactions with intricate traffic patterns linked to commuting, commercial transactions and leisure/cultural activities. Conceptually, the urban transport system is intricately linked with urban form and spatial structure (Rodrigue et al., 2009).

Historically, cities have always been the engines of economic development and the centers of industry and commerce (Brockerhoff, 2000). According to Rodrigue et al. (2009), cities are locations having a high level of accumulation and concentration of economic activities and are complex spatial structures that are supported by transport systems. However, transport is one of the most important, but also hardest-to-solve, problems of modern-day cities. Nevertheless, an efficient and effective urban transportation system is a means to both promoting urban development and providing adequate access and mobility to the urban dwellers (Kwakye et al., 1997). Urban transportation planning can therefore be considered as an important activity to promote mobility (Hasan, 2007) and national growth process.

A key element of transportation planning is the evaluation of alternative operating and capital investment strategies. This process requires estimates of current and forecasts of future travel on the surface transportation system, including highway, transit, non-motorized, and freight modes. These travel forecasts are generally accomplished through computerized network simulations of the transportation system, known as travel demand forecasting models. Travel forecasting models are used to study proposed investments in the transportation system and to determine which of those investments will best serve the public's needs for future travel and economic development. The models are also used to evaluate the travel impacts of alternative land use scenarios (TRB, 2007). In this way, travel modeling or forecasting is an important task to identify needs for the improvement of the city's infrastructure (Chen, 2007). Mode choice analysis is one of the most important and challenging components of the conventional four step travel demand modeling process.

Many practical transportation policy issues are concerned with mode choice. For example, the gain or loss in transit revenues caused by a fare increase depends on how travelers' mode choices are affected by the increase. Similarly, the effects of changes in transit routes and schedules on ridership, revenues, and traffic congestion all depend on how the changes affect individual travelers' mode choices. An understanding of the separate and combined effects of these decisions on travel mode choice is essential to selection of the best plan to meet specific transportation objectives (Horowitz et al., 1986).

The issue of mode choice, therefore, is probably the single most important element in transport planning and policy making. It affects the general efficiency with which we can travel in urban areas, the amount of urban space devoted to transport functions, and whether a range of choices is available to travelers. It is important then to develop and use models which are sensitive to those attributes of travel that influence individual choices of mode (Ortúzar & Williumsen, 2001).

1.2 Problem Definition and Research Motivation

Dhaka is one of the rapidly growing mega cities in the world but it experiences a serious lack of transport facilities for its dwellers. Dhaka's transport system is predominately road based. Traffic system in Dhaka is known as heterogeneous traffic system due to wide variation in the operating and performance characteristics of motorized, non-motorized, slow-moving or fast-moving etc. vehicles sharing the same road space (Karim et al., 1998).

Although several transport related studies have been conducted for Dhaka city, none has achieved the desired success. The single common reason behind this may be due to the misrepresentation or failure to embody the behavior of the city's traffic pattern as well as its users. Dhaka Master Plan (1959) by the erstwhile Dhaka Improvement Trust (DIT) is the first study concerning transport development followed by Dhaka Metropolitan Area Integrated Urban Development Plan (DMAIUDP) in 1979, Greater Dhaka Metropolitan Area Integrated Transport Study (DITS) in 1994; Dhaka Urban Transport Project (DUTP) in 1997; Dhaka Metropolitan Development Plan (DMDP) in 1995 by RAJUK. As a part of DUTP, a Strategic Transport Plan was prepared for the Dhaka Metropolitan Area (DMA) that establishes a multi-modal transport plan based upon an assessment of the inter-relationship between land use and transportation (STP, 2005). At present, a project titled, "Dhaka Urban Transport Network Development Study" (DHUTS) undertaken by Dhaka Transport Coordination Board (DTCB) with technical cooperation from Japan International Cooperation Agency (JICA) has been going on with the major objective of formulating the basic concept of urban development plan in DMA (JICA, 2009).

In STP, an urban transport planning model (UTP model) has been developed and used to forecast future travel demand resulting from different future land use scenarios and transport improvement strategies and to predict the performance of the existing, committed and alternative development strategies for Dhaka's urban transport network infrastructure, services and policies. In the UTP model, only two modes - transit and motorized (non-transit) - have been taken into consideration ignoring the significant portion of trips made by non-motorized mode. Also, presence of wide difference in the socio-economic level of the people in the model produces absurd results, for example, probability of choosing auto by Lower Income Group (LIG) is 90%.

Several other individual researches have been done on different aspects of Dhaka's transport. Among those, Ahsan (1990) investigated the status of public transport systems in Metropolitan Dhaka. Alam (1992) developed a traffic assignment model for simulation and optimization of road network for Dhaka city. Habib (2002) developed a transport-planning model through which he evaluated the planning options to alleviate traffic congestion and resulting air pollution in Dhaka city. Hasan (2007) developed a travel demand model for Dhaka city segregating pre-distribution walk and intra zonal trips and personal motorized trips with post-distribution transit, rickshaw and auto-rickshaw trips.

Both Habib and Hasan used only the mulinomial logit (MNL) model for mode chocie; neither hierarchical logit model had been examined to analyze choice behavior nor was the influence of exogenous variables on mode choice behavior demonstrated in the model.

With rapidly expanding urban growth and hence increasing travel demand of Dhaka city, extensive investments are expected for the development of urban transport infrastructures in future years. This can be manifested from STP study which recommended the introduction of Metro, Bus Rapid Transit (BRT), Elevated Express Way etc. which requires huge investment and infrastructure development. Therefore, a proper understanding of choice of travel mode of individuals whether and by how much they shift to the new modes is imperative for the decision-makers.

In the pursuit of developing a comprehensive mode choice model with appropriate approach based on locally dominating factors that were mostly deficient in the above studies by the foreign consultants, this study intends to show the effects of the exogenous variables, e.g. age, sex, income on choice of travel mode with the data available through the Household Interview Survey (HIS) conducted in the STP study (2005). The proposed model will be a disaggregate model, that is, the model works on individual level to replicate its choice behavior in trip making and mode selection. The disaggregate approach is better able to reflect changes in choice behavior due to changes in individual characteristics and attributes of alternatives. Additionally, the approach is more suited for proactive policy analysis since it is causal, less tied to the estimation data and more likely to include a range of relevant policy variables (Koppelman and Bhat, 2006).

The mode choice model for different trip purposes will be estimated using JICA STRADA (System for TRAffic Demand Analysis) 3.0 software. The STRADA is developed by Intel-Tech Institute Inc., Japan as a tool for transport planning and to build up common database thereof, for the technical assistance program of JICA in the transport sector for developing countries. It consists of 17 programs among which 'Disaggregate Model' module will be used to perform model building by the multinomial logit (MNL) and the two-level nested logit (NL) structure. The model will be able to provide useful information for evaluation of alternative transport strategies in terms of future investment, travel and economic development.

1.3 Objectives of the Study

The overall objective of this research is to develop a mode choice model considering heterogeneous traffic of Dhaka city with the specific objectives as following:

(1) To study the mode choice behavior and its contributing factors in Dhaka city using STP Household Interview Survey (HIS) data.
(2) To assemble the STP data in appropriate format for development of a mode choice model by JICA STRADA.
(3) To develop the mode choice model with the multinomial logit and nested logit approach using JICA STRADA.
(4) To compare model output with results available from other relevant studies.

1.4 Scope of the Study

The possible outcome of this research will be the development of an analytical tool which will be able to simulate the complex travel behavior. The model will be helpful to be applied to support the planner in the process of planning and decision making about which of the investments or policy measures in the transportation system will best serve the public's need for future travel and economic development.

1.5 Organization of the Thesis

The thesis consists of six chapters including the present one. The first chapter deals with the introduction, research motivation, objectives and scope. Chapter 2 presents a brief overview on travel behavior and theoretical purview of mode choice model. It also reviews the related literatures about mode choice behavior and model in developing countries and similar transport studies in Dhaka. Chapter 3 gives insight into the relevant background information of the study area, transportation network and data set. Chapter 4 is devoted to the analysis of mode choice behavior in respect of different socio-economic characteristics. It also presents the results of multinomial logistic regression models developed. Chapter 5 deals with development of the mode choice model. The chapter starts with the discussion of modeling principles and methodology; then it describes the modeling development and calibration procedures with the specification of the preferred model. Summary, conclusions and future research scope are presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a brief overview on travel behavior along with theoretical purview of mode choice model with special emphasis on multinomial logit and nested logit approaches. Next, the chapter attempts to collate few mode choice related studies in different cities of the developing world. The literature on transport studies so far conducted for Dhaka city is critically reviewed and presented in the last section of this chapter. Some ideas from this review have been incorporated in the current study.

2.2 Travel Behavior

2.2.1 General

Human activities are spatially separate, and travel is needed because of that separation. Travel consumes time, money, and resources, but it is necessary because of the need to reach activities that are not close by (Stopher and Meyburg, 1975). Demand for travel is, thus, “derived.” Except for certain recreational purposes, people do not demand travel for its own sake. Rather, they demand such daily activities as work, shopping, recreation, and education, and travel allows them to reach these activities (Meyer and Miller, 2001).

Therefore, travel behavior is the study of what people do over space, and how people use transport. But this is a complex phenomenon which largely depends on a number of factors such as travelers personal/household attributes, socioeconomic characteristics, purposes of trips, the places of origin-destination and the medium of transport under the constraints of time, cost, comfort, availability and so on. (Takyi, 1990).

2.2.2 Factors that Influence Choice of Travel Mode

The choice of travel mode is affected by a great many factors, everything from transport-specific factors (describing the various components of the transport system) to individual-related factors such as a person’s attitudes and habits. These factors are classified in many different ways by Olsson (2003). Some of these are described below:

Hard and soft factors

Hard factors are normally found in the traditional travel mode choice models that are based on maximization of utility. Examples of hard factors are traveling time, waiting time and ticket price (fare). Soft factors are things like comfort, service and information. Soft factors may also be psychological, for example flexibility, ease of orientation etc.

Internal and external factors

Factors that control choice of travel mode can also be divided into internal and external factors. Internal factors include attitudes, socio-economic and demographic factors, habits and perceived level of control. External factors include such things as traveling time and the cost of the journey.

Subjective and objective factors

The objective factors are normally based on objective measures and are easy to measure and quantify. The alternative's so-called hard standard factors such as traveling time, fare etc. as well as soft standard factors such as comfort, information etc. are grouped as objective factors. The objective factors also include socio-economic factors such as gender and age, and also trip-related factors such as purpose. Examples of other objective factors are weather, topography, security and environment. Subjective factors include valuations of the alternative's characteristics, attitudes and lifestyle. These factors are based on the individual's perception and are often more difficult to quantify.

Olsson (2003) further grouped the factors that affect mode choice into the following specific categories:

Transport-specific factors

Transport specific factors are related to the various parts of the transport system, for example timetables, proximity to stops and stations, congestion charges, service level, proximity to the cycle-way network and accessibility. In addition to traveling time, fare, comfort and information, transport-related factors also include station-related factors such as the general appearance of stations and stops. These factors are mainly affected by the local authority, companies, operators, and the individual's home and work locations, and choice of travel mode.

Environment-specific factors

Environment-specific factors describe the environment of the route traveled, i.e. the things that are not part of the transport system; the topography, the weather access to shops and schools etc. Some of the factors have been predetermined for a long time and are thus difficult to influence. Others can be influenced in the long term, e.g. through physical planning.

Individual-specific factors

Individual-specific factors consist of factors that describe not only the individual and the individual's characteristics, but also to a certain degree the whole household. Such factors include socio-economic factors such as age and gender, and also attitudes, status and habits. A person's lifestyle is also an individual-related factor. Gender and age are pre-determined, while attitudes and lifestyle can be influenced more easily.

Trip-specific factors

This category includes the factors that have to do with the trip itself. These can be the reason for the trip and the type of luggage the traveler is carrying on the trip. The individual can also affect these factors.

Quality factors

Quality factors are factors that have to do with the individual's perception of the journey and the standard of the transport system. The safety and security factor is an example of a quality factor. Both the individual and central government can affect these factors.

2.3 Mode Choice Model

A model, according to Krick (1965) is "something which in some respect resembles or describes the structure and/or behavior of a real life counterpart. There is some correlation between the model and its corresponding reality, although obviously a less than perfect correlation." According to Hensher and Button (2000), "Modeling is an important part of most decision making processes…It is concerned with the methods, be they quantitative or qualitative, which allows us to study the relationships that underlie decision-making."

The need for transportation model as a planning tool is particularly important due to the extent and diverse characteristics of transportation systems as well as the complexity of people's travel behavior. Modeling travel behavior is a key aspect of demand analysis (Ben-Akiva and Bierlaire, 1999). Mode choice has traditionally played a central role in transportation modeling research and applications (Portoghese et al., 2009).

2.3.1 Discrete Choice Modeling

Discrete choice methods have been used for many years for the development of mode-choice models (TRB, 2007). Discrete-choice models are so named because most such models analyze choices among discrete rather than continuous alternatives (Small, 2005). These models are also referred to as disaggregate models, meaning that the decision-maker is assumed to be an individual (Ben-Akiva and Bierlaire, 1999) since travel decisions are made by individuals, not by traffic analysis zones (Domencich and McFadden, 1975). Made possible by micro data (data on individual consumers), this approach explains behavior directly at the level of a person, household, or firm. Disaggregate models are based on a more satisfactory microeconomic theory of demand (Small, 2005).

The framework for a discrete choice model can be presented by four elements associated with the choice process (Ben-Akiva and Lerman, 1985; Koppelman and Bhat, 2006):

1. Decision-maker -- defining the decision-making entity and its characteristics;
2. Alternatives -- determining the options available to the decision-maker;
3. Attributes -- measuring the benefits and costs of an alternative to the decision maker;
4. Decision rule -- describing the process used by the decision-maker to choose an alternative.

2.3.2 Random Utility Model

Discrete choice models are usually derived under an assumption of utility-maximizing behavior by the decision maker. Thurston (1927) originally developed the concepts in terms of psychological stimuli. Marschak (1960) interpreted the stimuli as utility and provided a derivation from utility maximization. Following Marschak, models that can be derived in this way are called random utility models (RUMs).

The hypothesis underlying RUM is that when faced with a choice situation, an individual's preferences toward each alternative can be described by an "attractiveness" or "utility" measure associated with each alternative (Abdel-Aty and Abdelwahab, 2001). The utility function generates a numerical value or score based on several attributes of the mode for the trip as well as the characteristics of the trip maker (Chatterjee and Venigalla, 2004). The decision-maker is assumed to choose the alternative that yields the highest utility. Utilities, however, cannot be observed or measured directly (Ben-Akiva and Lerman, 1985). Furthermore, the name "random" implies that the decision-maker has a perfect discrimination capability, that is, the analyst is supposed to have incomplete information about the individual's choice decisions. Therefore, uncertainty must be taken into account in the utility function. Manski (1973) identified four different sources of uncertainty: unobserved alternative attributes, unobserved individual attributes (or unobserved taste variations), measurement errors and imperfect information, and instrumental (or proxy) variables.

To incorporate the effects of uncertainty, the utility of each alternative is expressed as a random variable. Mathematically, the utility that individual n is associating with alternative j within choice set C_n which is the set of available modes, can be expressed as (Small, 2005):

$$U_{jn} = V(z_{jn}, s_n, \beta) + \varepsilon_{jn}, \forall j \in C_n \qquad (2.1)$$

where V(·) is a function known as the systematic or deterministic part of the utility, z_{jn} is a vector of attributes of the alternatives as they apply to this consumer, s_n is a vector of characteristics of the consumer (effectively allowing different utility structures for different groups of consumers), β is a vector of unknown parameters, and ε_{jn} is an random or error component of utility which captures idiosyncratic preferences.

The alternative with the highest utility is chosen. The choice is probabilistic because the measured variables do not include everything relevant to the individual's decision. This fact is represented by the random terms ε_{jn}. Denoting $V(z_{jn}, s_n, \beta)$ by V_{jn}, the choice probability for alternative i is then

$$P_n(i) = \Pr[U_{in} > U_{jn}, \forall j \in C_n, j \neq i]$$
$$= \Pr[V_{in} + \varepsilon_{in} > V_{jn} + \varepsilon_{jn}, \forall j \in C_{n,} j \neq i]$$
$$= \Pr[\varepsilon_{jn} - \varepsilon_{in} < V_{in} - V_{jn}, \forall j \in C_n, j \neq i] \quad (2.2)$$

This probability is a cumulative distribution, namely, the probability that each random term $\varepsilon_{jn} - \varepsilon_{in}$ is below the observed quantity $V_{in} - V_{jn}$. By specifying a joint cumulative distribution function for these random terms $F(\varepsilon_{in},....,\varepsilon_{Jn})$, this cumulative probability (xx.2) can be rewritten as

$$P_n(i) = \Pr[\varepsilon_{jn} - \varepsilon_{in} < V_{in} - V_{jn}, \forall j \in C_n, j \neq i]$$
$$= \int_{-\infty}^{\infty} F_i(V_{in} - V_{1n} + \varepsilon_{in}, \ldots\ldots., V_{in} - V_{Jn} + \varepsilon_{in}) d\varepsilon_{in} \quad (2.3)$$

where F_i is the partial derivative of F with respect to its i-th argument. Different discrete choice models are obtained from different specifications of this density, that is, from different assumptions about the distribution of the unobserved portion of utility.

The deterministic term of the utility

The deterministic term V_{in} of each alternative is a function of the attributes of the alternative itself and the characteristics of the decision-maker. As for the functional form of *V*, by far the most common is linear in unknown parameters β. If we denote $\beta = [\beta_1, \beta_2, ..., \beta_K]$ as the vector of *K* unknown parameters and rewrite $V_{in} = V(x_{in})$, where $x_{in} = h(z_{in}, s_n)$ is defined as a vector of attributes *x* including all possible combinations of both z_{in} and s_n (where h is a vector-valued function), then the functional form of systematic utility can be written as:

$$V_{in} = \beta_1 x_{in1} + \beta_2 x_{in2} + \beta_3 x_{in3} + ... + \beta_K x_{inK}$$
$$= \sum_{k=1}^{K} \beta_k x_{ink}$$
$$= \beta' x_{in} \quad (2.4)$$

where we can think of β' as a "weighting vector", a way of weighting the importance of the characteristics x_{ink}. (Formally, both x_{in} and β are a *K*-item column vectors so β' - the transpose of β - is a *K*-item row vector).

Alternative specific constants

It is often reasonable to specify the observed part of utility with a constant for an alternative, known as alternative-specific constant which captures the average effect on utility of all factors that are not included in the model. That is, the systematic utility may be of the form:

$$V_{in} = \alpha_i + \beta' x_{in} \quad (2.5)$$

Where α_i is a constant that is specific to alternative *i*. Since only utility differences matter; differences in the alternative-specific constants are relevant, not their absolute levels. Because of the fact, at least one of the alternative-specific constants must be normalized (usually to zero); that alternative then serves as a "base alternative" for comparisons. Of course, using alternative-specific constants makes it impossible to forecast the result of adding a new alternative unless there is some basis for a guess as to what its alternative-specific constant would be.

Equation (2.4) is really a special case of (2.5) in which one or more of the variables *Z* are alternative-specific dummy variables, D^k, defined by $D^k_{jn} = 1$ if j=k and 0 otherwise (for each j=1,…,J). (Such a variable does not depend on *n*.) In this notation, parameter α_i in (2.5) is viewed as the coefficient of variable D^i included among the *z* variables in (2.4).

The random part of the utility

The random or error term represents those components of the utility function which are not included in the model. By definition, error terms are unobserved and unmeasured. A wide range of distributions could be used to represent the distribution of error terms over individuals and alternatives.

2.3.3 Multinomial Probit Model

The Multinomial Probability Unit or Multinomial Probit (MNP) model is derived from the assumption that the error terms of the utility functions are normally distributed. The

Probit model captures explicitly the correlation among all alternatives. Therefore, a vector notation is applied for the utility functions (Ben-Akiva and Bierlaire, 1999):

$$\boldsymbol{U}_n = \boldsymbol{V}_n + \varepsilon_n \quad (2.6)$$

where $\boldsymbol{U}_n$, $\boldsymbol{V}_n$ and ε_n are $(J_n \times 1)$ vectors. The vector of error terms $\varepsilon_n = [\varepsilon_{1n}, \varepsilon_{2n}, ..., \varepsilon_{Jn}]^T$ is multivariate normal distributed with a vector of means **0** and a $(J_n \times J_n)$ variance-covariance matrix $\sum_n$.

The probability that a given individual *n* chooses alternative *i* from the choice set C_n is given by

$$P_n(i) = \Pr[U_{jn} - U_{in} < 0, \forall j \in C_n, j \neq i]$$

$$= \int_{-\infty}^{0} ... \int_{-\infty}^{0} f_i(x) dx_1 .....dx_{i-1} dx_{i+1} ....dx_{Jn} \quad (2.7)$$

The double integral makes the MNP model difficult to estimate, interpret and predict and has limited its use in practice.

2.3.4 Multinomial Logit Model

By far the easiest and most widely used discrete choice model is the Logistic Probability Unit, or the Logit Model (Train, 2003) which was first introduced in the context of binary choice based on the logistic distribution. Its generalization to more than two alternatives is referred to as the multinomial logit (MNL) model. The popularity of the MNL is due to the fact that the formula for the choice probabilities takes a closed form and is readily interpretable (Train, 2003). Originally, the logit formula was derived by Luce (1959) and later Marschak (1960) showed that the model is consistent with utility maximization. McFadden (1974) completed the analysis with necessary underlying assumptions for the choice probabilities.

The specific assumptions that lead to the MNL model are (Koppelman and Bhat, 2006):

- The error components are extreme value (or Gumbel) distributed;
- The error components are identically and independently distributed across alternatives;

- The error components are identically and independently distributed across observations or individuals.

The Gumbel (or Type I extreme value) distribution is selected because it has computational advantages in a context where maximization is important, closely approximates the normal distribution and produces a closed-form probabilistic choice model. The Gumbel has the following cumulative distribution and probability density functions:

$$F(\varepsilon) = \exp\{-\exp[-\mu(\varepsilon-\eta)]\} \tag{2.8}$$

$$f(\varepsilon) = \mu\{\exp[-\mu(\varepsilon-\eta)]\} * \exp\{-\exp[-\mu(\varepsilon-\eta)]\} \tag{2.9}$$

where η is a location parameter and μ is a strictly positive scale parameter. Here the convention is to normalize by setting μ=1. With this normalization and assuming η=0 (not in any case restrictive as long as each systematic utility has a constant term), McFadden (1974) shows that the resulting probabilities have the logit form:

$$P_n(i) = \frac{exp(V_{in})}{\sum_{j=1}^{J} exp(V_{jn})} \tag{2.10}$$

This formulation implies that the probability of choosing an alternative increases monotonically with an increase in the systematic utility of that alternative and decreases with increases in the systematic utility of each of the other alternatives.

The logit probabilities exhibit several important properties. First, the relation of the logit probability to representative utility is sigmoid, or S-shaped, as shown in Figure 2-1.

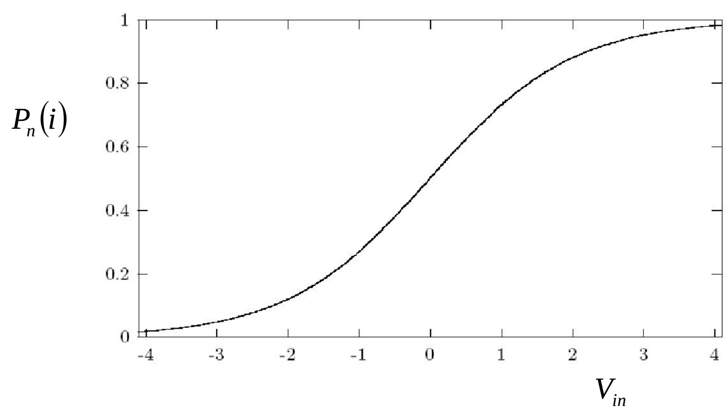


Figure 2-1: Shape of the Logit Probability (Source: Cramer, 2003)

The S-shape limits the probability range between zero and one. The logit probability for an alternative is never exactly zero. A probability of exactly 1 is obtained only if the choice set consists of a single alternative.

Second, the equivalent differences property, that is, the choice probabilities of the alternatives depend only on the differences in the systematic utilities of different alternatives and not on their actual values. Eqn. (2.10) can be expressed as follows:

$$P_n(i) = \frac{1}{1 + \sum_{j \neq i} exp(V_j - V_i)} \forall j \in C_n \tag{2.11}$$

Third, the property of *independence from irrelevant alternatives* (IIA): namely, that the odds ratio (P_{in} / P_{jn}) depends on the utilities V_{in} and V_{jn} but not on the utilities for any other alternatives. This property implies, for example, that adding a new alternative *k* (equivalent to increasing its systematic utility V_{kn} from -∞ to some finite value) will not affect the relative proportions of people using previously existing alternatives. It also implies that for a given alternative *k*, the cross-elasticities $\partial \log P_{in} / \partial \log V_{kn}$ are identical for all $j \neq k$: hence if the attractiveness of alternative *k* is increased, the probabilities of all the other alternatives $j \neq k$ will be reduced by identical percentages.

Estimation of Multinomial Logit

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

$y_{in} = \begin{cases} 1 \\ 0 \end{cases}$, where 1 is for if individual *n* chose alternative *i* and 0 is for otherwise.

Then, the likelihood function is defined as,

$$L = \prod_{n=1}^{N} \prod_{i \in C_n} P_n(i)^{y_{in}} \tag{2.12}$$

Where for a linear *n* parameters logit,

$$P_n(i)=\frac{e^{\beta' x_{in}}}{\sum_{j\in C_n} e^{\beta' x_{jn}}} \tag{2.13}$$

which is other form of the equation (2.10). Taking the logarithm of equation (2.12), the following loglikelihood function can be obtained.

$$LL=\sum_{n=1}^{N}\sum_{j\in C_n} y_{in}.ln[P_n(i)]$$

$$=\sum_{n=1}^{N}\sum_{i\in C_n} y_{in}\left(\beta' x_{in}-ln\sum_{j\in C_n} e^{\beta' x_{jn}}\right) \tag{2.14}$$

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

$$\frac{\partial LL}{\partial \beta_k}=\sum_{n=1}^{N}\sum_{i\in C_n} y_{in}\left(x_{ink}-\frac{\sum_{j\in C_n} e^{\beta' x_{jn}}.x_{jnk}}{\sum_{j\in C_n} e^{\beta' x_{jn}}}\right)=0 \tag{2.15}$$

$$or\sum_{n=1}^{N}\sum_{i\in C_n}[y_{in}-P_n(i)].x_{ink}=0,\forall k \tag{2.16}$$

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

$$\frac{\partial^2 L}{\partial \beta_k \beta_l}=-\sum_{n=1}^{N}\sum_{j\in C_n} P_n(i)\left[x_{ink}-\sum_{j\in C_n} x_{ink}.P_n(j)\right]\left[x_{inl}-\sum_{j\in C_n} x_{ink}.P_n(j)\right] \tag{2.17}$$

2.3.5 Nested Logit Model

The standard logit model exhibits IIA property which implies proportional substitution across alternatives and causes the cross-elasticities between all pairs of alternatives to be identical. To overcome this restriction, the nested logit model can be used for estimation in practical applications (Guadagni and Little, 1998; Ortúzar, 2001). It is computationally straightforward and fast compared to the multinomial probit, mixed logit, or other even more flexible models due to the existence of a closed-form expression for the likelihood function (Heiss, 2002). The model was first derived by Ben-Akiva (1973) and subsequently formalized in different ways based on utility maximization by Daly and Zachary (1979), Williams (1977), Ben-Akiva and Lerman (1979), McFadden (1978), and Williams (1977). The nested logit model is a natural generalization of multinomial logit (MNL), sharing some of its computational advantages (McFadden, 1981).

The idea of the nested logit model lies in the grouping of similar alternatives into nests and thus creating a hierarchical structure of the alternatives (Ben-Akiva and Lerman, 1985). Train (2003) elaborates the statement using the term 'appropriate' with nested logit model when the set of alternatives faced by a decision maker can be partitioned into subsets, called *nests*, in such a way that the following properties hold:

> 1. For any two alternatives that are in the *same* nest, the ratio of probabilities is independent of the attributes or existence of all other alternatives. That is, IIA holds within each nest.
> 2. For any two alternatives in *different* nests, the ratio of probabilities can depend on the attributes of other alternatives in the two nests. IIA does not hold in general for alternatives in different nests.

A convenient way to picture the substitution patterns is with a tree diagram as shown in the Figure 2-2. In such a tree, each branch denotes a subset of alternatives within which IIA holds, and every leaf on each branch denotes an alternative.

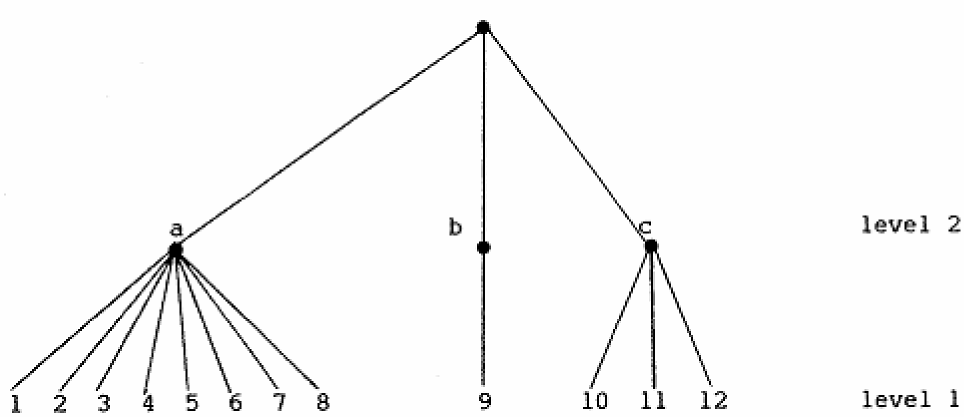


Figure 2-2: Nested Logit Tree Structure

In the case of nested logit model, Ben-Akiva and Lerman (1985) express the total utility of any alternative *i* under a multidimensional choice set C_n as the sum of its observed and unobserved components, each further divided into components defined by the dimensions of choice over which it varies. Let assume a two-level nesting structure and the set of alternatives *j* be partitioned into *K* non-overlapping subsets. Then the utility of an alternative *i* within nest *k* for individual *n* can then be expressed as:

$$U_{ikn} = U_{kn} + U_{(i|k)n} = [V_{kn} + \varepsilon_{kn}] + [V_{(i|k)n} + \varepsilon_{(i|k)n}] \qquad (2.18)$$

For the nested logit models to be used, it is further assumed that the dimensions can be ordered so as to satisfy the following conditions (Ben-Akiva and Lerman, 1985):

- All components of the total disturbance involve level *l*, but not all the higher levels have zero variance.
- All disturbance terms are mutually independent.
- The sum of the disturbance terms at level l and those at the next lower level are identically Gumbel distributed.

The assumptions, in consistent with notation in the equation (above), imply that the error terms ε_{kn} and $\varepsilon_{(i|k)n}$ are independent. The error terms $\varepsilon_{(i|k)n}$ are identically and independently distributed (i.i.d.) extreme-value with scale parameter μ_k. This can be interpreted as a measure of the correlation of the alternatives' errors within nest *k*. The compound error terms ε_{ikn} are distributed such that the sum of U_{kn} and $U^*_{(i|k)n}$, the maximum of the $U_{(i|k)n}$, is distributed extreme-value with scale parameter λ_k.

Mathematically,

$$Var[\varepsilon_{(i|k)n}] = \frac{\pi^2}{6\mu_k^2} \qquad (2.19)$$

$$Var[\varepsilon_{ikn}] = Var[\varepsilon_{kn} + \varepsilon^*_{(i|k)n}] = \frac{\pi^2}{6\lambda_k^2} \qquad (2.20)$$

Under the preceding assumptions, the nested logit choice probability can be written as a product of marginal and conditional choice probabilities, each of which is a standard logit model, such as,

$$P_n(ik) = P_n(i \mid k).P_n(k) \qquad (2.21)$$

where $P_n(i \mid k)$ is the conditional probability of choosing alternative i given that an alternative in nest k is chosen, and $P_n(k)$ is the marginal probability of choosing an alternative in nest k (with the marginality being over all alternatives in k).

The marginal and conditional probabilities can be expressed as,

$$P_n(i \mid k) = \frac{\exp[\mu_k . V_{(i|k)n}]}{\sum_{j \in C_n} \exp[\mu_k . V_{(j|k)n}]} \quad (2.22)$$

$$P_n(k) = \frac{\exp[\lambda_k . V_{kn} + \frac{\lambda_k}{\mu_k} . IV_{kn}]}{\sum_{l \in K} \exp[\lambda_l . V_{ln} + \frac{\lambda_l}{\mu_l} . IV_{ln}]} \quad (2.23)$$

$$IV_{kn} = \ln \sum_{j \in C_n} \exp[\mu_k . V_{(j|k)n}] \quad (2.24)$$

It is customary (Train, 2003) to refer to the marginal probability (choice of nest) as the *upper model* (Level-1) and to the conditional probability (choice of alternative within the nest) as the *lower model* (Level-2). A node with only one attached alternative is said to be degenerate. The quantity IV_{kn} links the upper and lower models by bringing information from the lower model into the upper model. IV_{kn} is often called the *inclusive value* or *inclusive utility* of nest *k*. It is also called the "logsum term" because it is the *log of a sum* of exponentiated representative utilities. The coefficient of IV_{kn} in the upper model is often called the logsum coefficient. The scale parameters μ_k and λ_k describe the variances of the unobservable effects (Silberhorn et al., 2006). The variances on the upper level cannot be smaller than those on the lower level and therefore, the scale parameters need to satisfy the following condition (Carrasco and Ortúzar, 2002; Hensher et al, 2005):

$$\frac{\lambda_k}{\mu_k} \leq 1 \quad (2.25)$$

Different Nested Logit Model Specifications

Train (2003), Heiss (2002), Hunt (2000) and Koppelman and Wen (1998a, b) point to the existence of different nested logit model specifications and the issues arising from this regarding different estimation results. The non-normalized nested logit (NNNL) model was derived from the standard logit model to relax the IIA-assumption. The elementary NNNL form is not consistent with utility maximization theory (Koppelman and Wen, 1998b). On the other hand, the utility maximization nested logit (UMNL) model, which was derived from McFadden's Generalized Extreme Value (GEV) theory (McFadden, 1978, 1981), is consistent with utility maximization theory (Koppelman and Wen, 1998b).

The difference between these nested logit model specifications lies in the explicit scaling of the deterministic utility component in the UMNL form. In the case of generic coeffcients, this means for the NNNL specification that the estimated parameters are indeed constant for all alternatives but not the hidden "true" parameters. The reason lies in the implicit nest-specific scaling within the NNNL specification (Heiss, 2002). Table 2-1 compares the two specifications (Hunt, 2000; Koppelman and Wen, 1998a).

Table 2-1: Specifications of the Nested Logit Model

	UMNL	*NNNL*
$P_n(i\mid k)$	$\dfrac{\exp[\mu_k . V_{(i\mid k)n}]}{\sum_{j\in C_n}\exp[\mu_k . V_{(j\mid k)n}]}$	$\dfrac{\exp[V_{(i\mid k)n}]}{\sum_{j\in C_n}\exp[V_{(j\mid k)n}]}$
$P_n(k)$	$\dfrac{\exp[\lambda_k . V_{kn} + \frac{\lambda_k}{\mu_k} . IV_{kn}]}{\sum_{l\in K}\exp[\lambda_l . V_{ln} + \frac{\lambda_l}{\mu_l} . IV_{ln}]}$	$\dfrac{\exp[V_{kn} + \frac{1}{\mu_k} . IV_{kn}]}{\sum_{l\in K}\exp[V_{ln} + \frac{1}{\mu_l} . IV_{ln}]}$
IV_{kn}	$\ln \sum_{j\in C_n}\exp[\mu_k . V_{(j\mid k)n}]$	$\ln \sum_{j\in C_n}\exp[V_{(j\mid k)n}]$

Due to identification problems, one of the scale parameters in the UMNL specification needs to be normalized to 1 (Daly, 2001; Hunt, 2000). A normalization on the lower Level 1 (μ_k =1) leads to the RU1 UMNL model; a normalization on the upper Level 2 (λ_k = 1) results in the RU2 UMNL model.

The NL model we have developed in our study is a two-level model with RU1 UMNL approach, which can be represented diagrammatically by the “tree structure” shown in the Figure 2-2.

Estimation of the Nested Logit Model

The parameters of a nested model can be estimated by standard maximum likelihood technique. This approach yields consistent and asymptotically efficient estimates of the parameters (Ben-Akiva and Lerman, 1985). The logarithmic likelihood function is given as follows,

$$LL = \sum_{n=1}^{N} \sum_{k=1}^{K_n} \sum_{j \in C_n} \delta_{(ik)n} [\ln P_n(i \mid k) + \ln P_n(k)] \tag{2.26}$$

In order to obtain the maximum likelihood for the undetermined parameters, the Newton-Raphson Method is usually applied to the simultaneous equations, subject to $\nabla LL = 0$. This method requires the analytical calculation of variable vector (primary partial differentiation) and Hesse matrix (secondary partial differentiation) of the likelihood function. However, the likelihood function of the NL model indicated above is too complex to obtain the variable vector and the matrix at each update. The STRADA Disaggregate Model directly applies the likelihood function to determine the parameters, by employing the Quasi-Newton Method based on the BFCS theorem.

2.4 Studies on Mode Choice Behavior and Model in Developing Countries

Shanghai, China

Ho et al. (1999) presented an urban transportation planning model developed for the base year 1995 in Shanghai. They developed a model framework that consists of a sequence of model elements with relatively simple structures so that the models can be calibrated, updated, implemented and applied easily. The model considered various kinds of variables that can effectively reflect the regional economic growth as well as the urban and transportation development in Shanghai.

The model was a sequential process consisting of trip generation, trip distribution, modal split and traffic assignment. A special feature of this model framework was that the modal split procedure was broken down into three sub-models to be carried out separately before or after the trip distribution model. The walk trips and personal motorized trips were determined before the trip distribution model. The rest of trips were split between bicycle and transit (bus, rail) after the trip distribution model. The two-stage modal split process separated different travel market segments (walk, personal motorized and bike/transit) with distinct travel characteristics at the early stage of the modeling process. The models, therefore, could handle the trips of various market segments with different individual model element with appropriate structure and variables.

The multi-stage modal split procedure can effectively reflect the impacts of the development of the transportation system on modal split. The structures of individual sub-models are much simpler than a single modal split model (e.g. the post-distribution modal split model). These sub-models thus can be calibrated, implemented and updated easily. It has greater flexibility for modal split procedure modification, if necessary, to handle any new travel modes. Finally, the multi-stage procedure allows conducting a detailed demand analysis of individual travel modes. The sequential modeling process is considered the most practical modeling approach, in particular for the developing countries, where the availability of reliable data, software tools and professionals with advanced modeling knowledge is relatively limited.

Liu (2006) analyzed travelers' choice behavior by using data from a stated preference survey on work-trip mode choice in Shanghai. Several versions of a multinomial choice model were specified and estimated. According to the estimation results the utility function with money cost divided by income adjusted by an equivalence scale is chosen as the preferred model.

Hyderabad, India

EPTRI (2005) study developed a 4-step transport demand model for Hyderabad which is one of the fastest growing centers of urban development in India. In the modal split stage, separate models were developed for respondents who had no access to any individual vehicle, those who had access to 2- wheelers and those had access to cars. A multinomial logit model was developed to examine empirically how travelers trade-off among the attributes of price, time and reliability. Stated Preference (SP) survey was carried out to know the modal preferences of respondents. The results from SP survey data analysis indicated that travelers are relatively more sensitive to time and reliability, and relatively less sensitive to cost. For all the groups reliability is relatively more important criteria than time. Among all groups, buses suffer from an image problem in

Hyderabad and vehicle owners showed inherent preferences for their own vehicle over buses.

Chennai, India

Srinivasan and Rogers (2005) investigated the travel behavior pattern of low-income residents from two contrasting locations in the city of Chennai, India. Travel behavior and its relationship to urban form are the focus of this study. They analyzed the differences in travel behavior due to differences in accessibility to employment and services between the two settlement locations. The results indicate that differences in accessibility appear to strongly affect travel behavior. Residents in the centrally located settlement were more likely to use non-motorized modes for travel (walk or bicycle) than the peripherally located residents. They suggested that the policy makers of developing country like India should consider location of employment in the planning of new housing for low-income households.

In this study, two separate models were developed to investigate the travel behavior pattern of the city. To understand the determinants of travel behavior, discrete choice models were estimated for mode choice and trip frequency. The models were estimated by individual for mode choice and by household for trip frequency.

For the mode choice model the choice is between NMT, combined transit (bus) and NMT and private vehicle (includes three wheelers and two wheelers). The model censored choice of mode. Thus, in the absence of a bus route to the destination the implication is that the mode bus will not be included as a mode choice for the person. Likewise, if the household did not own a vehicle the choice of private vehicle was not available to them. The model was estimated separately for persons with jobs and for all persons. The trip frequency model is estimated as a binary choice model between less than or average number of trips versus more than average number of trips (per person and per household).

Kuala Lumpur, Malaysia

With a view to analyze a policy measure to improve public transport as well as control car Ownership in Kuala Lumpur, Nurdeen et al. (2007) developed mode choice models to express car users and public transport users' behavior and investigate their response, such as the probability of car drivers shifting to public transport, based on a scenario of a reduction in bus and train travel time and travel cost A binary logit model was developed for the three alternative modes, bus, train and car. It was found that travel time, travel cost, gender, age, income level and car ownership are significant in influencing car users' mode choice behavior. Reduction of total travel time and travel cost for the bus and train mode emerges as the most important element in a program aimed at attracting car users towards public transport and away from car mode.

Addis Ababa, Ethiopia

Gebeyehu and Takano (2007) analyzed the public transport modal choice behavior of residents and their perception on bus condition parameters as a determining factor in their bus choice in the city of Addis Ababa. The major modes of public transportation in Addis Ababa are buses and taxis. There is no rail transit within the city. Existing public transportation is of a low quality due to the limited number of buses and taxis, poor management, and bad behavior of drivers. This research is a significant effort on these prevailing problems of the city's urban transportation. In this study an ordered logit model was developed to examine citizens' perceptions on bus conditions, in addition to the widely used binary logit model, which was developed for public transport mode choice analysis. A diagnostic analysis was undertaken based on the two models. The result revealed that citizens' perceptions of the three chosen bus condition aspects -fare, convenience, and frequency- have a significant influence on public transport mode choice.

Yangon, Myanmar

Focusing on the role of a new transit system in mitigating current and future potential traffic issues in Yangon City of Myanmar, Zhang et al. (2008) attempted to analyze the mode choice behavior based on a stated preference (SP) survey. Four types of transportation modes are available in Yangon: private car, rail, taxi and bus. In developing countries, socio-economic environments (especially, income) are changing rapidly and thus, it is required to reflect the influence of such decision context in both survey method and modeling framework. In view of the fact, SP survey was first designed and conducted to incorporate the influence of future income, as well as other level-of-service attributes, whereas a revealed preference (RP) survey was also prepared. After checking the reliability of SP data by estimating the SP model, a RP/SP combined mode choice model was estimated in which the parameters of travel time and cost were defined as a function of future income, respectively. The effectiveness of the proposed model structure was empirically confirmed. Furthermore, simulation analysis suggested that future income would bring about a potentially large increase in car usage and consequently reduction in transit systems.

2.5 Transport Related Studies in Dhaka City

It is imperative to review the past studies to have an idea relating to transportation planning, analysis of travel behavior and development of mode choice model of Dhaka city. This section presents a brief review of those studies.

2.5.1 Transportation Planning and Policy Related Study

The first study on transportation planning and development "Dhaka City Master Plan" was prepared in 1959 by the supervision of the erstwhile Dhaka Improvement Trust (DIT), covering roughly 830 sq. km (320 sq. miles) with a target population little over one million assuming an average annual population growth rate of 1.75% in the city areas. It provided a detailed plan for future expansion of city and construction of roads (RAJUK, 2010). The second study "Dhaka Metropolitan Area Integrated Urban Development Plan" (DMAIUDP) began in 1979 and was aimed at preparing a strategy plan for Dhaka including transport development which emphasized on the construction and management of road network. It also described physical characteristics such as capital cost, life of vehicles and capacity of different modes in the study area. However, this plan was not formally approved by government.

The Greater Dhaka Metropolitan Area Integrated Transport Study (DITS) (1991- 1993) was an initiative of the Government of Bangladesh (GOB) with assistance from UNDP. The project's aim was to collect information about the demand for transport services and the infrastructure to deliver those services to greater Dhaka, to prepare an immediate action plan for the effective management of existing traffic and transport system and to prepare a sound basis for the strategic planning of longer term transport infrastructure investments in the Greater Dhaka Metropolitan Area. DITS began in 1991 and ended in 1993. DITS produced numerous recommendations within its Immediate Action Plan

(IAP). Recommendations had embraced projects ranging from strategic policy advice involving little or no expenditure to capital investments. Mohakhali and khilgaon flyovers are built up in 2004 and 2005 under DITS recommendations in order to ease traffic congestion. But in turn, it is found that Mohakahli flyover achieves little success in minimizing the congestion; rather it deteriorates the situation in some places particularly at peak hour. However, Khilgaon flyover performs relatively well in reducing severe congestion at some links (Hasan, 2007).

The Dhaka Urban Transport Project (DUTP) originated from the recommendations of the DITS study. The objectives of the project were to improve urban transport infrastructure and services in the Dhaka Metropolitan Area (DMA) in an economically and environmentally sustainable manner; strengthen institutional and capacity building of the concerned organizations dealing with transport issues; and address long-term transport planning and coordination issues in the DMA.

With new perspective, the Dhaka Metropolitan Development Plan (DMDP) was prepared for sustainable growth of Dhaka. The plan addressed Dhaka's urban planning issues at three geographic levels: sub-regional, urban and sub-urban and is comprised of the three components. The first component, “The Structural Plan” provided a long term strategy for 20 years (1995-2015) for the development of the greater Dhaka sub-zone with a population target of 15 million. The main objective of the strategy was to establish a long-term road network for the metropolitan area which would effectively serve the needs of the growing urban concentrations, by providing improved access to the main urban area itself and linkages to areas with potential for growth. The second component, “The Urban Area Plan” provided an interim mid-term strategy for 10 years (1995-2005) and covered for the development of urban areas within Metropolitan Dhaka. The third component, “The Detailed Area Plan” provided detailed planning proposals and transport network for specific sub-areas of Dhaka, (RAJUK website, Nagari 2001).

Habib (2002) in his study evaluated alternative planning options such as elimination of rickshaws and auto-rickshaws, improvement of road network, improvement of bus transit and introduction of rail transit system on and their impact in Dhaka’s traffic congestion and air pollution.

In 2004, a project was undertaken by the GOB with the help of World Bank (WB) to prepare a long term Strategic Transport Plan (STP) for the Dhaka Metropolitan Area. A major objective of the STP was to establish a sound policy framework to ensure the sustainability of the current and future investments in transport sector. Critical to this objective was the preparation of a long-term (20 years) and a multi-modal transport plan for the greater Dhaka area, based on an assessment of the inter-relationship between land use and transportation. The plan covered the comprehensive policy issues including pedestrians, public transport, non-motorized transport, urban freight transport development policies and strategies, including public transport, non-motorized transport, urban freight transport, mass transit, traffic management, parking, land use - transport planning, pedestrians, institutional and financial aspects and so on.

At present, a project titled, “Dhaka Urban Transport Network Development Study” (DHUTS) undertaken by Dhaka Transport Coordination Board (DTCB) with technical cooperation from Japan International Cooperation Agency (JICA) has been going on. The objectives of the DHUTS study are to formulate urban transport network development plan integrated with urban development plan of DMA for the period up to 2025, to draw general outline of the urban transport projects to be implemented on priority basis, to clarify the roles of the project implementation agency and the operation/maintenance/management agency, and to propose the development of their implementation capability, to draw an outline of the feasibility study plan for construction of the urban transport system. The study area of the project covers the DMA within the area surrounded by Turag, Balu and Buriganaga rivers and encompasses Dhaka city, northern side and east district of outer edges of Dhaka city. The major difference between STP and DHUTS study is that STP aims at formulating comprehensive and long-term urban transport policies and strategic transport plans for DMA, while DMA aims at preparing effective measures and actions for implementation of urban transport projects with particular attention to be paid to mass transit development.

2.5.2 Travel Behavior Related Study

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

In the DITS study (1993), travel behavior of the people of Dhaka city was revealed and reported as key findings, some of which are:

- Dhaka has a very low level of motorization as compared to other large cities of the world. About 60% of trips are on foot while almost half of the remaining trips are on human powered vehicles;
- The average trip time across all modes is about 15 minutes and the average transport cost ranges from about 8% of household income for high income groups (HIGs) to 17% for low income groups (LIGs).
- Large groups such as women and the urban poor have very poor access to transport services.
- Bus services based on large capacity vehicles are by far the most efficient way to provide public transport in Dhaka and also to address the special needs of women and LIGs.

In the STP study, the socio-economic and travel characteristics of the people of Dhaka city were demonstrated from the data collected by conducting a household interview survey (HIS) with 6,035 households of Dhaka city area. The study shows that bus trips dominate with 44% share of all trips, whereas it was estimated as 9.5% in the DITS study. 14% of all trips are walk trips which were 60% as reported in the DITS study. However, such a high percentage (60%) of walk trips in the DITS seems unrealistic for Dhaka. The other information relating to travel characteristics found from the STP study will be discussed in the next chapters.

In the DHUTS study, a Household Interview Survey was carried out in 18,110 HHs to obtain the daily travel characteristics of the residents in 90 wards of DCC and adjacent populous areas. Travel behavior of individuals was analyzed with the survey results from seven standpoints: socio-economic profile, trip production, trip purpose, transport mode, trip generation and attraction, origin and destination matters, and trip length. The major findings of the study on characteristics of person's movements in Dhaka were:

- By the residents in DMA, approximately 20.8 million trips have been produced in daily basis. Of total trips of 20.8 million, non-motorized transport (NMT), walking and rickshaw, accounts for 58%. NMT has still played an important role in Dhaka.
- Trips produced by female fall below male, and female's trip has a tendency to concentrate on private and return home purpose. It shows that female is acting in or around their house.
- As a major transport mode, rickshaw has a dominant share with 38.3% followed by public bus (28.3%), walk (19.8%), auto rickshaw (6.6%), and car (5.1%). Without NMT, public bus accounts for 71%.
- The high income group (HIG) with household income more than Tk 50,000/- shares 20.4% of trips which is much higher as compared to trip percentage by HIG in STP.

2.5.3 Mode Choice Model Development Related Study

A major objective of the DITS study was to establish a framework for identifying long term transport needs for Dhaka and evaluating capital intensive proposals to respond to these needs. The basis for this framework was the setting up of a transport planning model using the data collected from the various surveys of transport demand, infrastructure and system performance.

The modes considered in the DITS model were walk, rickshaw, public transport (bus or tempo) and private motorized transport. The choice among multi-modes was simplified into binary choices by considering walk versus public transport or rickshaw trips, then car versus public transport or rickshaw trips and finally rickshaw versus public transport trips. However, a binary choice model is appropriate in situation where equally competing choices are available. But in Dhaka modes are not equally competing like walking is used either for short-distance trips or for trips where other alternatives are not available or affordable. Car ownership is very low in Dhaka as compared to other cities; car trips are made only by them who own cars, and therefore comparing with the choice of car is not pragmatic. It was found from the study that nearly 60 % of the trips are walking trips.

Habib (2002) in his study developed an Urban Transportation Model System for transportation planning of Dhaka city. As a part of the model, modal split model was developed using multinomial logit approach. Four modes were considered: rickshaw, auto-rickshaw, bus and car. The utility equation was formed with incorporation of cost, time and comfort as variables. The estimated coefficients of cost and time have positive sign which indicates counter-intuitiveness. Comfort was used as a generic variable in the model. But in real sense, comfort is generally considered as a perception of individual to a particular mode and so it should be applied as a dummy – specific variable.

As a part of the STP project, an urban transport planning model (UTP Model) was developed and used to forecast future travel demand resulting from different land use scenarios and transport strategies and to predict the performance of the existing, committed and alternative development strategies for Dhaka's urban transport network infrastructure, services and policies. In UTP model, only two modes – transit and motorized (non-transit) were considered; no walk trips and non-motorized trips were considered where a significant proportion of the trips are being made by rickshaw. Auto-rickshaw was not considered in the model due to their limited number. But in reality, it was found to be greater than car as well as than taxi mode. The modal split model was developed considering travel time, travel cost and income group as the relevant variables; not trip-purpose-wise. The coefficient of travel time and cost had positive signs indicating counter-intuitiveness result (Appendix A). The coefficient of time for LIG was greater than that for MIG and HIG also which is quite unreasonable. The probability of choosing auto by lower income group was estimated as 90% which was simply illogical and impractical.

Hasan (2007) developed a travel demand model for Dhaka city. The modal split procedure was done in two stages: pre distribution and post distribution modal split. In the pre distribution stage, two separate trip splits were made. The first one Walk and Intra-zonal Trip Split which separated the total zonal trips into zonal walk and intra-zonal trips and zonal non-walk inter-zonal trips and then the second one the Personal Motorized Trip Split which separated zonal total non-walk inter-zonal trips into zonal personal motorized trips and zonal auto-rickshaw, rickshaw and transit trips. Total 0.76 and 2.21 million trips have been found for personal motorized vehicle trips and walk and intra zonal trips respectively. A disaggregate multinomial logit model was developed for this post distribution modal split modeling with rickshaw, auto-rickshaw and transit modes. The model considered modal service characteristics as independent variables in terms of the travel time and the travel costs of the three competing modes. However, in this model the effect of income on choice of travel mode was not demonstrated where income may be the dominant factor in respect of the socio-economic status of the users. Also, hierarchical logit model had not been examined to analyze choice behavior. With the three modes, possible nested logit structure like motorized mode (auto-rickshaw, transit) with non-motorized mode (rickshaw), public transit mode with para transit mode (auto-rickshaw, rickshaw) etc. could have been tested.

In the DHUTS study, mode choice model was developed using the multivariate logic models for each income stratum. A two-step method was adopted in projecting the modal choice- in the first step, the explanatory variables were the constant term and the OD distance for walk, rickshaw and others and in the second step, the parameter estimation was done with the constant term and generalized cost in terms of travel time, access travel time, transport fare/ time value and/or vehicle operating cost/ time value for the others mode estimated in step 1 which indicate private car, bus, and auto rickshaw. The constant term for step 1 was not reported. The t-value of the parameters for LIG and MIG estimated in step 2 was not statistically significant (Appendix A). The study also did not examine the nested logit structure for mode choice. Like in STP, DHUTS developed the modal split model based on income group; not trip-purpose-wise.

From the review of mode choice model development techniques in different countries and the lack of viability of the model developed so far for Dhaka, it can be concluded that the model development approach should be based on trip purpose. An individual whatever be his income level may choose bus for work trips whereas he/she is more likely to choose other mode for recreation or education trips. The nested logit model should have been attempted to determine either the characteristics of individual vehicles or the group characteristics of vehicles dominate in selecting travel mode.

CHAPTER 3

STUDY AREA AND DATA SET

3.1 Introduction

Dhaka, the capital of Bangladesh, is the largest and most industrialized city of the country of some 145 million people (BBS, 2009). Dhaka is the primate city as its share of national urban population was 25% in 1981, 31% in 1991 and 34% in 2001 respectively. Dhaka's dominance not only in terms of population but also in terms of economy, trade, commerce, and administration is obvious (SDNP, 2005).

This chapter presents the selection of the study area for this research; the profile of the study area in terms of urbanization, population, socio-economic characteristics, and transportation system; an overview of the transport network the data set considered for the study.

3.2 Selection of the Study Area

The study area selected for this study covers Dhaka City Corporation (DCC) and its surrounding areas. The area comprises 168 sq km area which is considered as the core of Dhaka Metropolitan City and known as capital Dhaka. This portion contains all major government and private commercial activities. Due to lack of proper planning and control over land use activities, people from all over the country rush to this portion and make it a horde of residential, commercial and business centers.

Zoning of the Study Area for Analysis

The study area is subdivided into 94 zones known as Traffic Analysis Zones (TAZs)- the use of which implies that all movements to and from a zone can be adequately represented as starting or ending at a single point in the zone known as the centroid. This centroid represents the zonal centre of transport activity. TAZ boundaries are defined using boundaries of census and administrative jurisdictions (Thanas and Wards). Thus, 90 TAZs are the 90 wards of DCC, 1 is under cantonment board (TAZ 91) and 3 other TAZs are located in the periphery of Dhaka city such as Uttara East (TAZ 92), Badda (TAZ 93), and Kamrangir Char (TAZ 94). The map of the study area is shown in Figure 3-1 where the number indicates the TAZ numbers.

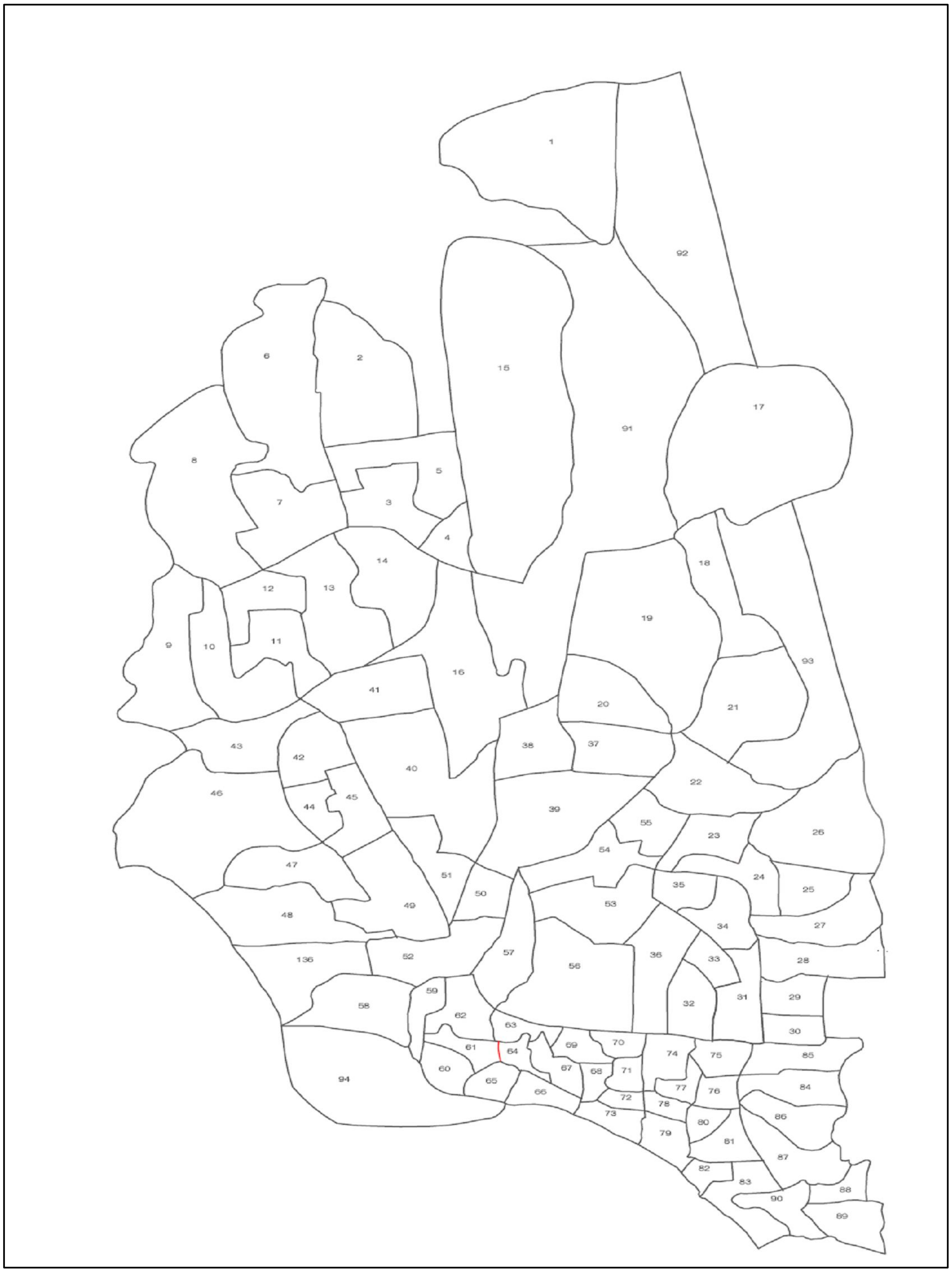


Figure 3-1: Map of the Study Area

3.3 Study Area Profile

3.3.1 Urbanization

Dhaka became the national capital of Bangladesh evolving from a provincial capital after independence in 1971. Since then, the urbanization activities have been achieving tremendous growth for the needs of the newly independent country's capital and the City has been expanding rapidly in all directions. However, after establishment of DIT in 1956, a number of residential areas were developed to meet the housing needs of the emerging elite class. A central Business District (CBD) was also developed to meet the demand for space required for increasing commercial and government administrative activities. Initially, the needs for official, educational, residential and administrational spaces were fulfilled by the expansion of the city in Purana Paltan to Naya Paltan, Eskaton to MoghBazar, Siddiheswari, Kakrail to Kamlapur through Razar Bagh and Shantinagar. Under the recommendations of 1959 Dhaka City Master Plan, Mirpur, Banani and Gulshan areas were acquired by the government in the early sixties. After independence, it began to expand over the low-lying areas of the east, such as Jurain, Goran, Badda, Khilgaon, Rampura, and to the west including the areas of Kamrangirchar, Shyamoli, Western Mohgammadpur, Kallyanpur. During this period the swamps and wetlands within the city started to disappear quickly and new areas of residential, administrational, business and commercial importance began to develop. In addition, slum and squatter settlements also sprang up in different areas of the city. Keeping pace with the magnitude of the urban growth, the new urbanized areas began encroaching on the low-lying areas within the city limits and even on some adjacent outlying areas which resulted in the expansion of the city area from 510 sq. km to 1353 sq. km. The mega city area has reached to 1530 sq km in 2001 (Hossain, 2008) (see Table 3-1).

Table 3-1: Area of Dhaka (1951-2001)

Year	Area (sq. km)
1951	85
1961	125
1974	336
1981	510
1991	1353
2001	1530

Source: Hossain, 2008

However, there is a great deal of confusion over the area of the city. Different operational area of different institutions of the city is mainly responsible for it. The area under the jurisdiction of Dhaka City Corporation is 14500 hectares (145 sq km) while Dhaka Metropolitan Area (DMA), the function of which is police administration for the maintenance of law and order is 36000 hectares (360 sq km). However, Dhaka Statistical Metropolitan Area (DSMA), which is also known as Dhaka Mega City, is 135300 hectares (1353 sq km) and the area under the jurisdiction of Capital Development Authority or Rajdhani Unnayan Kartripakkha (RAJUK), which in fact is a planning region and is larger than DCC and DSMA. The present planning area of RAJUK covers nearly 153000 hectares (1530 sq km). Within the area of RAJUK, there are four other municipalities apart from DCC, such as Narayangonj, Savar, Gazipur and Tongi. Normally, to most people, “Dhaka” generally means the central city alone that is jurisdiction of DCC and some adjoining areas (Rahman and Alam 2005). Figure 3-2 represents the area of Dhaka under different operational bodies.

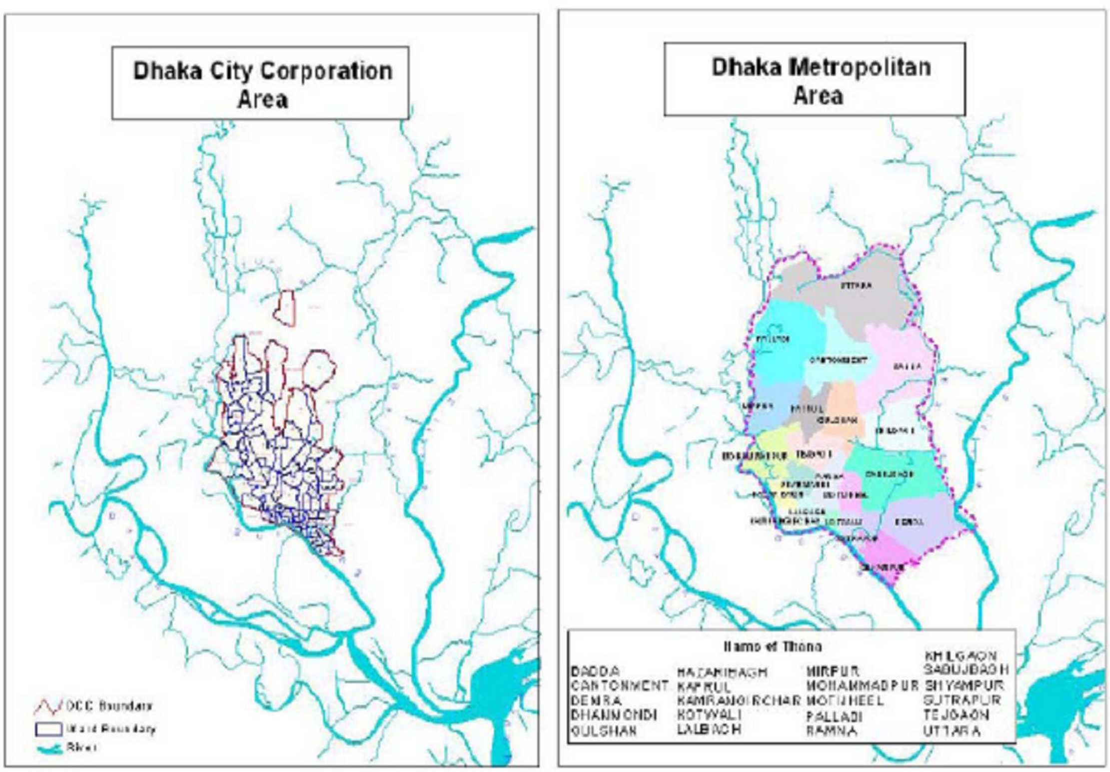


Figure 3-1: Map of Different Operational Areas of Dhaka (Source: Rahman and Alam ,2005) (contd.)

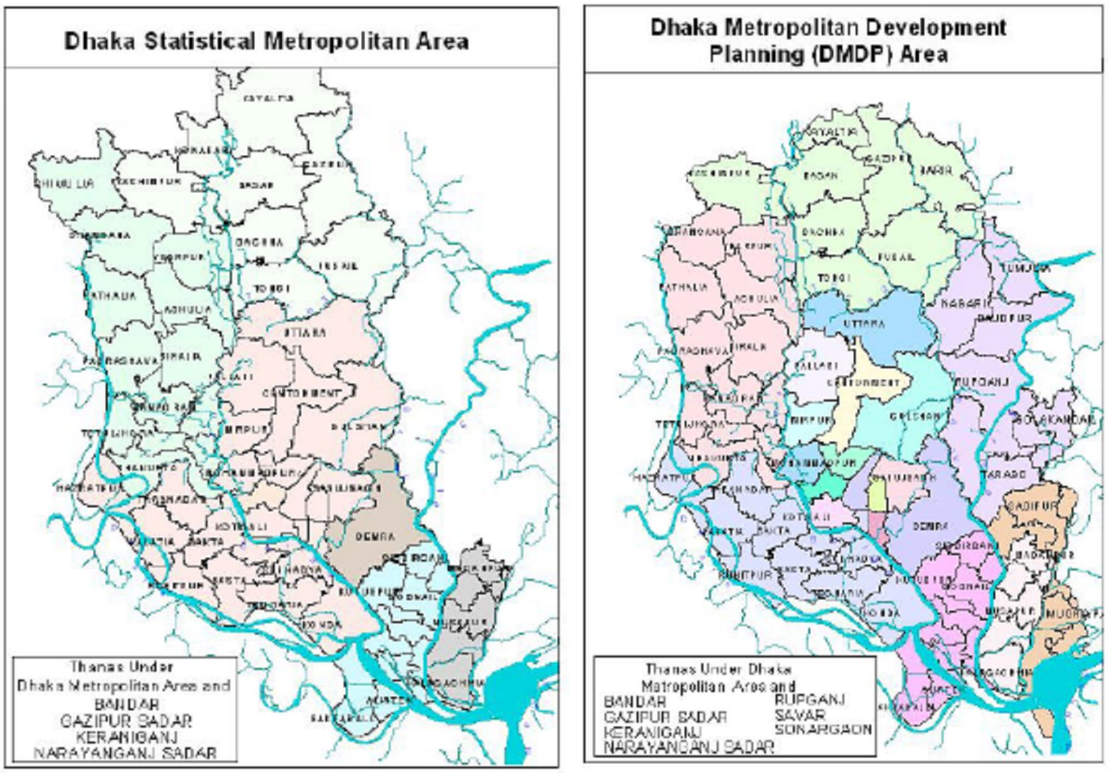


Figure 3-1: Map of Different Operational Areas of Dhaka (Source: Rahman and Alam ,2005)

3.3.2 Population Growth

The urban population of almost all developing countries is increasing at a rate twice the normal growth rate of the population in the country as a whole (Lowe, 1992). In Bangladesh, like some other developing countries, the rate of urban population growth is extremely high, (more than two to three times that of the national population growth rate), being consistently over 5 percent since 1974, and even up to 10 percent in some years (Islam, 1999).

Since independence in 1971, the influx of people to Dhaka from different parts of the country occurred due to several socio-economic factors, such as growing population pressure in rural areas, frequent and severe natural disasters, law and order concerns in remote and isolated areas, and the availability of more socio-economic opportunities in Dhaka (STP, 2005). Now, Metropolitan Dhaka is the largest urban centre in the country accommodating nearly 40 percent of total urban population (Hossain, 2008).

The population of Dhaka suddenly increased from a modest figure of just over one million in 1971 (STP, 2005) to about 2.1 million in 1974 which leapt to 3.4 million within a decade (see Table 3-2). The City faced its highest rate of population growth during 1981-1991, with the population doubling during that decade. The growth rate of population of the city during 1974-2001 is 5.9%. There is no city in the world, which has experienced such a high growth rate in population during this period. The United Nations (1999) describes the rapid population growth of this city as 'exceptional'. The growth rate of Dhaka City's population will also continue to remain high. During 2000-2015 it is expected to grow at a 3.6% annual growth rate and reach a total population of 21.1 million in 2015. This will put it in 4th position on the list of the world's mega cities (UN, 1999). The population of DSMA is estimated at 12.8 million while that of DCC area at 7.0 million in 2008 (BBS, 2009).

Table 3-2: Population of Dhaka City / SMA (1951-2001)

Year	Population	Growth Rate	Source
1951	411279	---	BBS, 1977
1961	718766	5.74	BBS, 1977
1974	2068353	8.47	BBS, 1977
1981	3440147	7.54	BBS, 1986
1991	6487459	6.55	BBS, 1997
2001	9672763	4.52	BBS, 2006
2008	12797394	4.08	BBS, 2009

The recent preparatory report of the DHUTS forecasts the population of RAJUK would be 25.4 million in 2025 with an annual growth rate of 3.56%, while that of DMA would be 15.7 million in 2025 with an annual growth rate of 3.41%. However, it is estimated that the population growth rate outside of DMA will be higher than those in DMA after 2015 (DHUTS, 2010).

3.3.3 Socio-economic Characteristics

The income of the city dwellers also plays a vital role regarding the transport scenario of a city. Cost on transport as a proportion of total daily expenditure is broadly correlated with income levels. For the poor, lack of access to transport services is a direct function of low income. Higher income people spend less on transport as a proportion of total daily expenditure (Mannan and karim, 2001). Although the car ownership is very low in

Dhaka, it can change drastically as the high income group (income > Tk. 50,000) occupies over 20 percent of the total urban population (DHUTS, 2010). This is due to the fact that people are more likely to buy a motorized vehicle (car/jeep/motor-cycle) when income leaps up. Even the slightest change in the car ownership would have a dramatic affect on the traffic scenario.

3.3.4 Transportation System of Dhaka City

The Transportation system in Dhaka is known as heterogeneous traffic system due to wide variation in the operating and performance characteristics of vehicles like motorized and non-motorized vehicles often using the same road space, slow-moving and fast-moving vehicles plying together in non-lane based traffic system (Karim et al., 1998). Long waiting time, delay on regular schedule, overloading, discomfort, and long walking distance from the residence and work place to bus stops are some of the obvious problems the users are facing in their daily life. Passengers often have to struggle for the few available seats (Maanan and Karim, 2001). Both the HDRC study (2004) and DUTP after-project study (2006) reported significant deterioration of waiting times for bus passengers. Again, as reported in the HDRC report, baby taxi operators are reluctant to take short trips, causing significant increases in waiting times for passengers. Similarly, finding suitable taxicabs at an affordable cost has become increasingly troublesome and time consuming for short trips. On the other hand, despite being removed from the main roads, rickshaws are still the most popular mode of transport (Bari, 2008). Moreover, uses of private cars are highly increasing (Figure 3-3). Cars take up a huge amount of space when in motion and for parking (Olsson, 2003). These factors coupled with lack of enforcement of traffic rules, widely insufficient traffic management diminish the efficiency and effectiveness of the existing transport uses (JICA, 2010). The deteriorating traffic conditions are causing huge delays and worsening air pollution, and seriously compromise the ability of the transport sector to serve and sustain economic growth and quality of life.

Transport system of Dhaka is mainly road based. Though there is a limited use of waterways, the rail and air transportation for movement within the metropolitan area is totally absent. The road network basically determines the accessibility to different locations of the metropolitan area (Habib, 2002). For this reason, the next of all descriptions about transportation system of Dhaka City will be that of road transport system only.

3.3.4.1 Road Transportation Network

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

Dhaka city has 436 km of four lane roads, 1408 km of two lane roads, 386 km of lanes/ by lanes and 220 km of footpath. Smooth traffic system demands roads and lanes to be constructed on 25% of the city's surface area, but unfortunately for Dhaka city it is only 8% (Hossain, 2004). Again, most of these roads are poorly maintained. Almost two-thirds of the available roads do not have engineered surfaces, and although more than a quarter of the roads have surface dressing, these show signs of extensive deterioration (Mannan and Karim, 2001).

As the existing pedestrian footpaths are of inadequate quality and mostly occupied for other uses, nearly 40% according to STP (2005) estimations, they do not provide sufficient levels of safety and comfort to encourage walking. Facilities for cyclists, such as bicycle lanes, are nonexistent. There are no special transportation considerations for the mobility-impaired such as the elderly and the disabled, as well as those of young children (Hossain, 2004).

3.3.4.2 Transport Modes

Metropolitan Dhaka has traditionally been served by a wide variety of transport modes. These modes can be classified in different ways such as in terms of motorization level or in terms of routes and schedules.

Transport modes, in terms of motorization level, can be grouped into two categories: the motorized transport (MT) which includes bus, truck, car, auto-rickshaw, auto-tempo, motor-cycle etc. and non-motorized transport (NMT) which includes rickshaw, rickshaw van, bicycle, push cart etc. (Habib, 2002).

Transport modes, in terms of routes and schedules can be classified into three groups, private transport; para transit and mass transit which is outlined (Ahsan, 1990) below:

Private transport

This consists of privately owned vehicles operated by owners for their own use, usually on publicly provided and operated streets. This includes:

- Private automobiles: Car, jeep, microbus, station wagon
- Staff bus, School/College/University bus
  (owned by the organization or institution for a special group of people).
- Motor cycle
- Moped
- Bicycle
- Walking

Para transit

Transportation service provided by an operator and available to all parties who meet the conditions of a contract for carriage (i.e., pay prescribed prices), but which is adjustable in various degrees to individual user's desires are known as para transit. Most para transit modes do not have fixed routes and schedules and do not stop to pick up other passengers en route. This includes:

- Taxi
- Rented car
- Auto-rickshaw: CNG/ baby taxi/ mishuk
- Auto-tempo (passenger can bound or alight at some suitable locations along a defined route between two fixed points)
- Rickshaw

Mass transit

These are transport systems with fixed routes and schedules, available for use by all persons who pay the established fare. This includes:

- Bus
- Minibus
- Hauler

3.3.4.3 Motorized and Non-motorized Vehicle Growth

Dhaka has a relatively low level of motorization compared to high-income countries and some other developing countries, but its motorization growth has been rapidly increasing. This increasing use of motor vehicles can change the mode split characteristics of Dhaka city (Hasan, 2007).

Figure 3-3 shows the growth trend of motorized vehicles in Dhaka during the period 1994 - 2009. It indicates that there were 139,675 vehicles in 1994 and the number increased to 553,714 in 2009 with an overall average growth rate of 9.62% annually. It can also be noticed that over 20,000 vehicles are being added every year to the vehicle fleet of Dhaka from 2003 with around 50,000 vehicles per annum in the recent two years 2008 and 2009.

A more clear picture of growth trend of different types of vehicles over 1995 to 2009 can be obtained from Figure 3-4 in which comparison between the augmentation in number of vehicles in three periods five years each - 1995 to 1999, 2000 to 2004, 2005 to 2009 - is shown. Motor car was increased at a slower rate during 2000 to 2004 as compared to the period of 1995 to 1999, whereas its increase was more than two times in the latest five year period (2005 to 2009). There is an increasing trend of Jeep / St. Wagon / Microbus, Bus, Truck, Motor cycle and other vehicles registrations over the years. The growth of Taxi, Minibus and Auto-rickshaw / Auto-tempo was decreasing since only 3,068 (790 + 489 + 1789) vehicles added in the vehicle fleet in recent five years. The reduction in Auto-rickshaw / Auto-tempo numbers is evident from the fact that existing 26,429 two-stroke three-wheeler (Auto-rickshaw/Auto-tempo) were removed from Dhaka's street in 2000 (Appendix B).

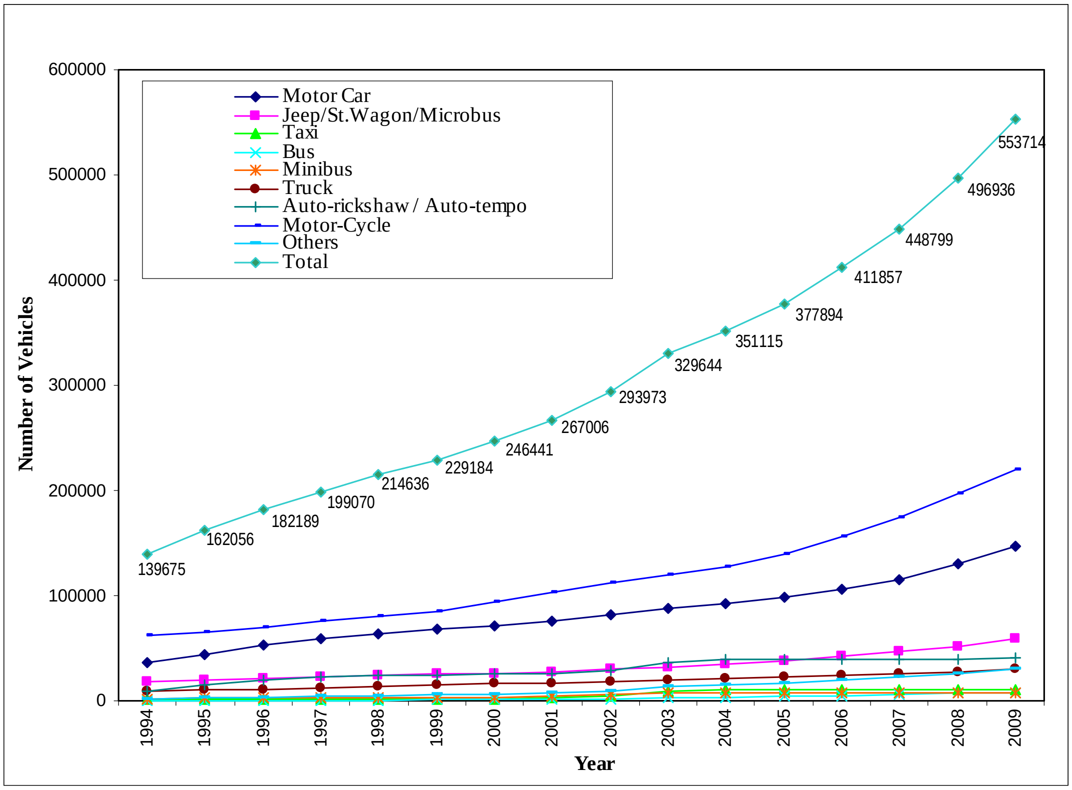
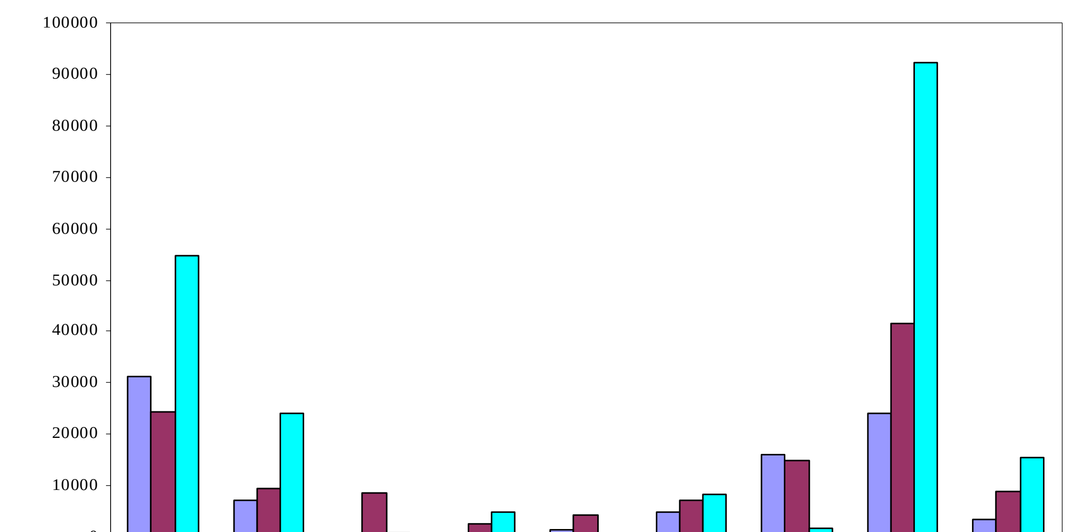


Figure 3-3: Growth Trend of Motorized Vehicles in Dhaka (1994-2009) (Source: BRTA, 2010)



	Motor Car	Jeep /St.Wagon /Microbus	Taxi	Bus	Minibus	Truck	Auto-rickshaw /Auto-tempo	Motor cycle	Others
1995-1999	31151	7244	391	684	1403	4787	16189	24122	3538
2000-2004	24451	9324	8714	2440	4416	7217	14912	41571	8886
2005-2009	54683	24103	790	4817	489	8236	1789	92272	15420

Figure 3-4: Growth Trend of Motorized Vehicles in Dhaka in 5 Years Period (1995-1999, 2000-2004, and 2005-2009) (Source: BRTA, 2010)

Figure 3-5 shows the motorized vehicle composition of Dhaka city for 2009. The figure also shows that the number of motor cycle has the largest share (39.63%) in the motorized vehicle population with private cars having the second largest share (26.60%).

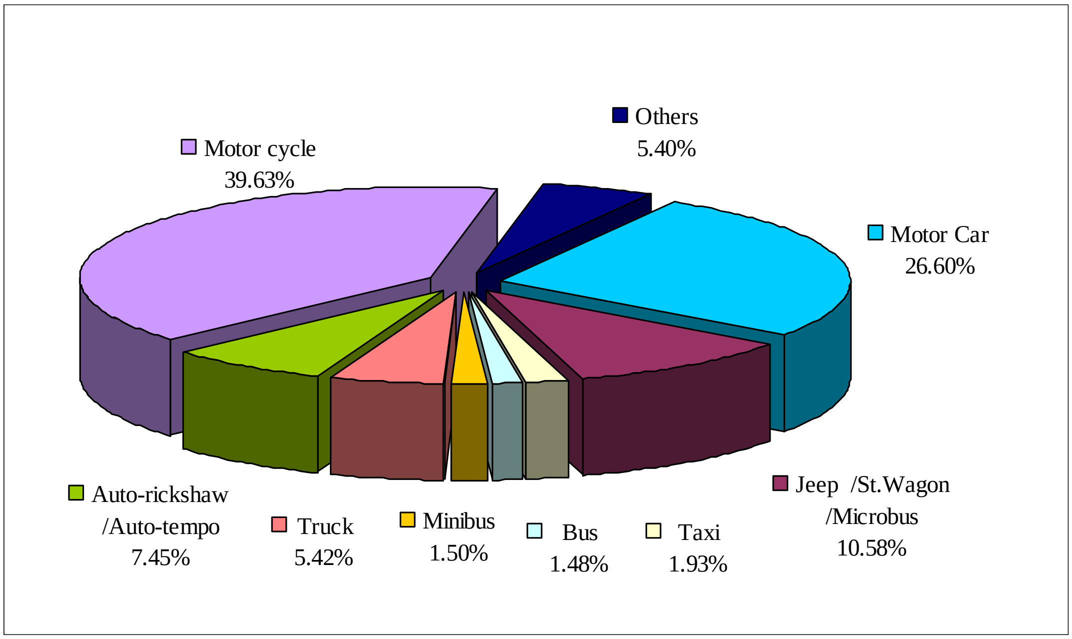


Figure 3-5: Composition of Motorized Vehicles in Dhaka in 2009 (Source: BRTA, 2010)

In addition to the motorized vehicles, there are significant numbers of rickshaws plying within the city. Dhaka city had only 37 rickshaws in 1941 and 181 rickshaws in 1947 (Banglapedia, 2006). The 'official' rickshaw population of Dhaka in 1972-73 had increased to 14,667 which then doubled to 28,703 in 1982-83, and thereafter increased rapidly to reach more than 88,000 by the end of 1986-87 (Gallagher, 1992). Although DCC restricts the number of rickshaw licenses issued to approximately 80,000, the number of rickshaws actually plying on the streets of Dhaka is many times the limit established by DCC. While there is no effective means to determine the actual number of rickshaws currently in operation, estimates indicate that there are more than 500,000 rickshaws plying the streets of Dhaka (STP, 2005).

Statistical data on bicycle ownership in Dhaka metropolitan areas are not known with any certainty (Mannan and Karim, 2001). In Dhaka, however, bicycles are not being used as a significant mode of transport. Ownership levels are very low compared to other cities in

Indian subcontinent, only 2% of households own bicycles. Traffic counts for STP study indicate that bicycles comprised only 2-4% of all vehicles (STP, 2005). However, Dhaka's roads are so crowded and dangerous that many potential users could be discouraged from bicycle riding (Mannan and Karim, 2001).

STP (2005) reports that the number of other non-motorized vehicle fleet such as rickshaw vans and push cart in Dhaka City is very small as compared to that of rickshaws.

3.4 Transportation Network within the Study Area

The road network considered for the present study has been developed based on STP network data. The network is built up with nodes and links of major and minor roads as found in STP database. TAZ centroids are connected with the road network by centroid connector links. For each individual link the coordinate of connecting nodes, link distance, maximum velocity on link, link capacity, directional control (one way/two way) etc. are to input. A total of 534.72 km of road which consists of 1,068 nodes and 1,565 links has been selected for present study. The map of the road network is shown in Figure 3-6.

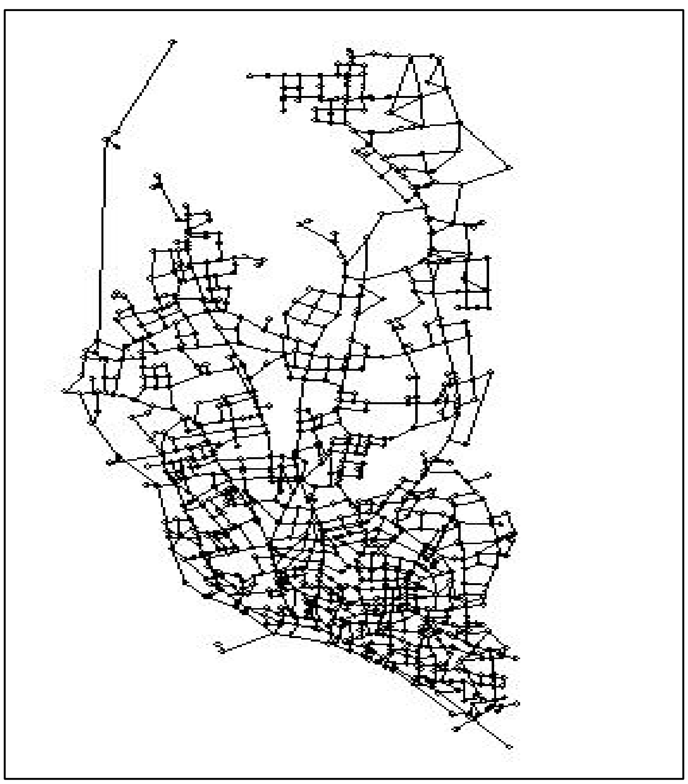


Figure 3-6: Transportation Network within the Study Area

3.5 Data Set

The data set used for mode choice behavior analysis and model estimation is extracted from the Household Interview Survey carried out for the STP study during the months of April, May, June and September of 2004. The survey was a revealed preference type collecting information from 6,035 households in 19 wards of DCC and slum areas of Kamrangir char. Information was collected about the number of members in household, their sex, age, education level, occupation, income, household ownership of transport vehicles, the number of trips made by HH members, purpose of each trip, origin and destination of each trip, travel time, the transport mode used for each trip, preference for modal choice and the reasons for such choices, etc.

3.5.1 Data Assembly

Although 6,035 HHs were surveyed as reported in the STP working paper and survey result, we have been able to retrieve the data set supplied to BUET as excel files of 4,906 HHs consisting of 20,107 members making 43,083 trips (including the possibility of some respondents making zero trips on the survey day). It was a very big task to select and assemble the raw data in a specific format as required for our study.

It has been observed from the review of the existing data set that the information regarding HH or individual trip maker or trip report required for analysis and model development for the current study are not available or not representative. Therefore, the data set needs to be screened before going further to work with. Several other factors in the following are taken into consideration for data screening:

- The trips made by bicycle or truck or rail or water transport have not been included since the trips are insignificant and not an appropriate choice in Dhaka's environment.
- Trips only by persons over 5 years have been considered; for education trips the consideration is over 4 years' trips.
- Only the trips with both ends within the study area are considered. Thus, trips with either ends or only one end outside the study area have been excluded.

With the above considerations, total number of valid records available was obtained for 4,825 HHs representing 19,792 people making 40,318 trips. Table 3-3 lists the number of households with respect to size and income group, number of males/females in the households.

Table 3-3: Characteristics of Valid Data Set

Characteristics	Numbers	
	HHs	**Persons**
HH Size		
≤2 persons	353	
3 persons	1,105	
4 persons	1,781	
5 persons	1,028	
≥6 persons	558	
HH Income per month		
Income group 1 (≤ Tk 12,500)	2,095	7,966
Income group 2 (Tk 12,500 ~ ≤ Tk 30,000)	1,755	7,396
Income group 3 (Tk 30,000 ~ ≤ Tk 55,000)	769	3,448
Income group 4 (≥ Tk 55,000)	206	982
Sex		
Male		10,541
Female		9,251

These valid data have been used to analyze the mode choice behavior which is presented in the next chapter.

CHAPTER 4

ANALYSIS OF MODE CHOICE BEHAVIOR

4.1 Introduction

Analysis of mode choice behavior is an important research topic in the field of transportation engineering and urban planning, irrespective of developed and developing countries. It provides the background information necessary to better understand the complex relationship among urban structure, transportation system and people's activity participation. The growing volume and complexity of urban travel in developing countries has become a major concern to transportation planners, service sponsors in urban areas, and policy makers. Designing transport strategies which meet the common political aims for the environment and the society requires a deeper insight into the routines of individual travel behavior.

This chapter starts with the selection and coding of variables for analysis of mode choice behavior which is one of the prime objectives of the study. This chapter attempts to demonstrate the trend of mode choice in respect of different personal (sex, age), household (size, income), and travel (purpose, zone type) characteristics. Multinomial logistic regression approach is applied to analytically determine the factors that contribute to choice of travel mode.

4.2 Coding of Selected Mode Choice Variables

Before going through the detailed analysis on mode choice behavior relating to socio-economic characteristics of the residents of Dhaka, we have considered several variables. The variables are household size, personal attributes (sex, age), household income group, and travel purpose. It is necessary to mention that one important variable 'car ownership' is widely used in almost all studies related to travel behavior analysis. But this variable is not considered in the current study as the level of car ownership (at household/personal level) in Dhaka is still very low in Dhaka and many car users use official cars which does not stand for the actual representation (Rahman, 2008). The grouping and coding of each variable mentioned above is briefly described below:

4.2.1 Household Size

HH size is defined as the total number of persons in a household. HH size affects the number of trips made. A travel study of three Indian cities (Fouracre and Maunder, 1987) found that a 10 per cent increase in household size was associated with a 6 per cent increase in household trip making, and a 1 to 3 per cent reduction in per capita trip making.

For our current study, HH size is grouped into five categories - 1&2, 3, 4, 5, and 5+ persons named as HH group 1,2,3,4, and 5 respectively. The average household size is found to be 4.10 persons/ HH.

4.2.2 Personal Attributes

The sex and age of household members are also likely to have an important influence on travel characteristics. In developing countries, women have a lower participation rate than men in both work and education and for their domestic responsibilities like child-care, household upkeep, etc., women are less likely to travel long distances for employment. Women also have a disinclination to travel by public transport. Many women will not travel unaccompanied on any kind of business, apart from local shopping and school (accompanying young children) trips (Fouracre and Turner, 1992).

Age structure is important largely in respect of children and the retired. Pre-school children are unlikely to make any significant trips except in the company of elders. While all school children make school trips their mode of travel may well be influenced by their age; young children will have only a short trip to a local school which can be accomplished on foot, while older children attending secondary school and colleges will inevitably travel further, possibly using some mechanized mode. Song (1989) also noted, in Beijing, a large (over two-thirds) increase in trip making as students progress from primary to secondary education age. The same study also demonstrated the rapid drop in trip making which results from old age.

For our current study, it is assumed that people within the same age range behave in a similar fashion to mode choice. Age of trip makers is grouped into six categories nearly consistent with the STP HIS survey. These are:

Age Group 1 (AG 1): 6~14 years (for education trips 4~14 years)

Age Group 2 (AG 2): 15~19 years

Age Group 3 (AG 3): 20~29 years

Age Group 4 (AG 4): 30~49 years

Age Group 5 (AG 5): 50~59 years

Age Group 6 (AG 6): 60 and above

4.2.3 Household Income Group

Household (HH) incomes have an impact on trip generation rates, choice of travel modes as well as on overall travel behavior of a person or even of a household (Rahman, 2008). The study of three Indian cities (Fouracre and Maunder, 1987) indicated that income has a relatively small impact on trip frequency: a 10 percent increase in either household or per capita income was associated with a 1 percent increase in household and per capita trip making respectively. More trip making must be a necessary part of life (to get to work or to school) irrespective of income level; only households, made up solely of the very poor, the unemployed or retired will not participate in these committed trips. Income is more likely to have an effect on trips associated with more leisurely pursuits, though these might account for only 20 percent of total trip making. Even here, however, there is no strong reason to believe that higher income groups will have markedly higher activity patterns (Fouracre and Turner, 1992).

Income clearly affects the way in which people choose to travel. It sets the limit on their capacity to acquire a personal vehicle and also, given that trip making is relatively inelastic to income, it sets the limit on how much of a particular mode they can 'consume' in order to achieve their desired level of travel. For example, it is quite common for low income commuters to switch their normal mode of travel from bus to walking towards the end of their pay-period as money runs out (Fouracre and Turner, 1992).

Not surprisingly, personal vehicle ownership is highly correlated with high income. Personal car ownership is largely confined to high income groups, though as Cundill (1986) noted in Kenya, the equi-probability income (i.e. the income level at which the probability of car ownership is 50 percent) seems to be falling. This would suggest that car ownership will increase regardless of any increase in household income. Perhaps as a cheaper 'second best' to car ownership, motor-cycle ownership amongst the middle income groups has increased at a very rapid pace in many cities. Bicycle ownership is high amongst low income groups in specific locations, notably Chinese and Indian cities. The reason for non-use of bicycles in other apparently 'fertile' locations is not clearly understood, although differences in attitude towards cycle use may be critical (Barrett, 1991).

The HHs sampled by the STP HIS were distributed into three IG as: Low Income Group (LIG) with monthly HH income less than Tk 12,500; Medium Income Group (MIG) with monthly HH income ranging from Tk 12,500 to Tk 55,000; and High Income Group (HIG) with monthly HH income more than Tk 55,000. However, it seems to be a wide difference in household income level for Middle Income Group (MIG). It is also evident from the preparatory survey report of the DHUTS which designated three levels of HIG as follows:

Group 1 (HIG) : Monthly HH income with more than Tk 50,000
Group 2 (MIG) : Monthly HH income between Tk 20,000 and Tk 50,000
Group 3 (LIG) : Monthly HH income with less than Tk 20,000

It is natural that income level of people increases in these five years between STP HIS (2004) and DHUTS HIS (2009) being carried out and so is reflected in the above grouping in the DHUTS. It is also observed that higher limit of income range for MIG in DHUTS is assumed to be lower than it was in the STP study. Therefore, we need to change the income range of MIG for our present study to be in consistent with the DHUTS for further analysis. If we assume that income of each IG increases with the same pace, i.e., with the same rate, then we find that the rate of growth of income is 9.86% (estimated from the income level of LIG considering the present income as in DHUTS and previous income as in STP). With this growth rate, the higher range of income level of MIG in the STP is found approximately Tk 31,200. Therefore, we have redefined the income level and grouped it into four sub categories as follows:

Income Group 1: Monthly HH income with less than Tk. 12,500
Income Group 2: Monthly HH income between Tk 12,500 and less than Tk 30,000
(because of simplicity and near to Tk 31,200 we have taken Tk 30,000)

Income Group 3: Monthly HH income between Tk 30,000 and less than Tk 55,000
Income Group 4: Monthly HH income of Tk 55,000 and over

4.2.4 Classification of Travel by Trip Purpose

In this research, person trips have been split into four categories of purpose based on the procedures followed by the STP (2005) study: Home Based work (HBW), Home Based Education (HBE), Home Based Other (HBO) and Non Home Based (NHB) trips. The definitions of trip purposes used here are given below:

- Home Based Work trips (HBW) – "Trips between the trip-makers' homes and their places of work, which could be trips from home to work trips or the return trips from work to home."(STP, 2005)
- Home Based Education trips (HBE) – "Trips between the trip-makers' homes and the places where they attend an educational institution and which could be from home to the education site or the return trip from school to home." (STP, 2005)
- Home Based Other trips (HBO) – "All other trips with either end of the trip at the trip-maker's homes. These could include travel to or from shopping, visiting, personal business or any other locations except the trip-makers' places of work or education." (STP, 2005).
- Non Home Based trips (NHB) – "All other trips having neither end of the trip at the home of the trip-maker." (STP, 2005)

4.2.5 Mode Classification

In the STP HIS, 20 categories of vehicle type were considered. As already stated in section 3.5.1, the modes bicycle or truck or rail or water transport are insignificant in Dhaka's transport system and so dropped out for the present study. In tabulating the HIS trip data for input to analysis and development of final data set, the remaining 16 modes are categorized into 8 aggregated categories of modes which are shown in Table 4-1.

Table 4-1: Mode Category Considered for the Study

Code	Aggregated Mode Category for Analysis and Model Development	Mode Category in STP HIS
1	Walk	Walk
		Rickshaw
		School Van
3	Taxi	Taxi
4	CNG	CNG
5	Public Bus	Auto Tempo
		Minibus/ Bus (private)
		AC Bus
		Bus (BRTC)
		Bus (Non-BRTC)
6	Private Bus	Staff Bus
		School / College Bus
7	Motor Cycle	Motor Cycle
8	Car/Jeep	Car
		Jeep/ Microbus
		Auto (private)

Also, as found from the HIS, many person trips involve the use of a series of travel modes (walk, rickshaw, auto rickshaw, bus, etc.) by the trip-maker to reach his/her destination. Therefore, for these trips a primary mode was defined as the mode used for the major segment of the trip. A LOOKUP Table is developed in this purpose. The aggregated mode in the above table is used as a primary mode under the following considerations of trips:

- Trips made by staff buses or school / college buses for any part of the journey are classified as trips by private buses;
- Trips that did not use staff bus or school / college bus but did use public buses for any part of the journey were classified as trips by public buses;
- Trips that did not use buses (private or public) for any part of the trip but did use personalized vehicles like cars or motor cycles were classified as trips by

private cars or by motor cycles;

- Trips that did not use buses (public or private) or any personalized motorized vehicles but did use taxi or CNG for any part of the journey were classified as taxi or CNG trips;
- Trips that did not use any motorized modes but did use rickshaw for any part of the journey were classified as rickshaw trips; and
- Trips made entirely by walking were classified as walk trips.

4.3 Analysis of Trip Characteristics

Trip characteristics are analyzed with respect to six viewpoints: trip purpose, zone type, HH size, sex, age, and HH income level.

4.3.1 Trip Characteristics with respect to Trip Purpose

Figure 4-1 indicates that most trips (35%) are attributed to home based other (HBO) purpose followed by HBW, HBE and NHB purposes with 31%, 26% and 8% respectively.

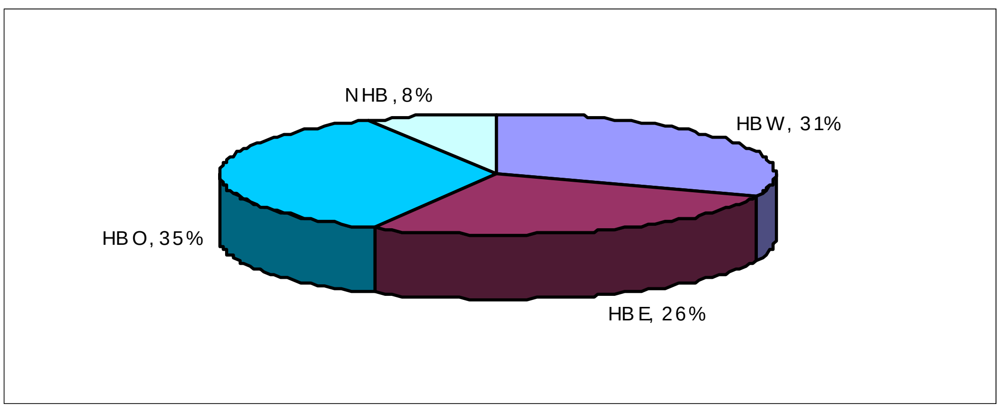


Figure 4-1: Proportion of Trips by Trip Purpose

It is worth mentioning that in the STP Working Paper (WP) No.7 Survey Results in December, 2004, the composition of trips by purpose was reported as, HBW: 31%, HBE :25%, HBO: 36% and NHB: 8%. Again, in the STP WP No.7 Survey Results (Revised) in May, 2005 and the STP Report in December, 2005, the trip purpose composition was noted as HBW: 32%, HBE: 13%, HBO: 46% and NHB: 9%. BUET, the counterpart consultant team in STP project, carried out an independent analysis of the raw data of

Household Interview Survey (HIS) and commented that HBE trips were much higher and HBO trips were much lower as compared to the revised STP WP No.7; rather very similar to that reported in the earlier WP by the Consultant. With the investigation of available and valid data set, we have also found the results to be conformed to the BUET comments and matched with the earlier reported data by the STP consultant.

The distribution of trips by purpose in the recent DHUTS study (2010) is shown in Figure 4-2. Excluding 'To Home' trips, most of the trips are dominated by 'Private' and 'Home to Work' purposes, accounting for 23% and 16% respectively, followed by 'Home to School' and 'Non Home Based Business' purposes.

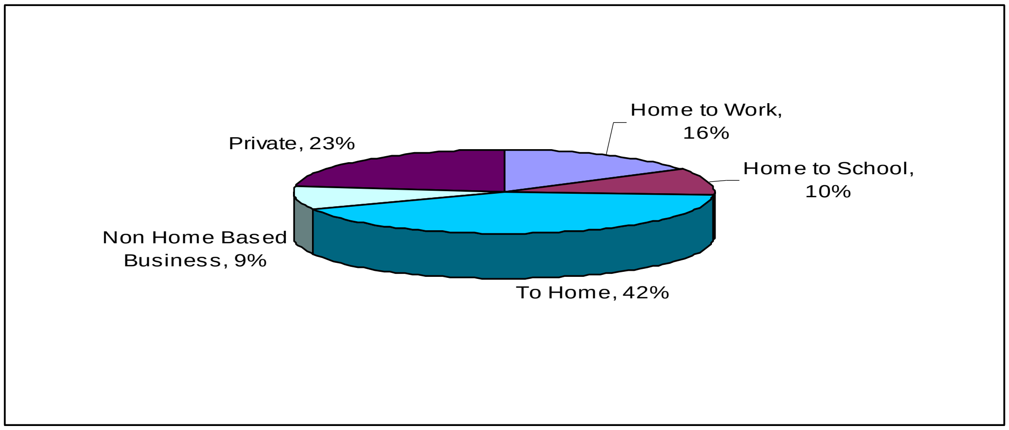


Figure 4-2: Trip Purpose Composition in the DHUTS Study (Source: JICA, 2010)

4.3.2 Trip Characteristics with respect to Zone Type

Of all the trips, 80% are inter zonal and the rest 20% are made within the same TAZ area (Figure 4-3).

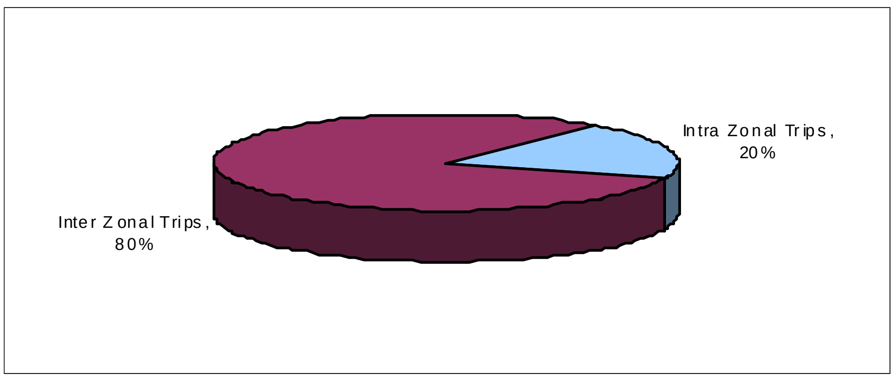


Figure 4-3: Proportion of Trips by Zone Type

From Table 4-2, it has been observed that over one-third of education trips are intra zonal, whereas for all other trip purposes, intra zonal trips are less than 20%.

Table 4-2: Proportion of Trips by Zone Type for Each Trip Purpose

Zone Type	HBW	HBE	HBO	NHB
Intra zonal	17%	37%	11%	7%
Inter zonal	83%	63%	89%	93%
	100%	100%	100%	100%

Table 4-3 shows that most intra zonal trips are education trips (50%). This is indicative of the fact that people are likely to choose their residential locations in the vicinity of the educational institutions of their children as compared to proximity of work stations. Majority of inter zonal trips are home based other trips (39%) such as shopping, social, medical or recreational trips followed by home based work trips (32%).

Table 4-3: Proportion of Trips by Trip Purpose for Each Zone Type

Purpose	Intra Zonal	Inter Zonal
HBW	27%	32%
HBE	50%	21%
HBO	19%	39%
NHB	3%	9%
	100%	100%

4.3.3 Trip Characteristics with respect to HH Size

It has been found from Figure 4-4 that HH group 3 (HHs with 4 members) is the highest trip maker followed by HH group 4 (HHs with 5 members), HH group 2 (HHs with 3 members), HH group 5 (HHs with 6 and more members) and HH group 1 (HHs with 1 or 2 members).

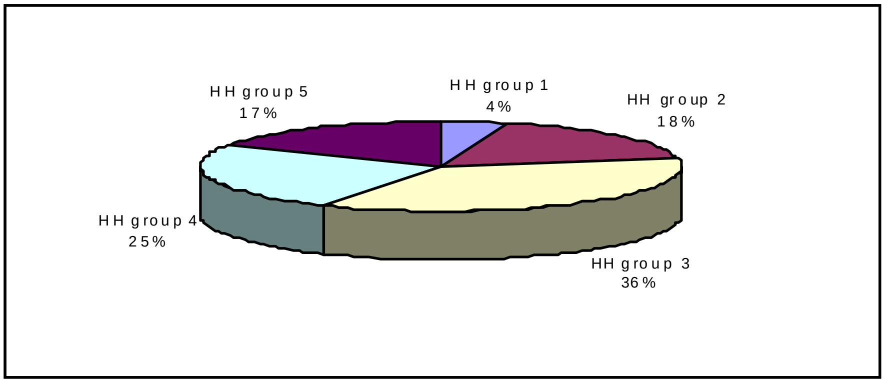


Figure 4-4: Proportion of Trips by HH Size

Table 4-4 shows share of trips for each HH group under different trip purposes. HHs with maximum of 2 members (group 1) share nearly equal percentage of HBO and HBW trips. HH group 2 shares more HBO trips than any other type of trip. Like HH group 2, HHs with 4 members (group 3) make more HBO trips, followed by nearly equal share of work and education trips. HH group 4 (5 members) share education trips more than other trip purposes. The share of home based work, education and other trips is above 30% each by HHs with more than 5 members. Overall it can be observed that all the HHs with different number of members make HBO trips more than any other type.

Table 4-4: Proportion of Trips by Trip Purpose for Each HH Size

Purpose	HH Size Group				
	1	2	3	4	5
HBW	42%	34%	30%	28%	30%
HBE	3%	16%	28%	33%	30%
HBO	41%	41%	34%	32%	33%
NHB	14%	9%	8%	7%	7%
	100%	100%	100%	100%	100%

Table 4-5 shows the percentage of trips by HH group for each trip purpose. Majority of trips of all types are made by HH group 3.

Table 4-5: Proportion of Trips by HH Size for Each Trip Purpose

HH Size Group	HBW	HBE	HBO	NHB
1	6%	0%	5%	8%
2	20%	11%	20%	20%
3	35%	38%	35%	36%
4	23%	31%	23%	21%
5	17%	19%	16%	15%
	100%	100%	100%	100%

4.3.4 Trip Characteristics with respect to Sex

The Figure 4-5 shows the share of trips made by male and female where the ratio of trips by male to that of female is about 2:3.

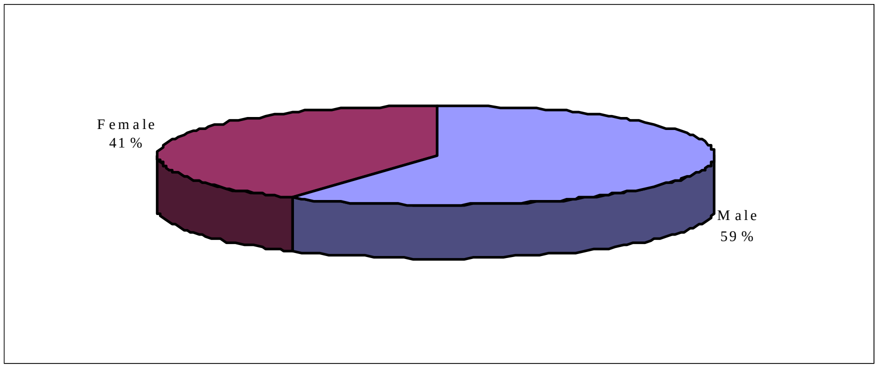


Figure 4-5: Proportion of Trips by Sex

Men make HBW trips more following HBE and HBO trips with almost equal share, while women make over 85% of their trips for HBO and HBE purposes (see Table 4-6).

Table 4-6: Proportion of Trips by Trip Purpose for Each Sex

Purpose	Male	Female
HBW	45%	10%
HBE	22%	33%
HBO	21%	54%
NHB	12%	2%
	100%	100%

HBE and HBO trips are mostly made by women as compared to those made by men, while the shares of work trips and non-home based trips by women are less than 15% (see Table 4-7).

Table 4-7: Proportion of Trips by Sex for Each Trip Purpose

Sex	HBW	HBE	HBO	NHB
Male	86%	48%	36%	87%
Female	14%	52%	64%	13%
	100%	100%	100%	100%

4.3.5 Trip Characteristics with respect to Age

Figure 4-6 illustrated that young and mature people aged between 20 and 49 years (age groups 3 and 4) make 64% of all trips. The share of trips by older people aged 60 years and above is only 4%.

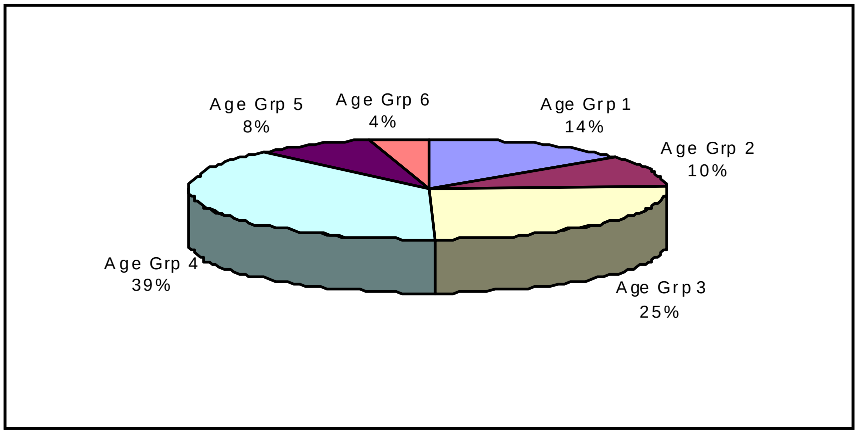


Figure 4-6: Proportion of Trips by Age Group

Table 4-8 shows that people under 20 years of age (age groups 1 & 2) mostly make education trips followed by HBO trips. Young people (20~29 years, age group 3) as well as older people (60 years and above, age group 6) make HBO trips more than other types. The most significant share of trips by people aged between 30 and 59 years representing age group 5 is attributed to HBW purpose followed by HBO purpose.

Table 4-8: Proportion of Trips by Trip Purpose for Each Age Group

Purpose	**Age Group**					
	1	**2**	**3**	**4**	**5**	**6**
HBW	2%	11%	29%	44%	50%	33%
HBE	84%	58%	23%	7%	1%	2%
HBO	13%	28%	41%	38%	39%	58%
NHB	1%	3%	8%	11%	11%	8%
	100%	100%	100%	100%	100%	100%

HBW, HBO and NHB trips are most significant for people aged between 30 and 49 years, while the share of HBE trips decreases with older people (see Table 4-9).

Table 4-9: Proportion of Trips by Age Group for Each Trip Purpose

Age Group	HBW	HBE	HBO	NHB
1	1%	46%	5%	1%
2	4%	22%	8%	3%
3	23%	22%	29%	25%
4	54%	10%	42%	55%
5	14%	0%	9%	12%
6	4%	0%	6%	4%
	100%	100%	100%	100%

4.3.6 Trip Characteristics with respect to HH Income Level

HH income group 1 and 2, i.e., HH with monthly income less than Tk 30,000 share almost 80% of total trips (see Figure 4-7).

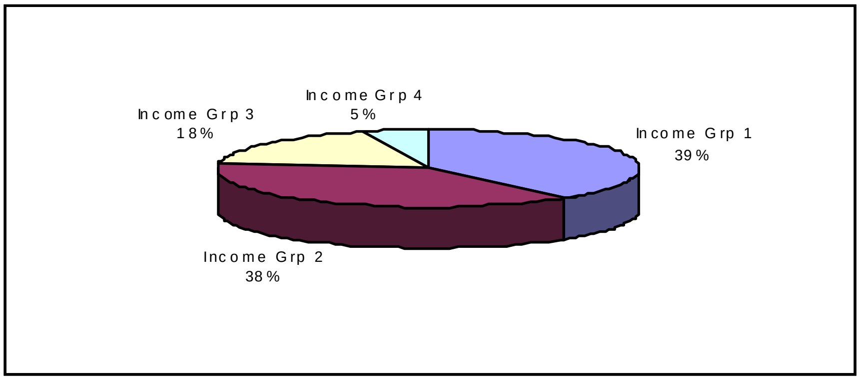


Figure 4-7: Proportion of Trips by HH Income Group

Table 4-10 presents the share of trips for each HH income group. The share of HBO trips increases with increasing HH income level, with maximum 38% share by income group 1 and minimum 30% share by income group 4. For high income people (income group 4), the share of HBW trips are more (32%) followed by HBO (30%) and HBE (27%) trips. All HHs make nearly 10% of NHB trips.

Table 4-10: Proportion of Trips by Trip Purpose for Each HH Income Group

Purpose	HH Income Group			
	1	**2**	**3**	**4**
HBW	31%	31%	29%	32%
HBE	24%	27%	29%	27%
HBO	38%	34%	32%	30%
NHB	7%	8%	10%	11%
	100%	100%	100%	100%

Most of the HBW and HBO trips are made by HH income group 1, where most of the HBE and NHB trips are made by HH income group 2 (see Table 4-11).

Table 4-11: Proportion of Trips by HH Income Group for Each Trip Purpose

HH Income Group	HBW	HBE	HBO	NHB
1	40%	36%	42%	33%
2	38%	39%	37%	37%
3	17%	20%	17%	23%
4	5%	5%	4%	7%
	100%	100%	100%	100%

Table 4-12 shows the percentage of trips by trip purpose and income group estimated in the recent DHUTS study. The share of NHBB trips increases with increasing household income.

Table 4-12: Proportion of Trips by Purpose and Income Group in DHUTS Study

Purpose	HIG	MIG	LIG
Home to Work	16.1%	15.6%	16.6%
Home to School	10.1%	11.0%	9.9%
To Home	41.2%	41.7%	41.6%
Non Home Based Business	9.8%	9.1%	8.6%
Private	22.9%	22.7%	23.2%
	100%	100%	100%

4.4 Analysis of Mode Choice Characteristics

Mode choice behavior is analyzed in different aspects of modal share to have an overall idea regarding selection of mode.

4.4.1 Modal Share in the Study Area

Figure 4-8 demonstrates the modal share of trips made within the study area. It indicates that the share of non-motorized transport (rickshaw and walk) is significant, which accounts for 47%, where rickshaw having 36% share is the most significant among all modes. The next significant mode is public bus accounting 32% of all trips. Among motorized transport, the share of bus is more than 60%.

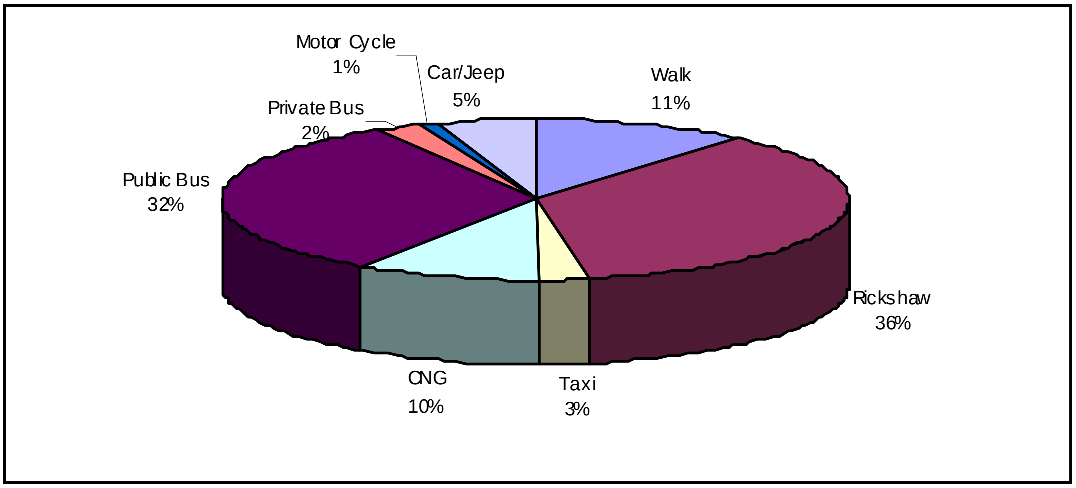


Figure 4-8: Modal Share Composition of Trips

The share of modes among four travel purposes is shown in Table 4-13. It reveals that the share of walk is most significant for HBW and HBE trips, rickshaw for HBO and HBE trips, taxi and CNG for HBO trips, Public bus for HBW and HBO trips, motor cycle for HBW trips and car/jeep for HBW and HBO trips.

Table 4-13: Proportion of Trips by Trip Purpose for Each Travel Mode Used

Modes	Walk	Rickshaw	Taxi	CNG	Public Bus	Private Bus	Motor Cycle	Car/Jeep
HBW	40%	23%	17%	15%	38%	60%	64%	35%
HBE	46%	37%	5%	10%	16%	36%	0%	20%
HBO	12%	35%	67%	65%	35%	0%	11%	30%
NHB	2%	5%	11%	9%	10%	5%	25%	16%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Table 4-14 shows modal share for each trip purpose. The major portion of HBW trips are made by public bus followed by rickshaw and then by walk. The major portion of HBE trips is made by rickshaw followed by nearly equal share of public bus and walk. HBO trips are mostly taken by rickshaw and public bus. The share of CNG is also significant for HBO trips. Most of the NHB trips are taken by public bus.

Table 4-14: Proportion of Trips by Travel Mode for Each Trip Purpose

Modes	HBW	HBE	HBO	NHB
Walk	14%	19%	4%	3%
Rickshaw	27%	50%	36%	24%
Taxi	1%	1%	5%	3%
CNG	5%	4%	18%	11%
Public Bus	40%	20%	33%	43%
Private Bus	4%	3%	0%	1%
Motor Cycle	2%	0%	0%	4%
Car/Jeep	6%	4%	4%	10%
	100%	**100%**	**100%**	**100%**

In the recent DHUTS study (2010), it has been found that (Figure 4-9) NMT (walking and rickshaw) is the most significant mode in DMA accounting for 58% of total trips. Next is bus transport (28%), including large bus, mini bus and micro bus. The share of private car, including jeep and taxi, accounts for 5% of all trips. In comparison with the modal share in 2004 (Figure 4-8), it can be observed that rickshaw is still the dominant mode of transport. The share of public bus, and auto rickshaw (CNG and Taxi) is decreased by a total of 6%, while the share of walk increases by 9%.

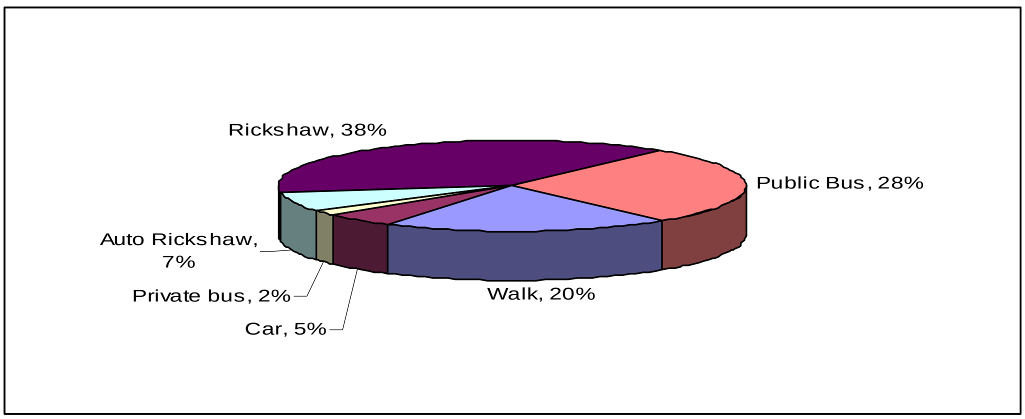


Figure 4-9: Modal Share in the DHUTS Study (Source: JICA, 2010)

4.4.2 Comparative Figure of Modal Share between Different Types of Attributes for All Trip Purposes

The modal share between zone types (intra and inter), sexes (male and female), income groups, age groups are depicted and briefly discussed in this section to have a comparative idea of choice of travel mode made by groups of these attributes.

4.4.2.1 Comparative Figure of Modal Share between Zone Types for All Trip Purposes

Figure 4-10 indicates that the share of walk trips is more for intra zonal HBW, HBE and HBO trips than that for inter zonal trips of those types. The share of rickshaw is almost 40% for intra zonal HBE trips, while the share of rickshaw is 20% or less for other intra zonal trips as compared to inter zonal trips.

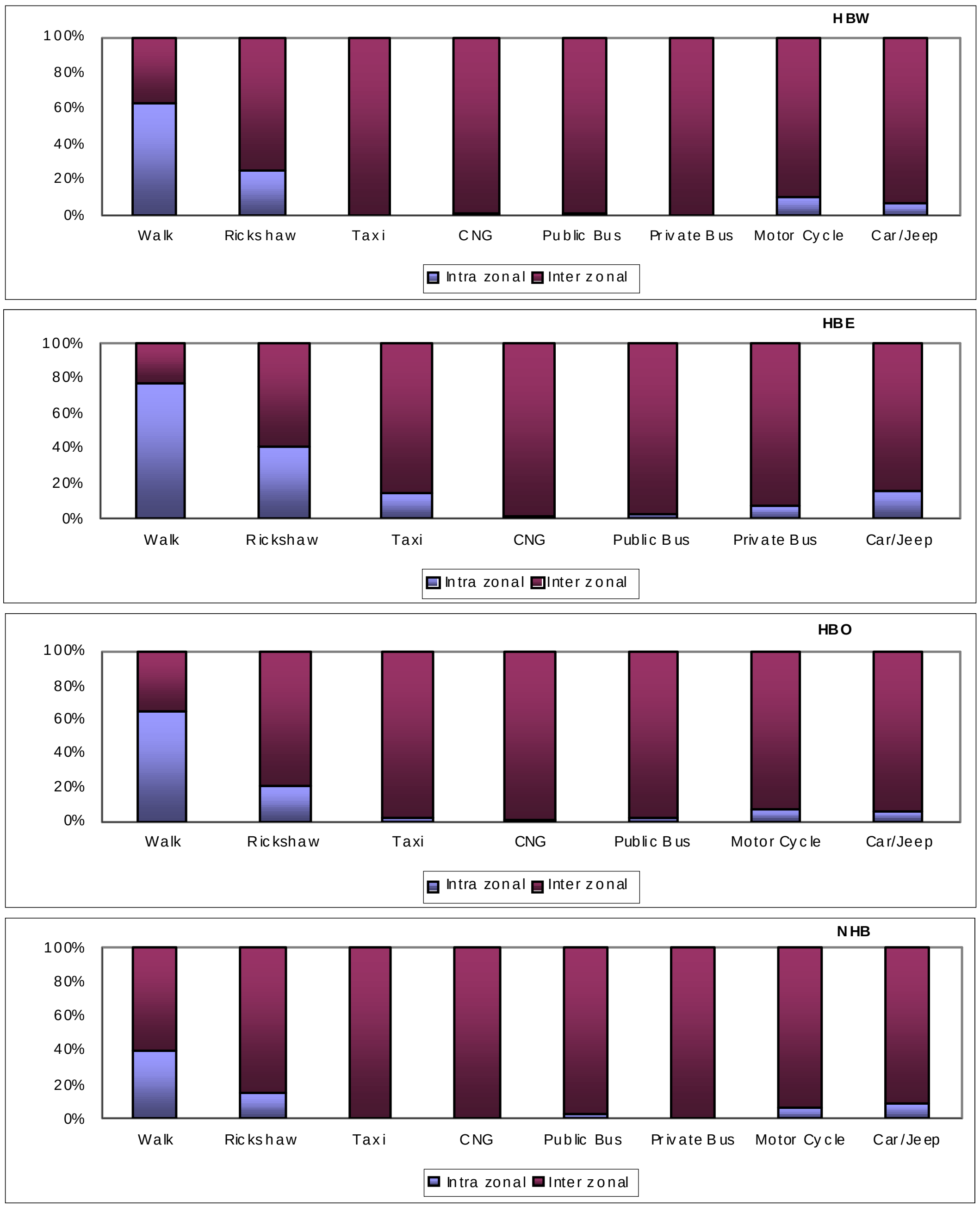


Figure 4-10: Comparison of Modal Share between Zone Types for All Purposes

4.4.2.2 Comparative Figure of Modal Share between Sexes for All Trip Purposes

Figure 4-11 illustrates that the share of all modes for work and non-home based trips by men is substantially higher than that by women. For education trips, women's share of all modes except taxi and public bus is more in comparison with men's share. Women use rickshaw, taxi, CNG, car/jeep as many as three to four times as compared to the use of these modes by men for HBO trips.

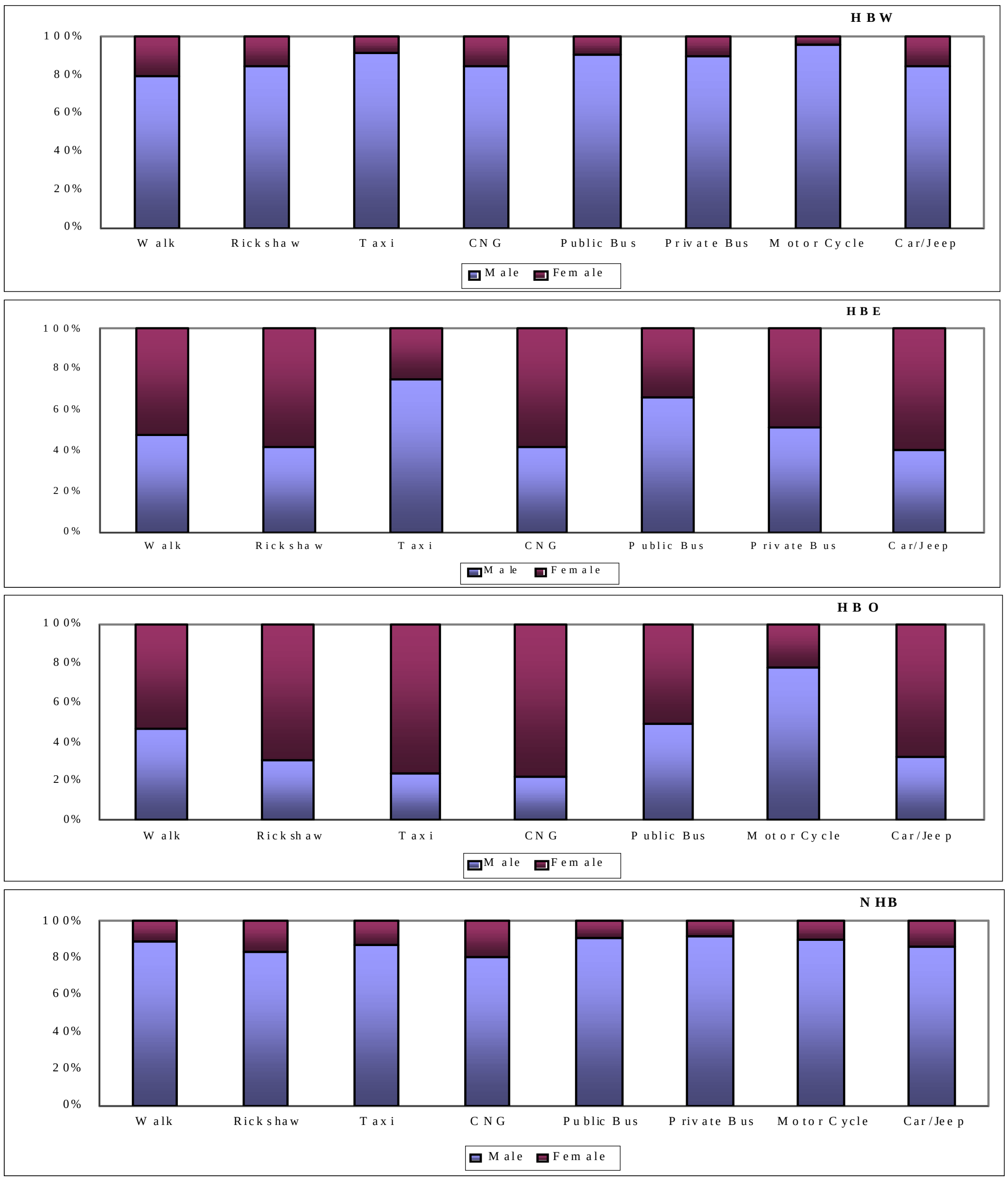


Figure 4-11: Comparison of Modal Share between Sexes for All Purposes

4.4.2.3 Comparative Figure of Modal Share between Age Groups for All Trip Purposes

Figure 4-12 shows that the share of all corresponding modes used for HBW, HBE and NHB trip purpose by middle age people (30~49 years) is more as compared to the share by others. School going children (4~14 years) walk or use rickshaw, private bus, or car/jeep more than any other student. College/ University going students (15~29 years, age group 2 & 3) use CNG and public bus in higher percentages than any other students or people accompanying students. The highest share (40%) of CNG by people aged between 30 to 49 years indicates that they use the mode to carry their son/daughter to educational institutions.

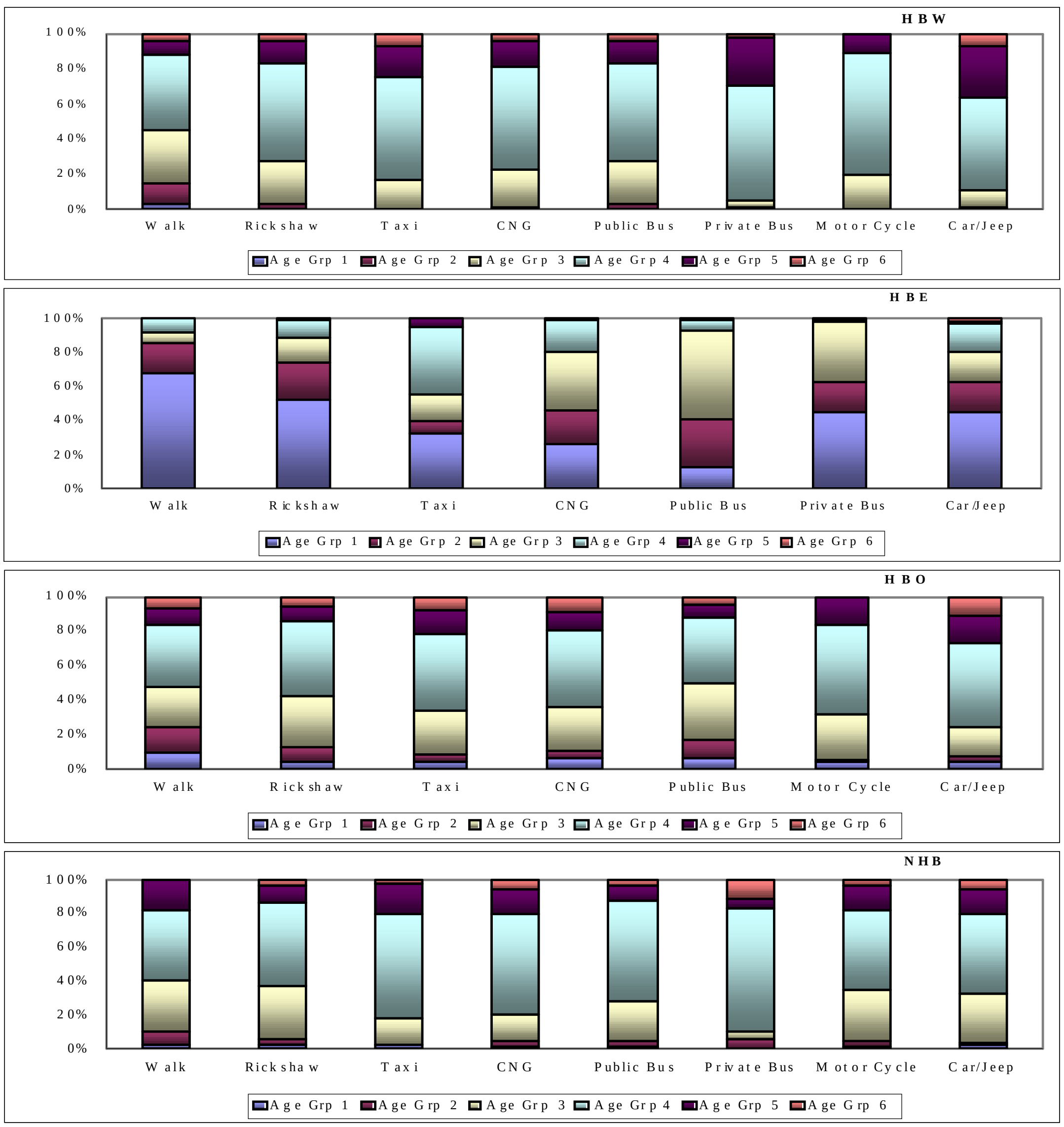


Figure 4-12: Comparison of Modal Share between Age Groups for All Purposes

4.4.2.4 Comparative Figure of Modal Share between Income Groups for All Trip Purposes

Figure 4-13 demonstrates that the share of walk and public bus modes for any trip purpose by income group 1 is more than that by other income groups. The share of rickshaw is more than 75% by income groups 1 and 2 for all trips. The share of CNG by income group 3 is dominant except for HBE trips, while the share of taxi by income group 3 is dominant except for HBO trips. The share of car/jeep is significant for income groups 3 and 4.

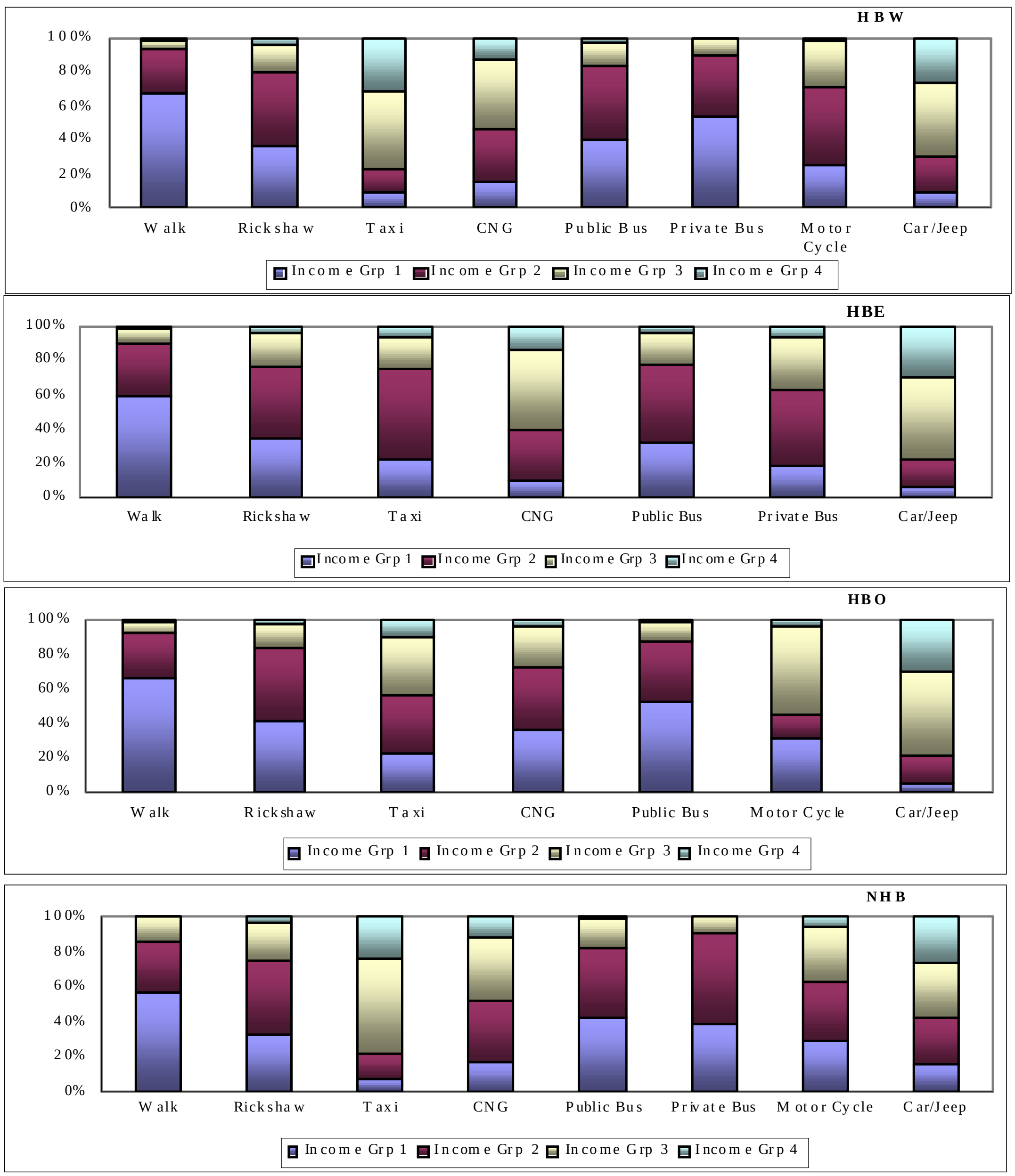


Figure 4-13: Comparison of Modal Share between Income Groups for All Purposes

4.4.3 Modal Share by Individual Attributes for Different Trip Purposes

4.4.3.1 Modal Share by Zone Type for Different Trip Purposes

Intra Zonal: Rickshaw and walk are the most significant modes for intra zonal trips (see Figure 4-14).

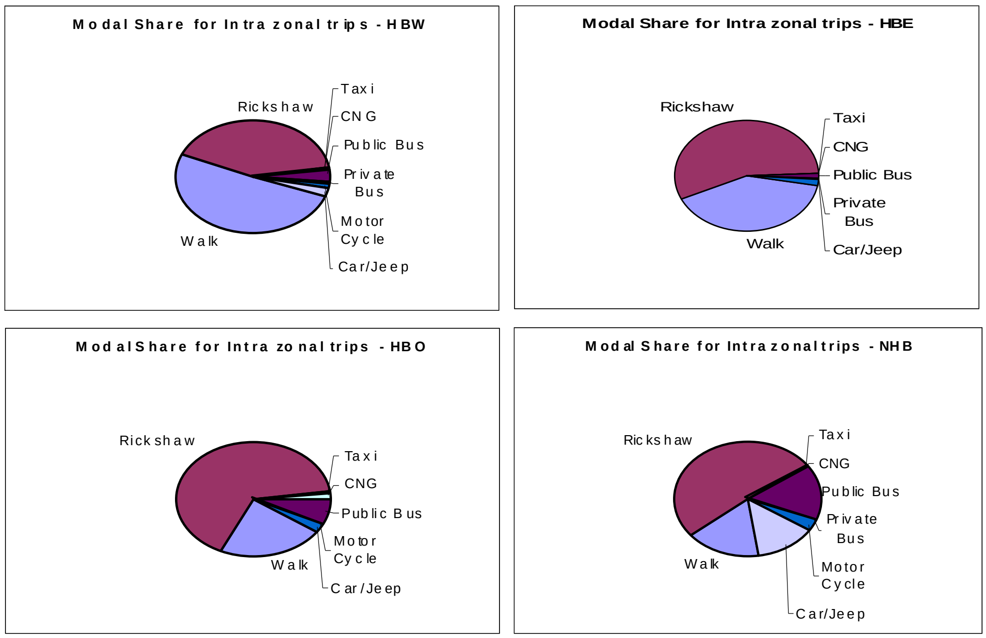


Figure 4-14: Intra Zonal Modal Share

Inter zonal: Rickshaw and public bus are most frequent modes followed by CNG and car/jeep for inter zonal trips (see Figure 4-15).

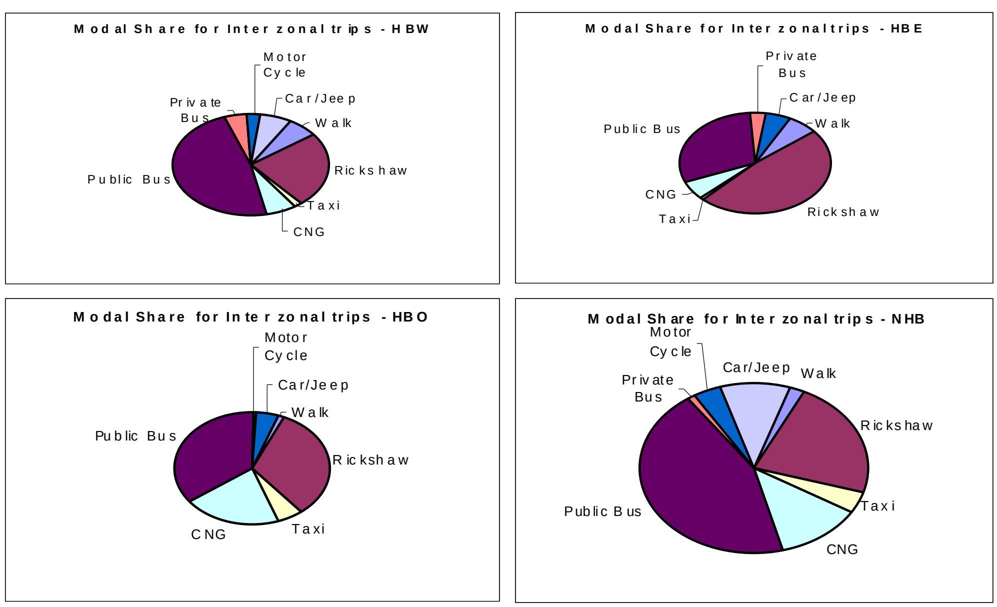


Figure 4-15: Inter Zonal Modal Share

4.4.3.2 Modal Share by Each Sex for Different Trip Purposes

Male: Public bus is the frequently used mode by men followed by rickshaw for HBW, HBO and NHB trips. For HBE trips, rickshaw is followed by public bus as frequently used mode. Walk has the 3rd largest share for making HBW and HBE trips, where CNG takes that place for other trip purposes. Car/jeep has nearly equal share of trips as compared to CNG trips (see Figure 4-16).

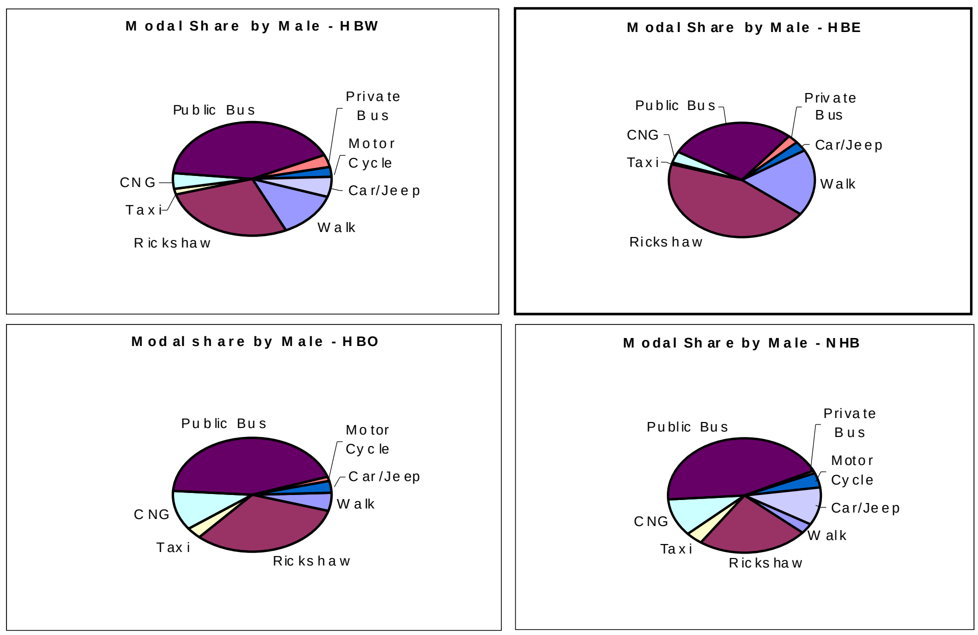


Figure 4-16: Modal Share by Male

Female: Rickshaw is the most significant mode used by female trip makers irrespective of purpose of trip. The 2nd largest share of trips is walk for HBE trips and public bus for other trip purposes. CNG is the next widely used mode for making HBO and NHB trips. The modal share of CNG used for all trip purposes by female trip makers ranks in the same order as compared to their use by male counterparts (see Figure 4-17).

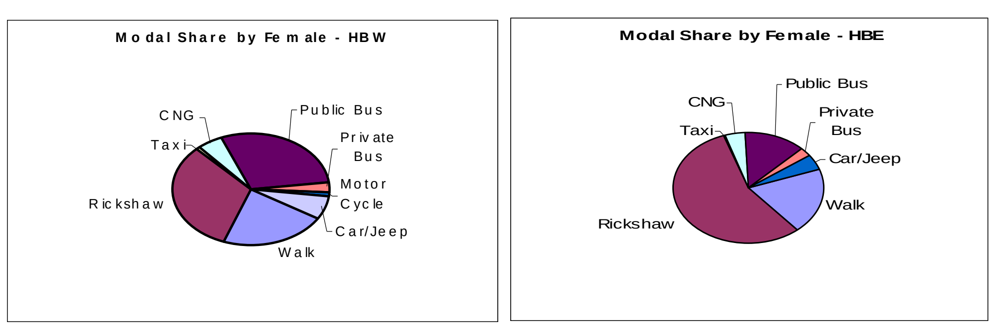


Figure 4-17: Modal Share by Female (contd.)

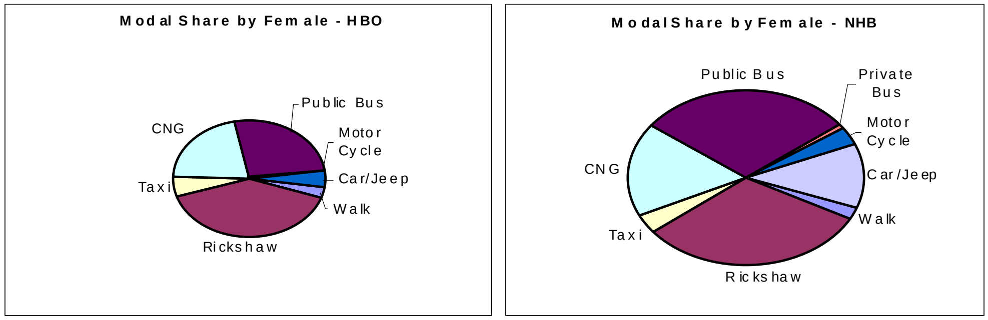


Figure 4-17: Modal Share by Female

4.4.3.3 Modal Share by Each Age Group for Different Trip Purposes

Age Group1: People of 14 years or less most frequently used rickshaw for making HBE and NHB trips, and bus/tempo for HBO trips. Walk contributes to 57% of total trips for HBW trips made by AG 1 (See Figure 4-18).

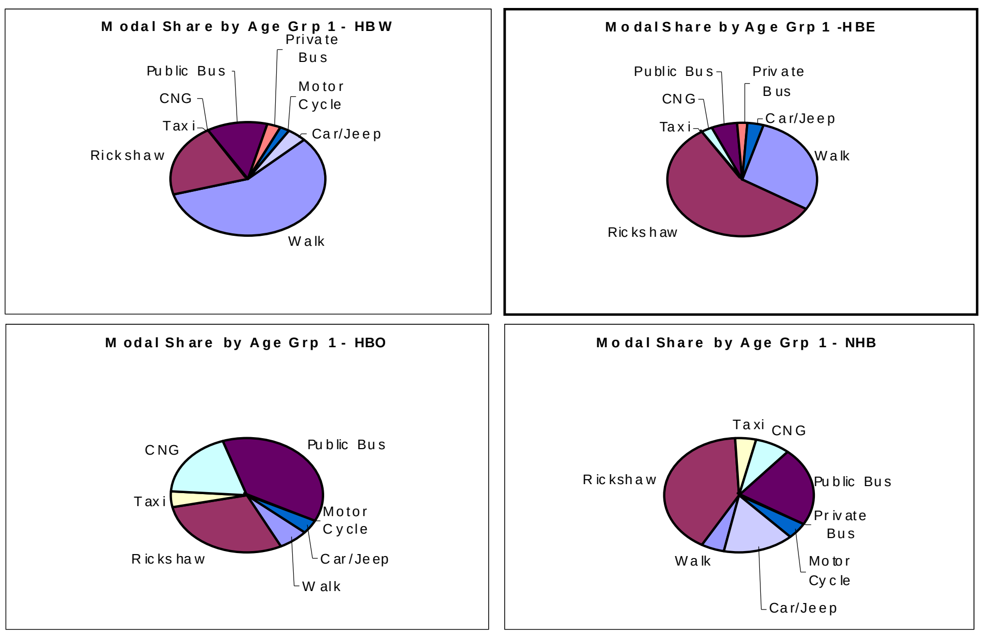


Figure 4-18: Modal Share by Age Group 1

Age Group2: Public bus and rickshaw are two significant modes for making trips, while walk is the most frequent mode for HBW trips. CNG use increases with HBW, HBE, HBO and NHB trips. Taxi is not so frequently used (see Figure 4-19).

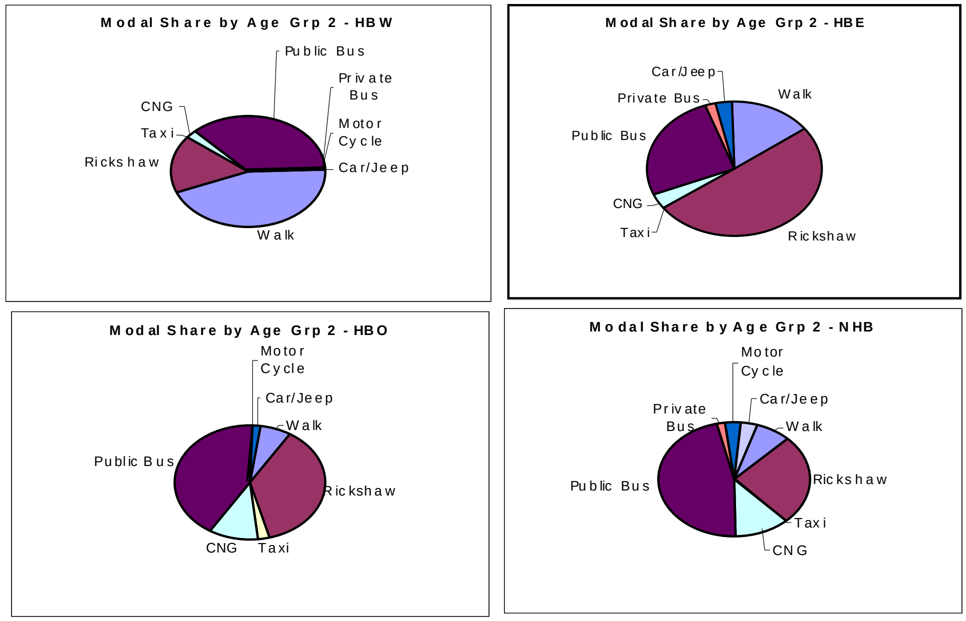


Figure 4-19: Modal Share by Age Group 2

Age Group3: Public bus is the most frequent mode followed by rickshaw for the people of this age group. CNG is the next frequently used mode except for NHB trips for which car/jeep takes the place (see Figure 4-20).

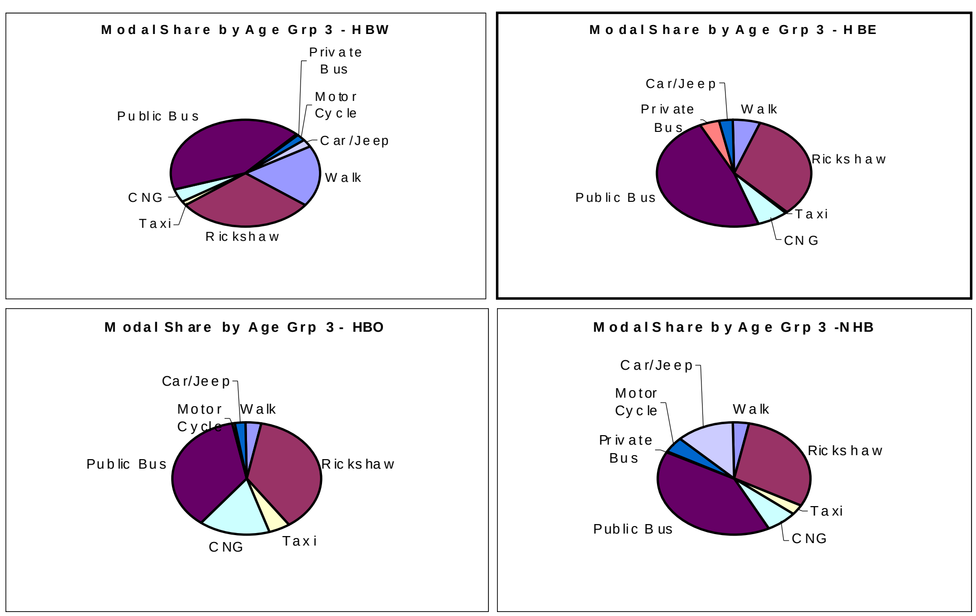


Figure 4-20: Modal Share by Age Group 3

Age Group 4, 5, 6: Public bus followed by rickshaw is the most frequent mode used by people aged over 29 years for making work and non-home based trips. Rickshaw is the most frequent mode followed by either public bus or CNG or car/jeep for making education and other home based trips (see Figures 4-21, 4-22 and 4-23).

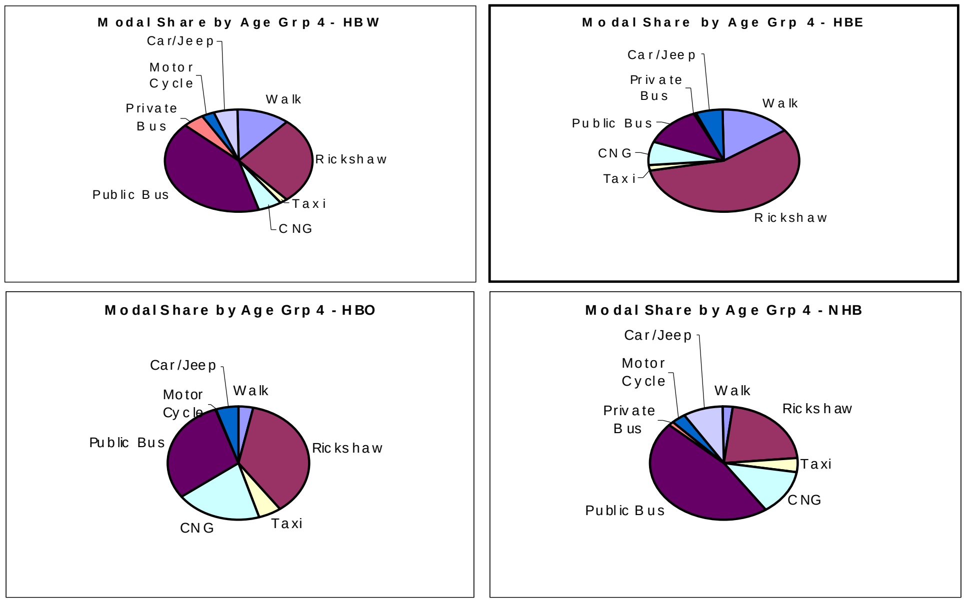


Figure 4-21: Modal Share by Age Group 4

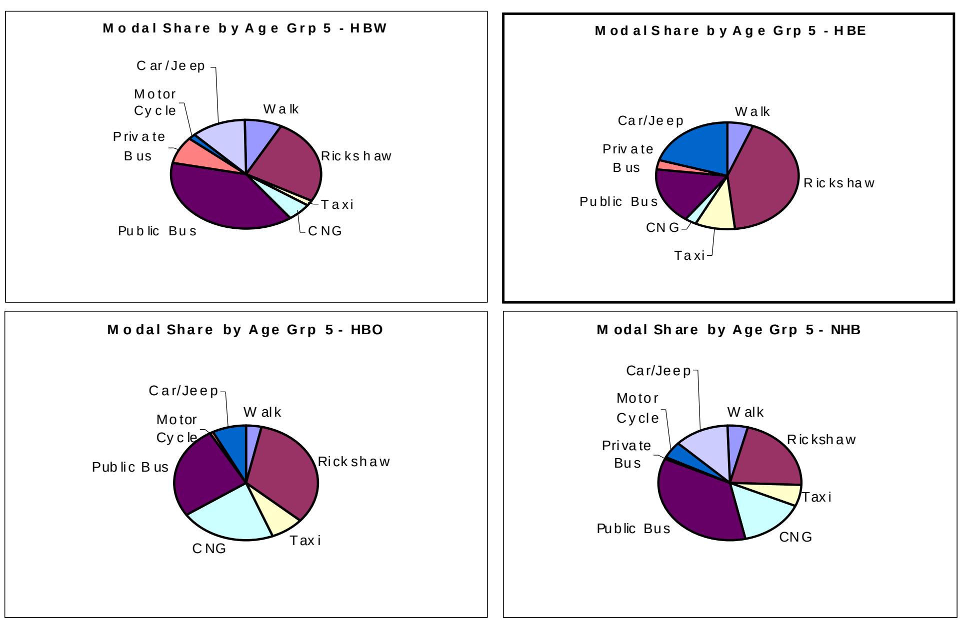


Figure 4-22: Modal Share by Age Group 5

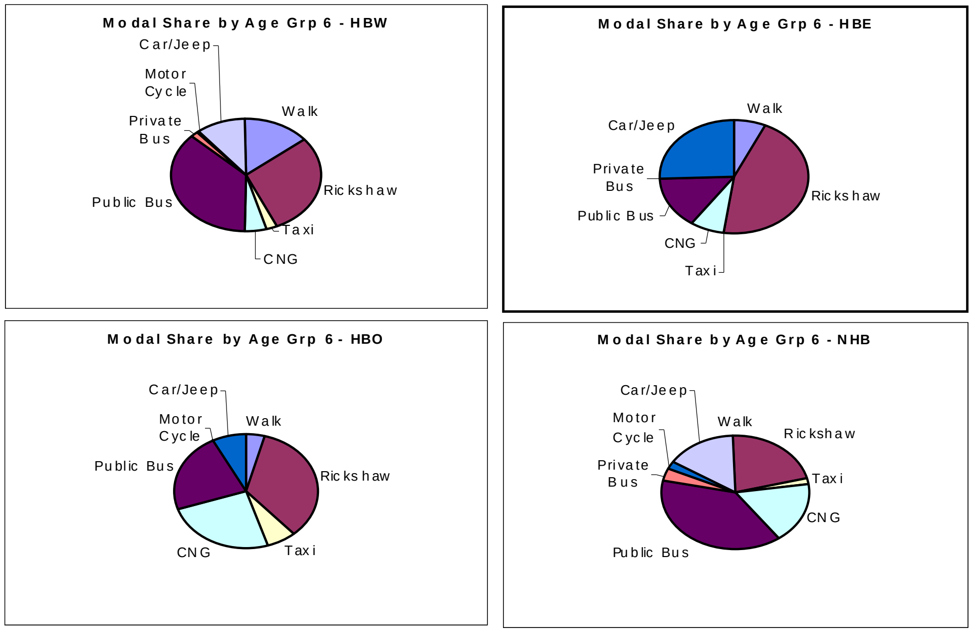


Figure 4-23: Modal Share by Age Group 6

4.4.3.4 Modal Share by Each HH Income Group for Different Trip Purposes

Income Group 1: Lower income group people most significantly use public bus for HBW, HBE and NHB trips and use rickshaw for HBE trips (see Figure 4-24).

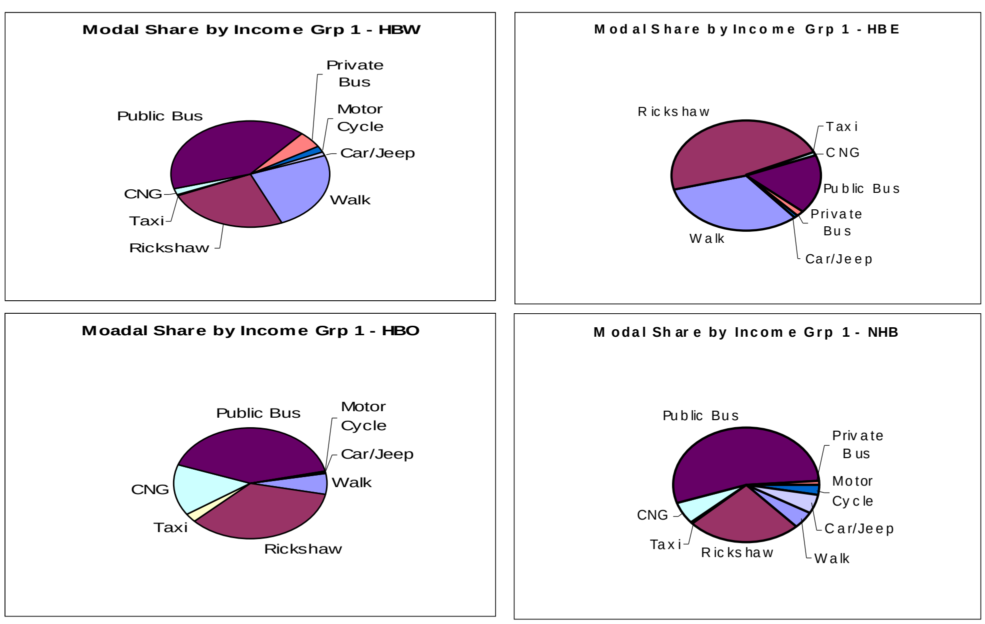


Figure 4-24: Modal Share by Income Group 1

Income Group 2: People under income group 2 frequently use public bus and then rickshaw for work and non-home based trips, while the use of these modes interchanges their places for education and other trips. The next frequent mode is walk for HBW and HBE trips and CNG for HBO and NHB trips (see Figure 4-25).

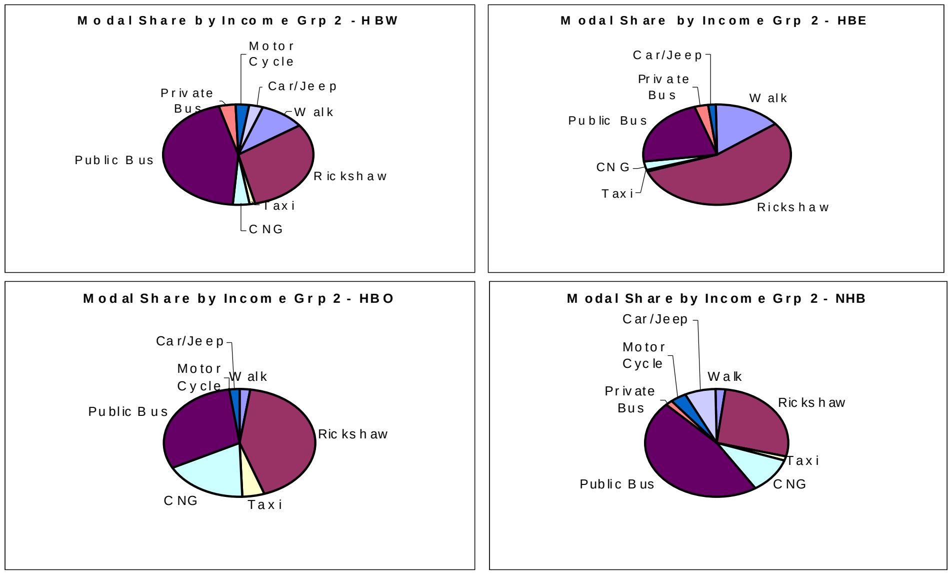


Figure 4-25: Modal Share by Income Group 2

Income Group 3: Public bus is the most frequent mode for HBW trips by people of this income group. The share of rickshaw for education trips is nearly 50%. Public bus and rickshaw are also frequently used for HBO and NHB trips. CNG and car/jeep have nearly equal share of trips for HBW, HBE and NHB purpose (see Figure 4-26).

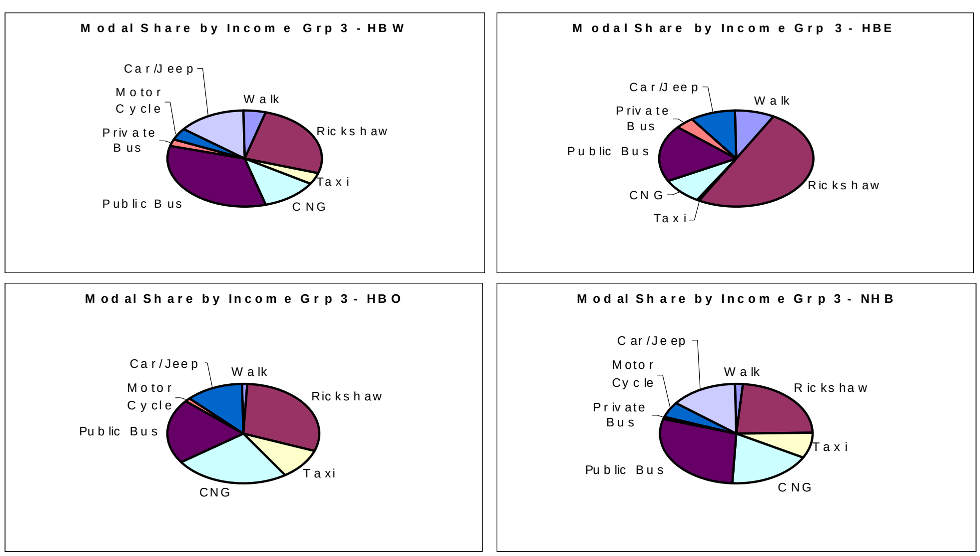


Figure 4-26: Modal Share by Income Group 3

Income Group 4: Car/jeep is the most significant mode taken up by high income people for HBW, HBO and NHB trips. It is evident from the fact that people under this group own more personalized car. Rickshaw is still the most frequent mode for home based education trips (see Figure 4-27).

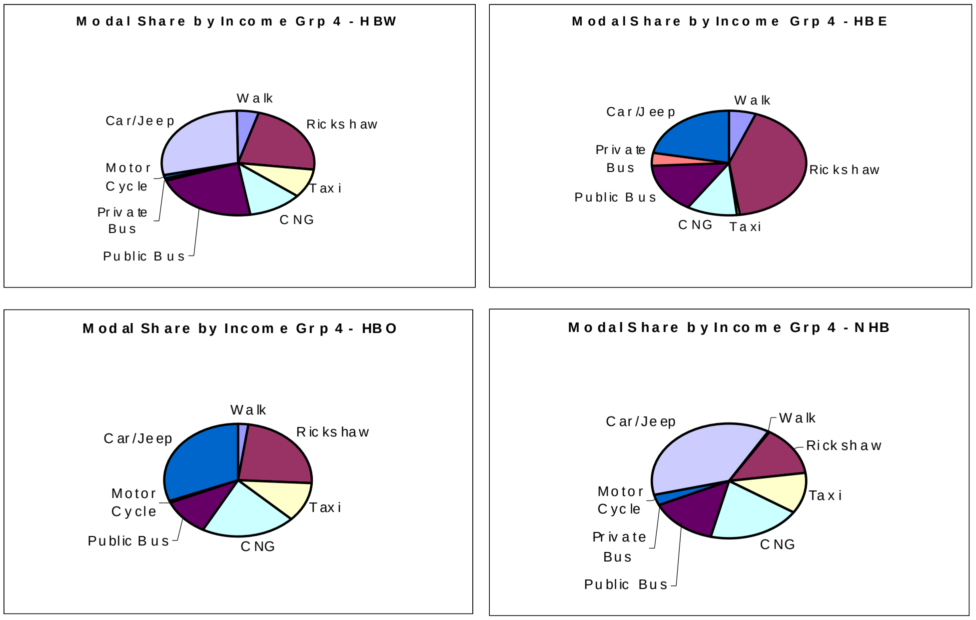


Figure 4-27: Modal Share by Income Group 4

4.5 Modeling the Effects of Socio-economic Factors on Mode choice

Multinomial logistic regression (MNLR) is performed to analyze the effects of socio-economic factors on choice of travel mode. It has been found from the graphs and charts in previous sections that many factors are contributed to selection of modes. MNLR is aimed at to determine analytically the relationship between the factors and mode choice. We have used SPSS 17.0 for our analysis. SPSS is an easily available, flexible and well-known package for statistical analysis. Before going through the detailed analysis, we put some insight on MNLR.

Logistic regression is a class of regression where the independent variable continuous and/or categorical in nature is used to predict the dependent variable which must be categorical in nature. When the dependent variable has two categories, then it is binary logistic regression. When the dependent variable has more than two categories, then it is called multinomial logistic regression**.**

The independent or predictor variables in logistic regression can take any form. That is, logistic regression makes no assumption about the distribution of the independent variables. They do not have to be normally distributed, linearly related or of equal variance within each group. The relationship between the predictor and response variables is not a linear function in logistic regression; instead, the logistic regression function (logit) is used. The impact of predictor variables is usually explained in terms of odds ratios.

Logistic regression applies maximum likelihood estimation after transforming the dependent into a logit variable which is the natural log of the odds. Odds are expressed as the ratio of the probability that an event will occur divided by the probability that an event will not occur. Let *z* be the logit (log odds) for a dependent variable, then the logistic prediction equation is:

$$z = \ln[odds(event)] = \ln\left[\frac{prob(odds)}{prob(non-event)}\right] = \ln\left[\frac{prob(event)}{1-prob(event)}\right]$$
$$= b_0 + b_1X_1 + b_2X_2 + \ldots\ldots\ldots\ldots + b_kX_k \qquad (4.1)$$

where b_0 is the constant, "*b*" terms are the logistic regression coefficients, also called parameter estimates and there are k independent (X) variables. Exp(b) is the odds ratio for an independent variable. An Exp(b)>1 means the independent variable increases the logit and therefore increases odds(event). If Exp(b) = 1.0, the independent variable has no effect. If Exp(b) is less than 1.0, then the independent variable decreases the logit and therefore decreases odds(event).

The results of parameter estimates under multinomial logistic regression method for each of the trips are shown in Tables 4-15 to 4-18. The independent variables that have been deemed here are sex, household income group and age. The number of persons under different age groups, for example, age groups 1, 5 and 6 are very small in proportion relative to people in other groups. Thus the age factor, if taken as groups for analysis would produce unreasonable and insignificant results. Therefore, sex and income are taken as categorical variables and age is taken as continuous variable. In each of the models, we have taken the use of car/jeep as the reference category; the parameters estimated here express all modes relative to car/jeep.

The log odds of person's age in which *b* coefficients are statistically significant for all modes except for taxi in HBW trips have value less than 1.0 indicating that with growing age, people are less likely to choose these modes relative to car/jeep. The *b* coefficient of age factor for all modes in HBE trips has been found statistically significant. The log odds of age for walk, rickshaw and private bus being less than 1.0 indicate that people with increasing age are less likely to choose these modes relative to car/jeep; while the log odds of age for taxi, CNG and public bus being greater than 1.0 indicates that people with increasing age are more likely to choose these modes relative to car/jeep. The significant b coefficients of age factor for walk, rickshaw, CNG, public bus and motor cycle modes in HBO trips result in logits less than 1.0 which suggest that people growing with age are reluctant to use these modes relative to the reference mode car/jeep. The b coefficients of rickshaw and CNG in NHB trips are found significant at 0.05 level.

Women show much less propensity to use public bus and motor cycle, whatever be the trip purpose. For example, Exp(b) of 0.227 for female in HBW trips implies that the log odds decreased by 77.3% (0.227-1=0.773). This indicates that women are 77.3% less likely to choose motor cycle than men relative to car/jeep. Women are more likely to choose CNG for HBO and HBE trips than their counterparts relative to car/jeep which is evident from the Exp(b) of 1.391 and 1.015 for female in HBO and NHB trips respectively.

Household income has found to have the strongest relationship with modal choice. Except in cases of taxi in all IGs for HBW trips, in IG 3 for HBE trips, in IGs 1 and 2 for NHB trips and walk in IG 3 for HBO trips, the b coefficients for all other modes are significant at maximum 0.05 level. The log odds of walk in income group 1 (low income) have much higher value; for example - 106.374 for HBW trips, 199.826 for HBE trips, 150.510 for HBO trips, 88.983 for NHB trips; indicating that people in this income group are more likely to choose walk than higher income group people relative to car/jeep. Propensity to walk mode decreases with higher income. Rickshaw, public bus, private bus and motor cycle are much more likely to be chosen by low income people than high income people relative to reference mode car/jeep.

Multi-colinearity in the multinomial logistic regression solution is detected by examining the standard errors for the *b* coefficients. A standard error larger than 2.0 indicates numerical problems, such as multi-colinearity among the independent variables, zero cells for a dummy-coded independent variable because all of the subjects have the same value for the variable, and 'complete separation' whereby the two groups in the dependent event variable can be perfectly separated by scores on one of the independent variables. Analyses that indicate numerical problems should not be interpreted. None of the independent variables in this analysis had a standard error larger than 2.0.

The presence of a relationship between the dependent variable and combination of independent variables is based on the statistical significance of the final model chi-square. For all the models, the probability of chi-square (2970 for HBW, 2799 for HBE, 2938 for HBO and 597 for NHB) was highly significant, all being equal to 0.000. Thus the null hypothesis that there was no difference between the model without independent variables and the model with independent variables for each trip purpose is rejected. In other words, the existence of a relationship between the independent variables and the dependent variable is supported.

Table 4-15: A) Parameter Estimates and B) Model Fitting Information of Multinomial Logistic Regression Model for HBW Trips

A.

Choice		B	Std. Error	Sig.	Exp(B)
Walk	Intercept	1.009	.268	.000	
	Age	-.076	.004	.000	.927
	Sex				
	Female	.165	.135	.220	1.180
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	4.667	.245	.000	106.374
	IG 2	2.967	.227	.000	19.435
	IG 3	.729	.237	.002	2.073
	IG 4	0[a]	.	.	.
Rickshaw	Intercept	1.434	.195	.000	
	Age	-.040	.004	.000	.961
	Sex				
	Female	-.005	.124	.970	.995
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	3.108	.173	.000	22.384
	IG 2	2.478	.141	.000	11.917
	IG 3	.741	.134	.000	2.098
	IG 4	0[a]	.	.	.
Taxi	Intercept	-.306	.340	.368	
	Age	-.019	.007	.007	.981
	Sex				
	Female	-.801	.292	.006	.449
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	-.344	.336	.305	.709
	IG 2	-.660	.269	.014	.517
	IG 3	-.143	.200	.474	.866
	IG 4	0[a]	.	.	.
CNG	Intercept	.599	.245	.014	
	Age	-.035	.005	.000	.965
	Sex				
	Female	-.129	.158	.413	.879
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	1.169	.216	.000	3.220
	IG 2	1.049	.176	.000	2.856
	IG 3	.650	.162	.000	1.916
	IG 4	0[a]	.	.	.

Public Bus	Intercept	1.630	.192	.000	
	Age	-.043	.004	.000	.958
	Sex				
	Female	-.577	.125	.000	.562
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	3.591	.173	.000	36.255
	IG 2	2.809	.141	.000	16.601
	IG 3	1.073	.133	.000	2.923
	IG 4	0[a]	.	.	.
Private Bus	Intercept	-4.049	.559	.000	
	Age	.005	.005	.333	1.005
	Sex				
	Female	-.097	.191	.614	.908
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	5.304	.526	.000	201.222
	IG 2	4.027	.517	.000	56.096
	IG 3	1.916	.531	.000	6.792
	IG 4	0[a]	.	.	.
Motor Cycle	Intercept	-1.030	.456	.024	
	Age	-.051	.006	.000	.950
	Sex				
	Female	-1.485	.298	.000	.227
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	3.338	.422	.000	28.159
	IG 2	3.088	.404	.000	21.924
	IG 3	1.944	.406	.000	6.989
	IG 4	0[a]	.	.	.

a. The parameter is set to zero because it is redundant.

B.

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1.024E4			
Final	7.268E3	2.970E3	35	.000

Table 4-16: A) Parameter Estimates and B) Model Fitting Information of Multinomial Logistic Regression Model for HBE Trips

A.

Choice		B	Std. Error	Sig.	Exp(B)
Walk	Intercept	-.015	.234	.948	
	Age	-.072	.006	.000	.930
	Sex				
	Female	-.119	.120	.321	.887
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	5.297	.298	.000	199.826
	IG 2	3.551	.240	.000	34.863
	IG 3	1.174	.226	.000	3.235
	IG 4	0[a]	.	.	.
Rickshaw	Intercept	1.292	.161	.000	
	Age	-.038	.006	.000	.963
	Sex				
	Female	.048	.113	.669	1.049
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	3.774	.247	.000	43.547
	IG 2	2.911	.170	.000	18.375
	IG 3	1.019	.138	.000	2.770
	IG 4	0[a]	.	.	.
Taxi	Intercept	-4.369	.597	.000	
	Age	.073	.011	.000	1.075
	Sex				
	Female	-1.912	.333	.000	.148
	Male	0[b]	.	.	.
	Income Group (IG)				
	IG 1	3.112	.633	.000	22.466
	IG 2	2.804	.563	.000	16.518
	IG 3	.456	.611	.456	1.577
	IG 4	0[a]	.	.	.
CNG	Intercept	-1.025	.220	.000	
	Age	.018	.007	.008	1.019
	Sex				
	Female	-.143	.148	.333	.867
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	1.373	.315	.000	3.946
	IG 2	1.379	.223	.000	3.971
	IG 3	.687	.190	.000	1.988
	IG 4	0[a]	.	.	.

Public Bus	Intercept	-.452	.190	.017	
	Age	.030	.006	.000	1.030
	Sex				
	Female	-1.237	.119	.000	.290
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	3.944	.266	.000	51.613
	IG 2	3.147	.196	.000	23.269
	IG 3	1.166	.171	.000	3.210
	IG 4	0[a]	.	.	.
Private Bus	Intercept	-.972	.289	.001	
	Age	-.031	.009	.000	.969
	Sex				
	Female	-.364	.160	.023	.695
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	2.621	.351	.000	13.754
	IG 2	2.457	.282	.000	11.666
	IG 3	.933	.270	.001	2.543
	IG 4	0[a]	.	.	.

a. The parameter is set to zero because it is redundant.

B.

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1.011E4			
Final	7.308E3	2.799E3	30	.000

Table 4-17: A) Parameter Estimates and B) Model Fitting Information of Multinomial Logistic Regression Model for HBO Trips

A.

Choice		B	Std. Error	Sig.	Exp(B)
Walk	Intercept	-1.360	.330	.000	
	Age	-.018	.004	.000	.982
	Sex				
	Female	-.902	.131	.000	.406
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	5.014	.340	.000	150.510
	IG 2	2.895	.309	.000	18.084
	IG 3	.290	.338	.390	1.337
	IG 4	0[a]	.	.	.
Rickshaw	Intercept	.350	.173	.043	
	Age	-.013	.003	.000	.987
	Sex				
	Female	-.158	.100	.112	.854
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	4.467	.219	.000	87.098
	IG 2	3.347	.153	.000	28.431
	IG 3	1.117	.132	.000	3.057
	IG 4	0[a]	.	.	.
Taxi	Intercept	-1.068	.216	.000	
	Age	-.003	.003	.281	.997
	Sex				
	Female	.304	.127	.017	1.356
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	2.597	.248	.000	13.417
	IG 2	1.852	.186	.000	6.370
	IG 3	.777	.166	.000	2.174
	IG 4	0[a]	.	.	.
CNG	Intercept	-.391	.180	.030	
	Age	-.006	.003	.014	.994
	Sex				
	Female	.330	.104	.002	1.391
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	3.773	.223	.000	43.518
	IG 2	2.670	.158	.000	14.435
	IG 3	1.103	.137	.000	3.015
	IG 4	0[a]	.	.	.

Public Bus	Intercept	.501	.195	.010	
	Age	-.026	.003	.000	.974
	Sex				
	Female	-.973	.101	.000	.378
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	5.384	.238	.000	217.955
	IG 2	3.816	.181	.000	45.405
	IG 3	1.565	.165	.000	4.782
	IG 4	0[a]	.	.	.
Motor Cycle	Intercept	-2.938	.794	.000	
	Age	-.017	.009	.054	.983
	Sex				
	Female	-2.168	.341	.000	.114
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	4.051	.777	.000	57.463
	IG 2	1.914	.813	.019	6.780
	IG 3	2.183	.740	.003	8.872
	IG 4	0[a]	.	.	.

a. The parameter is set to zero because it is redundant.

B.

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1.088E4			
Final	7.944E3	2.938E3	30	.000

Table 4-18: A) Parameter Estimates and B) Model Fitting Information of Multinomial Logistic Regression Model for NHB Trips

A.

Choice		B	Std. Error	Sig.	Exp(B)
Walk	Intercept	-3.947	1.088	.000	
	Age	-.013	.011	.228	.987
	Sex				
	Female	-.352	.381	.356	.703
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	4.488	1.025	.000	88.983
	IG 2	3.278	1.031	.001	26.525
	IG 3	2.400	1.048	.022	11.024
	IG 4	0[a]	.	.	.
Rickshaw	Intercept	-.494	.303	.103	
	Age	-.013	.006	.027	.987
	Sex				
	Female	.116	.195	.552	1.123
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	2.527	.255	.000	12.514
	IG 2	2.241	.236	.000	9.407
	IG 3	1.427	.238	.000	4.164
	IG 4	0[a]	.	.	.
Taxi	Intercept	-1.543	.427	.000	
	Age	.009	.009	.301	1.009
	Sex				
	Female	-.122	.333	.713	.885
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	-.741	.461	.108	.477
	IG 2	-.462	.351	.187	.630
	IG 3	.639	.274	.020	1.895
	IG 4	0[a]	.	.	.
CNG	Intercept	-1.347	.318	.000	
	Age	.015	.006	.017	1.015
	Sex				
	Female	.431	.212	.042	1.538
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	.929	.266	.000	2.531
	IG 2	1.076	.232	.000	2.934
	IG 3	.929	.226	.000	2.532
	IG 4	0[a]	.	.	.

Public Bus	Intercept	-.884	.299	.003	
	Age	-.001	.006	.809	.999
	Sex				
	Female	-.504	.196	.010	.604
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	3.405	.253	.000	30.103
	IG 2	2.830	.235	.000	16.941
	IG 3	1.721	.237	.000	5.593
	IG 4	0[a]	.	.	.
Private Bus	Intercept	-23.077	.785	.000	
	Age	.015	.015	.300	1.016
	Sex				
	Female	-.523	.629	.406	.593
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	21.305	.594	.000	1.790E9
	IG 2	21.050	.570	.000	1.386E9
	IG 3	19.292	.000	.	2.391E8
	IG 4	0[a]	.	.	.
Motor Cycle	Intercept	-2.130	.516	.000	
	Age	-.006	.009	.521	.994
	Sex				
	Female	-.432	.348	.215	.649
	Male	0[a]	.	.	.
	Income Group (IG)				
	IG 1	2.005	.432	.000	7.427
	IG 2	1.640	.416	.000	5.156
	IG 3	1.403	.415	.001	4.068
	IG 4	0[a]	.	.	.

a. The parameter is set to zero because it is redundant.

B.

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	4.343E3			
Final	3.746E3	597.362	35	.000

CHAPTER 5

DEVELOPMENT OF THE MODE CHOICE MODEL

5.1 Introduction

Capital investments have been made in transportation sector based on the estimates of current and forecasts of future travel demand. The estimation of travel mode choice model is an important component of urban and intercity travel demand analysis (Bhat, 1997). The mode choice model is the strongest sub model of the four step travel demand model in terms of its behavior (Johnston, 2004).

The chapter is devoted to the objective of developing mode choice model based on MNL and NL approaches. In order to comply with the objective, the underlying principle, modeling tool, methodology of model development are discussed in the next three sections. After assembly of required data for model building, the MNL model is estimated first for each of the four trip purposes with alternative specifications. The preferred model is selected based on some statistical tests which are discussed in section 5.5. The assumption of MNL structure is then tested against some nested structures and the best fitted model is sought. The model output is compared with results of other relevant studies and an additional analysis of model estimation with BIOGEME is outlined in the last two sections.

5.2 Modeling Principles

The modeling procedure for the current study is based on a number of principles as stated below:

- The mode choice model has been developed as a tool for strategic transportation planning of Dhaka city.
- The model can allow changes, assess present status, analyze different future scenarios and evaluate strategic options within a specific time frame.
- The model framework considers the interaction of heterogeneous travel modes such as non motorized vehicles (rickshaw and walk) and motorized vehicles

(CNG, private car, taxi, motor cycle, and bus) and provides separate information for each mode.

- The structure of the model is established in such a way that future refinements can be made with increasing complexity of certain components. For example, the model structure can be applied to analyze changes in travel behavior of people of Dhaka city before and after the introduction of mass rapid transit (MRT) which was recommended in the STP study.

5.3 Modeling Tool

There are many software packages available such as LIMDEP, ALOGIT, ELM, EMME/2 etc. for discrete choice modeling estimation. For the present study, the multinomial and nested logit mode choice model estimations are implemented using JICA STRADA 3.0 software package, where JICA stands for Japan International Cooperation Agency and STARADA for System for Traffic Demand Analysis. Since most of the software packages are developed in the context of developed countries, these cannot be properly implemented in the transport environment of developing countries which is somewhat different. In view of these, the STARADA is developed as a tool for transport planning, and building up of common database, for the technical assistance program of JICA in the transport sector of developing countries. Transport planning proceeds in a series of stages, beginning from the analysis of present situations to model building for demand forecast, identification of development projects, demand forecast and project evaluation. The STRADA is developed as a tool to go through these stages with relative ease. It consists of 17 programs among which the 'Disaggregate Model' module will be used for mode choice model development. 'User Equilibrium Assignment' will also be used to produce mode related data (discussed in next section) through network analysis.

5.4 Modeling Methodology

The methodology consists of two main stages: Data preparation for the model, and Model development.

5.4.1 Data Preparation

Data requirements: The first step in the development of a choice model is to assemble data about traveler's choice and the variables believed to influence that choice process. In the context of travel mode choice, such data include:

- Traveler and trip related variables that influence the travelers' assessment of modal alternatives (e.g., income, age, sex, automobile ownership, trip purpose, origin and destination of trip etc.),
- Mode related variables describing each alternative available to the traveler (e.g., travel time, travel cost etc.) and
- The observed or reported mode choice of the traveler (the 'dependent' or 'endogenous' variable).

Choice of data set: The modeling procedure for the current study works with the data set (discussed in section 3.5.1) by separating intra zonal trips from it. The short distance trips are difficult to model as well as are insignificant in policy analysis. Separating intra zonal trips from the total trips provide 32,422 trips which are finally considered for model development.

Generation of mode related data: The mode related data will be generated from network analysis of JICA STRADA which requires an origin-destination (O-D) trip table, a road network file and an assignment parameter file. The O-D trip table for each mode is produced from the TAZ code of the trip from HIS database. The network file which includes number of nodes, number of links, link distance, node coordinates, free flow speed etc. is created based on the data collected from the STP database. The assignment parameter file requires turn penalty function, PCU equivalent, average occupancy of each vehicle which are collected from STP database, working paper and report. Travel time for each mode is thus obtained from network assignment result on the basis of minimum route search. The per kilometer cost of travel for specific modes of transport have been taken as stated in Chapter 3 of the STP Final Report (2005). The cost for the whole trip is obtained by multiplying the per-km cost with zonal distance which is measured by multiplying travel time with assumed average velocity.

Data structure for estimation: The above described data are assembled into a single data set to support model estimation. The software packages for discrete choice model estimation require the data to be structured in one of two formats: a) the trip format or b) the trip alternative format. In the trip format, each record provides all the relevant information about an individual trip, including the traveler/trip related variables, mode related variables for all available modes and a variable indicating which alternative was chosen. In the trip-alternative format, each record includes information on the traveler/trip related variables, the attributes of that modal alternative, and a choice variable that indicates whether the alternative was or was not chosen (Koppelman and Bhat, 2006). The structure of the resultant data file conforms to the trip format which is the required format of our modeling tool JICA STRADA.

5.4.2 Development of Mode Choice Model

- The modeling approach is a discrete choice model based on random utility maximizing principle.
- Two types of modal split models are developed: the Multinomial Logit (MNL) and the Nested Logit (NL) model to predict the modal shares.
- Firstly, simple MNL models are developed and calibrated for all trip purposes (based on daily travel activity) as the MNL model is the most popular form of discrete choice model in practical applications (Mohammadian and Doherty, 2005).
- Secondly, NL models are be developed and tested based on specific market segmentation in order to overcome the so-called independence of irrelevant alternatives (IIA) limitation in the MNL model by modifying the choice structure into two levels.

5.5 Estimation of MNL Model

The basic specification of the MNL model for any trip purpose includes alternative specific constants, travel time, travel cost and household income (will be designated by ‘income’ later) as the explanatory variables. Travel time and travel cost represent mode related attributes; all other things being equal, a faster mode of travel is more likely to be chosen than a slower mode and a less expensive mode is more likely to be chosen than a costlier one. Household income is included in the model with the expectation that travelers from high income households are more likely to use car than to use other travel modes.

The travel time (TT) and travel cost (TC) variables are specified as generic in this model and input as generic variable 1 and generic variable 2 respectively in the [Generic Variables] section of JICA STRADA. This implies that an increase of one unit of travel time or travel cost has the same impact on modal utility for all modes. Household Income (Income) is included as an alternative specific variable in the [Specific Variables] section of JICA STRADA (Appendix C).

The deterministic portion of the utility function for the selected modes may be written as:

$$V_{Walk} = \alpha_{Walk} + \beta_1 \times TT_{Walk} + \beta_{Income-Walk} \times Income$$

$$V_{Rickshaw} = \alpha_{Rickshaw} + \beta_1 \times TT_{Rickshawk} + \beta_2 \times TC_{Rickshaw} + \beta_{Income-Rickshaw} \times Income$$

$$V_{Taxi} = \alpha_{Taxi} + \beta_1 \times TT_{Taxi} + \beta_2 \times TC_{Taxi} + \beta_{Income-Taxi} \times Income$$

$$V_{CNG} = \alpha_{CNG} + \beta_1 \times TT_{CNG} + \beta_2 \times TC_{CNG} + \beta_{Income-CNG} \times Income$$

$$V_{Public\ Bus} = \alpha_{Public\ Bus} + \beta_1 \times TT_{Public\ Bus} + \beta_2 \times TC_{Public\ Bus} + \beta_{Income\text{-}Public\ Bus} \times Income$$

$$V_{Private\ Bus} = \alpha_{Private\ Bus} + \beta_1 \times TT_{Private\ Bus} + \beta_2 \times TC_{Private\ Bus} + \beta_{Income\text{-}Private\ Bus} \times Income$$

$$V_{Motor\ Cycle} = \alpha_{Motor\ Cycle} + \beta_1 \times TT_{Motor\ Cycle} + \beta_2 \times TC_{Motor\ Cycle} + \beta_{Income\text{-}Motor\ Cycle} \times Income$$

$$V_{Car/Jeep} = \beta_1 \times TT_{Car/Jeep} + \beta_2 \times TC_{Car/Jeep}$$

where $\alpha_{Walk,}\alpha_{Rickshaw}$ etc. are the alternative specific constant terms,

β_1 is the coefficient of travel time,

β_2 is the coefficient of travel cost,

$\beta_{Income-Walk,}\beta_{Income-Rickshaw}$ etc. are the coefficients of income specific to corresponding modes.

The outputs from JICA STRADA include the following estimated results (Appendix C):

- Variable names specified as constant 1-1, constant 1-2 etc. for alternative specific constants; generic 1-1, generic 1-2 for travel time and travel cost respectively; and income specific to alternative mode;
- Parameter estimates, standard errors of these estimates, and the corresponding t-values for each variable/parameter;
- Critical chi-square test statistic (χ^2), rho-squared (ρ^2), adjusted rho-squared ($\bar{\rho}^2$) values, and hit rate 1 and hit rate 2 in percentages.

The base model is then tested, according to Koppelman and Bhat (2006), with the models developed imposing some restrictions such as exclusion of generic variables (TT, TC) and specific variables (Income) to show their effects on the model. Thus, two hypotheses are considered. The first is that travel time and travel cost variables have no impact on the mode choice decision, that is,

$$H_{0,A}: \quad \beta_1 = \beta_2 = 0$$

The second is that income has no effect on the travel mode choice; that is

$$H_{0,B}: \quad \begin{aligned} &\beta_{Income\text{-}Walk} = \beta_{Income\text{-}Rickshaw} = \beta_{Income\text{-}Taxi} = \beta_{Income\text{-}CNG} = \beta_{Income\text{-}Public\ Bus} \\ &= \beta_{Income\text{-}Private\ Bus} = \beta_{Income-Motor\ Cycle} = \beta_{Income\text{-}Car/Jeep} = 0 \end{aligned}$$

A test statistic is used to show whether both the null hypotheses can be rejected, that is, the parameters should remain in the model.

At next stage of model development process, a variety of different specifications is tested against the base model obtained with remaining / excluding the generic and/or specific variables. For our study, we have attempted to explore specifications based on the interaction of travel cost with income in two forms, cost divided by Ln(income) or cost divided by income. This formulation reflects the rationale that cost becomes a less important factor in the choice of a travel mode as the income of the traveler increases (Koppelman and Bhat, 2006).

The estimation results for the developed models are justified using the following different tests as suggested by Koppelman and Bhat (2006) which provide a basis to evaluate each model and to compare models with different specifications:

- Informal judgment tests
- Goodness-of-fit measures
- Statistical tests

➢ **Informal judgment tests:**

A variety of informal tests can be applied to an estimated model. These tests are designed to assess the reasonableness of the implications of estimated parameters. The most common tests concern:

- The sign of parameters (do the associated variables have a positive or negative effect on the alternatives with which they are associated?);
- The difference (positive or negative) within sets of alternative specific variables (does the inclusion of this variable have a more or less positive effect on one alternative relative to another?); and
- The ratio of pairs of parameters (is the ratio between the parameters of the correct sign and in a reasonable range?).

➢ **Goodness-of-fit measures:**

The rho-squared value (ρ^2) can be used to describe the overall goodness of fit of the model. It is simply the ratio of the difference in log-likelihoods between the reference model and the estimated model divided by the difference in log-likelihoods between the reference model and a perfect model. Mathematically,

$$\rho^2 = \frac{LL(\hat{\beta}) - LL(0)}{LL(*) - LL(0)} \tag{5.1}$$

where $LL(0)$ represents the log-likelihood with zero coefficients (which results in equal likelihood of choosing each available alternative), $LL(\hat{\beta})$ represents the log-likelihood for the estimated model and $LL(*)$ is the log-likelihood for the perfect prediction model.

Since the log-likelihood value for the perfect model is zero, the ρ^2 measure reduces to:

$$\rho^2 = 1 - \frac{LL(\hat{\beta})}{LL(0)} \tag{5.2}$$

By definition, the value of ρ^2 measure lies between 0 and 1. A value of zero implies that the model is no better than the reference model, whereas a value of one implies a perfect model; that is, every choice is predicted correctly. Thus, the closer is the value to 1, the better is the model. The rho-squared measures are widely used to describe the goodness of fit for choice models because of their intuitive formulation (Koppelman and Bhat, 2006).

A problem with the rho-squared measure is that there are no guidelines for a “good” rho-squared value. Another problem is that it improves no matter what variable is added to the model independent of its importance. This directly results from the fact that the objective function of the model is being modeled with one or more additional degrees of freedom and that the same data that is used for estimation is used to assess the goodness of fit of the model. One approach to this problem is to replace the rho-squared measure with an adjusted rho-squared measure which is designed to take account of these factors. The adjusted rho-squared for the zero model is given by:

$$\bar{\rho}^2 = 1 - \frac{LL(\hat{\beta}) - K}{LL(0)} \tag{5.3}$$

where K is the number of degrees of freedom (parameters) used in the model.

➢ Statistical Tests

Statistical tests may be used to evaluate formal hypotheses about individual parameters or groups of parameters taken together.

Test of Individual Parameters

Standard error

The magnitude of the sampling error in a parameter is provided by the standard error associated with that parameter; the larger the standard error, the lower the precision with which the corresponding parameter is estimated.

t-statistic

The statistic used for testing the null hypothesis that a parameter $\hat{\beta}_k$ is equal to some hypothesized value, $\hat{\beta}_k^*$, is the asymptotic t-statistic, which takes the following form:

$$t - statistic = \frac{\hat{\beta}_k - \hat{\beta}_k^*}{SE\left(\hat{\beta}_k\right)} \tag{5.4}$$

where $\hat{\beta}_k$ is the estimate for the k^{th} parameter, $\hat{\beta}_k^*$ is the hypothesized value for the parameter and $SE(\hat{\beta}_k)$ is the standard error of the estimate $\hat{\beta}_k$.

The hypothesized value is zero for STRADA. So, equation (5.4) becomes:

$$t - statistic = \frac{\hat{\beta}_k}{SE\left(\hat{\beta}_k\right)} \tag{5.5}$$

Sufficiently large absolute values of the *t-statistic* lead to the rejection of the null hypothesis that the parameter is equal to the hypothesized value. The rejection of this null hypothesis implies that the corresponding variable has a significant impact on the modal utilities and suggests that the variable should be retained in the model. Low absolute values of the t-statistic imply that the variable does not contribute significantly to the explanatory power of the model and can be considered for exclusion.

Tests of Entire Models

The t-statistic is used to test the hypothesis that a single parameter is equal to some pre-selected value. To test multiple hypotheses simultaneously, a test statistic is used to compare two models provided that one is a restricted version of the other; that is, the restricted model can be obtained by imposing restrictions (setting some parameters to zero, setting pairs of parameters equal to one another and so on) on parameters in the unrestricted model. This test statistic can then be used for any case when one or more restrictions are imposed on a model to obtain another model. The test statistic is:

$$-2 \times [LL_R - LL_U] \tag{5.6}$$

where $LL_{R,}$, LL_U are the log-likelihoods of the restricted and unrestricted models respectively.

If the value of the test statistic is sufficiently large than the critical chi-squared value for selected confidence level by number of restrictions, the hypothesis that all the restrictions are valid will be rejected with the desired confidence level.

- **Non-nested hypothesis Tests**

The likelihood ratio test can only be applied to compare models which differ due to the application of restrictions to one of the models. Such cases are referred to as nested hypothesis tests. However, in cases when the base model is required to compare with alternative specifications, non-nested hypothesis test can be performed (Koppelman and Bhat, 2006). In this test, the null hypothesis that the model with the lower value is the true model is rejected at the significance level determined by the following equation:

$$\text{Significance Level} = \Phi\left[-\left(-2\left(\overline{\rho}_H^2 - \overline{\rho}_L^2\right)\times LL(0) + \left(K_H - K_L\right)\right)^{\frac{1}{2}}\right] \tag{5.7}$$

where $\overline{\rho}_H^2$ and $\overline{\rho}_L^2$ are the adjusted likelihood ration index for the model with the lower and higher value respectively, K_H and K_H are the number of parameters in models H and L respectively, and Φ is the standard normal cumulative distribution function.

- **Hit Rates**

The STRADA Disaggregate Model calculates two hit rates (STRADA Manual, 2005) as follows:

Hit Rate-1: Either [1] if the actual choice δ_n coincides with the calculated choice $\overline{\delta}_n$ from the estimated maximum probability $\overline{P}_n$ for all person trips in the sample, or [0] if it does not, with S_n as the difference between the two.

$$HitR1 = \frac{1}{N}\sum_{n=1}^{N} S_n \tag{5.8}$$

Hit Rate-2: $\overline{P}$ is the estimated probability of choice that corresponds to the actual choice δ_n for all person trips in the sample.

$$HitR2 = \frac{1}{N}\sum_{n=1}^{N} \overline{P}_n \tag{5.9}$$

5.5.1 MNL Model for Home Based Work (HBW) Trips

Table 5-1 presents the estimation results of the base model and the models with restrictions specified in the previous section for HBW trips. In the Base Model, the estimated parameters of travel time and cost variables have the expected negative signs implying that the utility of a mode decreases as the mode becomes slower and/or more expensive. This in turn, will reduce the choice probability of the corresponding mode. The parameters for the alternative specific income variables have the expected negative sign relative to car/jeep implying that with increasing income people are more likely to choose car/jeep than other modes. However, the sign of the parameter for income specific to CNG is positive and the parameter itself is not significant (very small t-value). The absolute t-values of all other parameters are much greater than the critical value of 3.29 at 99.9% confidence interval. This leads us to reject the hypothesis that those variables have no effect on modal utilities at a confidence level higher than 99.9%.

The parameters of the model without generic variables cause ρ^2 and $\bar{\rho}^2$ to drop substantially and also the parameters of mode constants are insignificant with t-values being zero. Thus the model with specific variables only does not have sufficient explanatory power on the model. Moreover, the test statistic of the hypothesis $H_{0,A}$ is 8821.8, which, with 2 degrees of freedom, is much higher than the critical χ^2 value of 13.82 at the .001 level of significance. Therefore, the hypothesis which is travel time and cost variables have no effect on the model can be rejected at very high level which leads to the conclusion that these variables should remain in the base model. On the other hand, the model without income variables has higher ρ^2 and $\bar{\rho}^2$, and t-values of all the parameters are significant. The test statistic is negative which reveals that the hypothesis $H_{0,B}$ that income has no effect on the model cannot be rejected. In other words, income variable can be excluded from the base model which now consists of alternative specific constants, travel time and cost variables in the utility specification.

Considering the fact that although income directly has insignificant effect on mode choice for HBW trips, income interacted with cost may have some effect on mode choice and therefore, the base model is compared with alternative specifications in which the variable cost is replaced with cost divided by Ln(income) or cost divided by income. The estimation results for all three models are presented in Table 5-2. Since the model using cost/income has the best goodness of fit (highest $\overline{\rho}^2$), the null hypotheses for these tests is that the model with cost variable or the model with cost/Ln(income) variable is the true model.

The rejection significance for the hypothesis of the model with cost variable being true is:

$$\Phi\left[-\left(-2(.36641-.34648)(-21291)\right)^{\frac{1}{2}}\right]=\Phi\left[-29.13\right]<<0.001$$

The rejection significance for the hypothesis of the model with cost/Ln(income) variable being true is:

$$\Phi\left[-\left(-2(.36641-.34979)(-21291)\right)^{\frac{1}{2}}\right]=\Phi\left[-26.60\right]<<0.001$$

Thus, both the null hypotheses are rejected at a significance level greater than 0.001.

Therefore, the model with three explanatory variables - alternative specific constants, travel time and travel cost/income can be considered as the preferred model for HBW trips.

Table 5-1: Estimation Results of the Base Model and its Restricted Versions for HBW Trips

Variables	Base Model		Model without Generic Variables		Model without Specific Variable	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	0.19317	68.25	-1.11E-09	0.00	3.34082	33.11
Rickshaw	2.24562	69.87	1.12E-08	0.00	3.05949	51.48
Taxi	-0.61396	-69.76	-1.47E-08	0.00	-0.68082	-7.97
CNG	-0.54982	-69.90	-1.47E-08	0.00	0.48607	9.03
Public Bus	1.57383	69.90	5.12E-08	0.00	2.00619	34.43
Private Bus	-0.49934	-69.71	-5.09E-09	0.00	-0.53947	-7.12
Motor Cycle	-0.64734	-69.73	-9.47E-09	0.00	-1.19353	-15.70
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.02344	-30.63			-0.05675	-41.50
Travel Cost (Tk.)	-0.04620	-37.10			-0.02044	-13.94
Specific Variable – Income (Tk./month)						
Walk	-0.000012	-7.07	-0.000059	-0.14		
Rickshaw	-0.000022	-19.11	0.000009	0.62		
Taxi	-0.000001	-0.92	-0.000053	-0.61		
CNG	0.000004	4.02	-0.000017	-1.72		
Public Bus	-0.000034	-27.41	0.000017	1.13		
Private Bus	-0.000064	-21.86	-0.000062	-0.16		
Motor Cycle	-0.000050	-17.63	-0.000071	-0.21		
Car/Jeep (Base Mode)	0.00		0.00			

Goodness-of-fit Measures			
ρ^2	0.33579	0.12866	0.34656
$\bar{\rho}^2$	0.33564	0.12849	0.34648
χ^2	14298.79	5478.92	14757.49
Hit-Ratio1 (%)	58.67	47.87	57.44
Hit-Ratio2 (%)	37.69	19.44	37.91
$LL(0)$	-21291.3	-21292.2	-21291.4
$LL(\hat{\beta})$	-14141.9	-18552.8	-13912.6
Likelihood Ratio Test for Hypotheses $H_{0,A}$ and $H_{0,B}$			
Test statistic		8821.8	-458.6
No. of Restrictions		2	7
Critical χ^2 Value at 99.9% Confidence		13.82	24.32
Rejection Significance		0.000	NOT REJECTED

Table 5-2: Estimation Results of Models with Alternative Specifications for HBW Trips

Variables	Base Model (Cost Variable)		Model with Cost/Ln(Income) Variable		Model with Cost/Income Variable	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	3.34082	33.11	3.14269	31.76	2.94744	29.89
Rickshaw	3.05949	51.48	2.98740	55.25	3.01270	52.27
Taxi	-0.68082	-7.97	-0.58366	-6.65	-0.58828	-7.22
CNG	0.48607	9.03	0.53061	9.78	0.54351	9.77
Public Bus	2.00619	34.43	1.82225	33.93	1.67473	33.25
Private Bus	-0.53947	-7.12	-0.75661	-10.15	-1.00467	-14.48
Motor Cycle	-1.19353	-15.70	-1.33537	-17.96	-1.42751	-20.20
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.05675	-41.50	-0.05571	-38.28	-0.05638	-38.24
Travel Cost (Tk.)	-0.02044	-13.94				
Travel Cost (Tk.) / Ln(Income in Tk./month)			-0.26679	-18.36		
Travel Cost (Tk.) / Income (1000's of Tk./month)					-0.53814	-29.56
Goodness-of-fit Measures						
ρ^2	0.34656		0.34987		0.36649	
$\bar{\rho}^2$	0.34648		0.34979		0.36641	
χ^2	14757.49		14898.55		15606.11	
Hit-Ratio1 (%)	57.44		57.36		58.20	
Hit-Ratio2 (%)	37.91		38.29		39.57	
$LL(0)$	-21291.4		-21291.6		-21291.3	
$LL(\hat{\beta})$	-13912.6		-13842.3		-13488.3	

5.5.2 MNL Model for Home Based Education (HBE) Trips

The estimation result for the base model and the restricted models for HBE trips is shown in Table 5-3. The parameters for travel time, travel cost and income variables have negative signs, as expected. The positive sign of the parameter of income variable relative to CNG is counter-intuitive. It may be due to the fact that CNG is readily available and its use is comparatively higher than car use (low car ownership) by high/middle income group people. The t-values of all the parameters are greater than its critical value at 99.9% confidence interval and thus, it ascertains the ineffectuality of the hypothesis that these variables have no effect on mode choice. The cost coefficient is more negative than the time coefficient. Both the hypotheses $H_{0,A}$ and $H_{0,B}$ can be rejected at very high levels; that is, neither time and cost nor income variables should be excluded from the model.

The estimation results for the models with alternative specifications already defined are presented in Table 5-4. The highest $\bar{\rho}^2$ value of the model with cost/Ln(income) leads to the null hypotheses that the model with cost variable or the model with cost/income variable is the true model. All the parameters for income variables are significant and had expected negative sign in the model with cost/Ln(income).

The rejection significance for the hypothesis of the model with cost variable being true is:

$$\Phi\left[-\left(-2(.35401-.34382)(-12969.5)\right)^{\frac{1}{2}}\right]=\Phi[-16.26]<<0.001$$

The rejection significance for the hypothesis of the model with cost/income variable being true is:

$$\Phi\left[-\left(-2(.35401-.33568)(-12969.5)\right)^{\frac{1}{2}}\right]=\Phi[-21.81]<<0.001$$

The above results imply that the null hypotheses are rejected at a significance level greater than 0.001.

The model with four explanatory variables - alternative specific constants, travel time, travel cost/Ln(income), and alternative specific income can be considered as the preferred model for HBE trips.

Table 5-3: Estimation Results of the Base Model and its Restricted Versions for HBE Trips

Variables	Base Model		Model without Generic Variables		Model without Specific Variable	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	0.17692	22.02	2.887E-09	0.00	-0.24890	-2.81
Rickshaw	2.63560	64.50	4.724E-08	0.00	2.35025	42.24
Taxi	-0.29866	-44.59	-1.130E-08	0.00	-1.16374	-7.84
CNG	-0.27128	-17.70	-2.110E-08	0.00	0.63332	8.72
Public Bus	1.30165	26.83	1.624E-08	0.00	0.67022	9.67
Private Bus	-1.48841	-42.33	-1.220E-08	0.00	-1.64299	-17.36
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.00216	-11.57			-0.00314	-15.26
Travel Cost (Tk.)	-0.06702	-35.51			-0.06388	-29.93
Specific Variable – Income (Tk./month)						
Walk	-0.000052	-14.71	-0.000044	-0.12		
Rickshaw	-0.000023	-14.90	0.000048	0.32		
Taxi	-0.000029	-5.10	-0.000210	-2.95		
CNG	0.000006	4.93	-0.000019	-0.13		
Public Bus	-0.000037	-18.27	0.000032	0.22		
Private Bus	-0.000018	-7.30	-0.000050	-0.23		
Car/Jeep (Base Mode)	0.00		0.00			
Goodness-of-fit Measures						
ρ^2	0.34405		0.15541		0.33038	
$\bar{\rho}^2$	0.34382		0.15516		0.33024	
χ^2	8924.34		4031.31		8569.65	
Hit-Ratio1 (%)	59.89		46.18		59.04	
Hit-Ratio2 (%)	39.78		27.07		38.82	
$LL(0)$	-12969.5		-12969.9		-12969.4	
$LL(\hat{\beta})$	-8507.4		-10954.2		-8684.6	
Likelihood Ratio Test for Hypotheses $H_{0,A}$ and $H_{0,B}$						
Test statistic			4893.6		354.4	
No. of Restrictions			2		7	
Critical χ^2 Value at 99.9% Confidence			13.82		24.32	
Rejection Significance			0.000		0.000	

Table 5-4: Estimation Results of Models with Alternative Specifications for HBE Trips

Variables	Base Model (Cost Variable)		Model with Cost/Ln(Income) Variable		Model with Cost/Income Variable	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	0.17692	22.02	0.87159	18.57	-0.01674	-6.25
Rickshaw	2.63560	64.50	2.99787	59.35	2.78171	55.82
Taxi	-0.29866	-44.59	-0.50862	-33.32	-0.24129	-50.91
CNG	-0.27128	-17.70	0.79557	11.70	-0.41958	-24.28
Public Bus	1.30165	26.83	1.15445	25.21	1.20605	27.99
Private Bus	-1.48841	-42.33	-1.90977	-43.75	-1.41557	-42.69
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.00216	-11.57	-0.00304	-13.79	-0.00238	-12.55
Travel Cost (Tk.)	-0.06702	-35.51				
Travel Cost (Tk.) / Ln(Income in Tk./month)			-0.77500	-37.11		
Travel Cost (Tk.) / Income (1000's of Tk./month)					-0.73416	-35.68
Specific Variable – Income (Tk./month)						
Walk	-0.000052	-14.71	-0.000073	-19.44	-0.000023	-7.631
Rickshaw	-0.000023	-14.90	-0.000028	-16.85	-0.000030	-16.511
Taxi	-0.000029	-5.10	-0.000016	-3.44	-0.000045	-8.176
CNG	0.000006	4.93	-0.000006	-4.01	0.000003	2.221
Public Bus	-0.000037	-18.27	-0.000033	-17.83	-0.000015	-10.192
Private Bus	-0.000018	-7.30	-0.000011	-4.89	0.000000	0.074
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Goodness-of-fit Measures						
ρ^2	0.34405		0.35423		0.33591	
$\bar{\rho}^2$	0.34382		0.35401		0.33568	
χ^2	8924.34		9188.47		8713.12	
Hit-Ratio1 (%)	59.89		60.03		55.77	
Hit-Ratio2 (%)	39.78		40.60		38.00	
$LL(0)$	-12969.5		-12969.6		-12969.4	
$LL(\hat{\beta})$	-8507.4		-8375.4		-8612.9	

5.5.3 MNL Model for Home Based Other (HBO) Trips

From Table 5-5, it can be observed that the parameter of travel time has expected negative sign, while that of travel cost shows counter-intuitive result with positive sign in the base model as well as in the restricted models. The test statistic of the model without specific income variable is negative which implies that the hypothesis that income has no effect on the model cannot be rejected. Therefore, it leads to the base model specification with only alternative specific constants and generic variables – travel time and travel cost. The parameter of travel cost with positive sign and small t-value leads to the establishment of the hypothesis that this variable has no effect on the model. However, the variable is retained in the model to check against the interaction of travel cost and income.

The models with different specifications for travel cost as shown in Table 5-6 demonstrates negative parameter for the corresponding cost variable as expected and the t-values also are significant at minimum 99.5% confidence level. The model using cost by income has the best goodness of fit (highest $\overline{\rho}^2$). Then, the rejection significance for the hypothesis of the model with cost variable being true is:

$$\Phi\left[-\left(-2(.36120-.35493)(-24487.5)\right)^{\frac{1}{2}}\right]=\Phi\left[-17.52\right]<<0.001$$

and the rejection significance for the hypothesis of the model with cost by Ln(income) variable being true is:

$$\Phi\left[-\left(-2(.36120-.35511)(-24487.5)\right)^{\frac{1}{2}}\right]=\Phi\left[-17.27\right]<<0.001$$

The above results imply that both the null hypotheses can be rejected at very high levels.

Therefore, the model with three explanatory variables - alternative specific constants, travel time and travel cost/income has been emerged as the preferred model for HBO trips.

Table 5-5: Estimation Results of the Base Model and its Restricted Versions for HBO Trips

Variables	Base Model		Model without Generic Variables		Model without Specific Variable	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	0.12040	21.99	-0.00007	-0.12	4.03650	33.92
Rickshaw	3.69006	69.14	0.00077	1.35	4.65051	72.22
Taxi	-1.37351	-68.88	-0.00061	-1.08	0.56227	9.60
CNG	1.49631	43.87	-0.00011	-0.20	2.07161	43.47
Public Bus	3.10783	58.45	0.00127	2.16	2.87210	52.85
Motor Cycle	-0.68871	-61.67	-0.00010	-0.18	-2.22446	-15.18
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.05495	-47.67			-0.08120	-49.02
Travel Cost (Tk.)	0.00499	6.07			0.00080	0.83
Specific Variable – Income (Tk./month)						
Walk	0.000008	4.18	-0.000177	-29.58		
Rickshaw	-0.000021	-14.91	0.000023	15.95		
Taxi	0.000010	8.43	-0.000021	-9.07		
CNG	-0.000012	-9.65	0.000017	12.06		
Public Bus	-0.000051	-28.55	0.000021	14.46		
Motor Cycle	-0.000074	-10.68	-0.000237	-37.15		
Car/Jeep (Base Mode)	0.00		0.00			
Goodness-of-fit Measures						
ρ^2	0.34455		0.15060		0.35500	
$\bar{\rho}^2$	0.34443		0.15046		0.35493	
χ^2	16874.21		7375.46		17386.10	
Hit-Ratio1(%)	53.54		32.36		52.16	
Hit-Ratio2(%)	36.28		21.39		37.02	
$LL(0)$	-24487.3		-24486.9		-24487.5	
$LL(\hat{\beta})$	-16050.2		-20799.2		-15794.4	
Likelihood Ratio Test for Hypotheses $H_{0,A}$ and $H_{0,B}$						
Test statistic			9498		-511.6	
No. of Restrictions			2		7	
Critical χ^2 Value at 99.9% Confidence			13.82		24.32	
Rejection Significance			0.000		NOT REJECTED	

Table 5-6: Estimation Results of Models with Alternative Specifications for HBO Trips

Variables	Base Model (Cost Variable)		Model with Cost/Ln(Income) Variable		Model with Cost/Income Variable	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	4.03650	33.92	3.95596	33.60	3.78598	32.39
Rickshaw	4.65051	72.22	4.62008	70.01	4.55848	70.30
Taxi	0.56227	9.60	0.65061	10.66	0.77600	13.89
CNG	2.07161	43.47	2.11177	43.46	2.17023	46.41
Public Bus	2.87210	52.85	2.75509	52.33	2.53035	50.17
Motor Cycle	-2.22446	-15.18	-2.32187	-15.76	-2.50113	-16.91
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.08120	-49.02	-0.08081	-48.52	-0.07994	-50.46
Travel Cost (Tk.)	0.00080	0.83				
Travel Cost (Tk.) / Ln(Income in Tk./month)			-0.02964	-3.16		
Travel Cost (Tk.) / Income (1000's of Tk./month)					-0.12682	-16.25
Goodness-of-fit Measures						
ρ^2	0.35500		0.35518		0.36127	
$\bar{\rho}^2$	0.35493		0.35511		0.36120	
χ^2	17386.10		17394.90		17693.20	
Hit-Ratio1(%)	52.16		52.16		52.64	
Hit-Ratio2(%)	37.02		37.16		38.06	
$LL(0)$	-24487.5		-24487.4		-24487.5	
$LL(\hat{\beta})$	-15794.4		-15789.0		-15640.9	

5.5.4 MNL Model for Non Home Based (NHB) Trips

The estimation results for the base model and its restricted versions for NHB trips in Table 5-7 shows that the parameters for travel time and travel cost variables for the base model as well as of the restricted model are significant and have the expected negative signs. The parameters of income with taxi and CNG are much less and found to have nominal effect (significant at less than 90% confidence level) on the utilities of these modes. However, we consider it in the model for uniformity and check with alternative specifications. Both the hypotheses $H_{0,A}$ and $H_{0,B}$ can be rejected at very high levels; that is, neither time and cost nor the income variables should be excluded from the base model.

Table 5-8 shows the model using cost by income has the best goodness of fit (highest $\bar{\rho}^2$) and all the parameters for income variables are significant and have negative signs as expected. The rejection significances for the hypotheses of the model with cost variable and the model with cost/Ln(income) variable being true are:

$$\Phi\left[-\left(-2(.32269-.30866)(-6101)\right)^{\frac{1}{2}}\right]=\Phi\left[-13.08\right]<<0.001, \text{ and}$$

$$\Phi\left[-\left(-2(.32269-.31042)(-6101)\right)^{\frac{1}{2}}\right]=\Phi\left[-12.24\right]<<0.001$$

which leads to the rejection of the hypotheses at high levels.

Therefore, the model with four explanatory variables - alternative specific constants, travel time, travel cost/income and alternative specific income can be considered as the preferred model for NHB trips.

Table 5-7: Estimation Results of the Base Model and its Restricted Versions for NHB Trips

Variables	Base Model		Model without Generic Variables		Model without Specific Variable	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	-0.16479	-39.09	-0.13259	-34.94	2.41923	10.34
Rickshaw	2.08985	40.91	1.46099	22.74	2.74523	23.66
Taxi	-1.04139	-40.87	-1.33932	-37.20	-0.53555	-4.71
CNG	0.08598	36.64	0.02788	0.93	0.70700	8.96
Public Bus	2.43350	40.88	2.49044	41.60	1.88001	20.37
Private Bus	-0.35840	-40.62	-0.20181	-30.27	-1.86022	-10.02
Motor Cycle	-0.94328	-40.83	-0.44856	-35.58	-1.01116	-8.41
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.03632	-17.07			-0.06618	-18.88
Travel Cost (Tk.)	-0.00970	-5.10			-0.00785	-3.24
Specific Variable – Income (Tk./month)						
Walk	-0.000004	-1.68	-0.000077	-14.29		
Rickshaw	-0.000017	-10.05	-0.000027	-12.33		
Taxi	0.000002	1.54	0.000002	1.19		
CNG	-0.000002	-1.18	-0.000004	-3.27		
Public Bus	-0.000045	-23.49	-0.000045	-18.04		
Private Bus	-0.000089	-9.88	-0.000085	-8.59		
Motor Cycle	-0.000016	-4.91	-0.000022	-5.59		
Car/Jeep (Base Mode)	0.00		0.00			
Goodness-of-fit Measures						
ρ^2	0.30920		0.27710		0.29529	
$\bar{\rho}^2$	0.30866		0.27661		0.29498	
χ^2	3772.90		3381.24		3603.12	
Hit-Ratio1(%)	49.52		46.08		48.98	
Hit-Ratio2(%)	33.45		30.27		31.70	
$LL(0)$	-6101.1		-6101.1		-6101.0	
$LL(\hat{\beta})$	-4214.6		-4410.5		-4299.4	
Likelihood Ratio Test for Hypotheses $H_{0,A}$ and $H_{0,B}$						
Test statistic			391.8		169.6	
No. of Restrictions			2		7	
Critical χ^2 Value at 99.9% Confidence			13.82		24.32	
Rejection Significance			0.000		0.000	

Table 5-8: Estimation Results of Models with Alternative Specifications for NHB Trips

Variables	Base Model (Cost Variable)		Model with Cost/Ln(Income) Variable		Model with Cost/Income Variable	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	-0.16479	-39.09	-0.17368	-33.08	2.62292	13.01
Rickshaw	2.08985	40.91	2.23610	33.81	3.30405	33.85
Taxi	-1.04139	-40.87	-1.03550	-34.74	-0.17760	-2.17
CNG	0.08598	36.64	0.17453	28.40	1.18874	15.20
Public Bus	2.43350	40.88	2.33110	34.94	2.77860	35.05
Private Bus	-0.35840	-40.62	-0.38645	-33.63	-1.42109	-19.74
Motor Cycle	-0.94328	-40.83	-0.97865	-33.85	-0.58066	-17.79
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.03632	-17.07	-0.04034	-35.19	-0.05968	-22.47
Travel Cost (Tk.)	-0.00970	-5.10				
Travel Cost (Tk.) / Ln(Income in Tk./month)			-0.11661	-8.09		
Travel Cost (Tk.) / Income (1000's of Tk./month)					-0.19185	-8.71
Specific Variable - Income						
Walk	-0.000004	-1.68	-0.000002	-0.43	-0.000027	-4.71
Rickshaw	-0.000017	-10.05	-0.000017	-8.13	-0.000022	-8.69
Taxi	0.000002	1.54	0.000003	2.18	-0.000004	-2.21
CNG	-0.000002	-1.18	-0.000002	-1.53	-0.000012	-7.33
Public Bus	-0.000045	-23.49	-0.000041	-19.96	-0.000037	-14.95
Private Bus	-0.000089	-9.88	-0.000086	-8.40	-0.000025	-3.28
Motor Cycle	-0.000016	-4.91	-0.000015	-4.74	-0.000015	-6.49
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Goodness-of-fit Measures						
ρ^2	0.30920		0.31096		0.32322	
$\bar{\rho}^2$	0.30866		0.31042		0.32269	
χ^2	3772.90		3794.39		3943.96	
Hit-Ratio1(%)	49.52		50.07		50.34	
Hit-Ratio2(%)	33.45		33.55		34.75	
$LL(0)$	-6101.1		-6101.1		-6101.0	
$LL(\hat{\beta})$	-4214.6		-4203.9		-4129.1	

5.6 Market Segmentation Test

In the models developed so far it is assumed that the entire population, represented by the sample, uses the same model decision structure, variable and importance weights (parameters) for their selection of mode. If this assumption is incorrect, the estimated model will not adequately represent the underlying decision processes of the entire population or of distinct behavioral groups within the population. For example, mode preference may differ between low and high-income travelers as low-income travelers are expected to be more sensitive to cost and less sensitive to time than high-income travelers. In order to account for the differences in the values of parameters among population groups, *market segmentation* procedure is used. The most common approach to market segmentation is to consider sample segments which are mutually exclusive and collectively exhaustive (that is, each case is included in one and only one segment).

The statistical test for market segmentation consists of three steps. First, the sample is divided into a number of market segments which are mutually exclusive and collectively exhaustive. A preferred model specification is used to estimate a pooled model for the entire data set and to estimate models for each market segment. Finally, the goodness-of-fit differences between the segmented models (taken as a group) and the pooled model are evaluated to determine if they are statistically different. This test is an extension of the likelihood ratio test described earlier to test the difference between two models. In this case, the unrestricted model is the set of all the segmented models and the restricted model is the pooled model which imposes the restriction that the parameters for each segment are identical. This test statistic is assumed to be χ^2 distributed with *n* degrees of freedom equal to difference in number of parameters between the restricted and unrestricted model. The hypothesis that all segments have the same choice function is rejected at level p if:

$$-2 \times [LL_R - LL_U] \geq \chi^2_{n,(p)} \qquad (5.10)$$

Market segments for mode choice model may be based on different features such as income, auto ownership, trip purpose, gender etc. Trip purpose has already been used in our analysis by segregating trips by purpose exclusively. Income is also incorporated in the preceding models through the use of alternative specific income variables and cost divided by income or cost divided by Ln(income) variable as generic in the utility specifications. The level of car ownership is not considered being very low as found in the data set. Therefore, we illustrate the market segmentation test here for *gender* only.

The summary of market segmentation test by gender for four trip purposes is presented in Table 5-9. The segmented model for HBW, HBE and HBO trip purposes rejects the pooled model (base model for entire data set) at a very high level of statistical significance as revealed from the test statistic and critical χ^2 value in Table 5-9. Several attempts have been made for HBW and HBO trips by incorporating a female dummy variable in the pooled model for every mode or a combination of modes or all modes, but the results are still significant. On the other hand, the incorporation of female dummy for different combination of modes for HBE trips is found to make the segmentation insignificant. However, we have considered for our analysis the female dummy for walk, taxi, public bus and private bus in the pooled model. The rationale behind taking the dummy variable relative to these modes is discussed in later part.

Table 5-9: Summary of Significance Level of Market Segmentation Test by Gender for Four Trip Purposes

Purpose	LL_U	LL_R	Test Statistic	Number of Restrictions	Critical $\chi^{2\,*}$	Comment
HBW	-13436.3	-13488.3	104	9	27.877	Significant
HBE	-8336.2	-8375.4	78.4	14	36.123	Significant**
HBO	-15259.0	-15640.9	763.8	8	26.125	Significant
NHB	-4734.2	-4129.1	-1210.2	16	39.252	Non-significant

* Critical χ^2 value is at 99.9% confidence level

** The inclusion of female dummy for walk, taxi, public bus and private bus modes in the base model makes it non-significant.

Table 5-10 presents the estimation results for the pooled and the segmented models for HBW trips. The differences in the alternative specific constants between the pooled model and the male segment are very small for all modes. The alternative specific constants for the female segment are much more positive for walk, rickshaw, and CNG modes indicating their preference to these modes compared to males. The alternative specific constants for taxi, motor cycle, public bus and private bus are much more negative or less positive for the female segment than for the male segment suggesting the preference for these modes among men than women. Both the groups show almost identical sensitivity to travel cost in term of cost/income variable. The female group is more sensitive to travel time than the male group.

Table 5-10: Estimation Results for Market Segmentation by Gender for HBW Trips

Variables	Pooled Model		Male Segmentation		Female Segmentation	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	2.94744	29.89	2.76109	26.09	4.39750	14.63
Rickshaw	3.01270	52.27	2.94389	47.94	3.63811	21.18
Taxi	-0.58828	-7.22	-0.52604	-6.17	-1.04387	-3.82
CNG	0.54351	9.77	0.52501	8.83	0.69885	5.08
Public Bus	1.67473	33.25	1.71768	32.34	1.44206	11.10
Private Bus	-1.00467	-14.48	-0.96445	-13.07	-1.19151	-6.42
Motor Cycle	-1.42751	-20.20	-1.30572	-18.11	-2.64624	-9.12
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.05638	-38.24	-0.05360	-34.01	-0.07915	-15.97
Travel Cost (Tk.) / Income (1000's of Tk./month)	-0.53814	-29.56	-0.53149	-27.11	-0.57454	-9.97
Goodness-of-fit Measures						
ρ^2	0.36649		0.36777		0.37737	
$\bar{\rho}^2$	0.36641		0.36768		0.37672	
χ^2	15606.11		13773.10		1936.67	
Hit-Ratio1 (%)	58.20		58.30		57.29	
Hit-Ratio2 (%)	39.57		39.88		38.76	
$LL(0)$	-21291.3		-18725.2		-2566.0	
$LL(\hat{\beta})$	-13488.3		-11838.6		-1597.7	

Table 5-11 presents the estimation results of the pooled model with the incorporation of female dummy variable (female=1, male=0) specific to walk, taxi, public bus, private bus modes. The values of the dummy parameter for the specific modes have negative signs. This point outs that women have less preference to these modes and thus proves the correctness of inclusion of this female dummy variable specific to the modes indicated. Both the parameters for travel time and cost/Ln(income) variables in the model with female dummy are almost identical with the pooled model without this dummy (see Table 5-4). The adjusted rho-squared value is higher for this model than that in the previously preferred model (see Table 5-4) indicating the best goodness-of-fit of this model over all the models.

Table 5-11: Estimation Result of the Pooled Model with Inclusion of Female Dummy Variables for HBE Trips

Variables	Parameter	t-value		
Alternative Specific Constants				
Walk	1.04000	17.96		
Rickshaw	3.10000	53.74		
Taxi	-0.57900	-30.23		
CNG	0.98600	12.84		
Public Bus	1.61000	33.48		
Private Bus	-1.58000	-38.84		
Car/Jeep (Base Mode)	0.00			
Generic Variables				
Travel Time (minutes)	-0.00300	-17.22		
Travel Cost (Tk.) / Ln(Income in Tk./month)	-0.77000	-40.29		
Specific Variables	**Income (Tk./month)**		**Female Dummy**	
Walk	-0.000074	-20.53	-0.18300	-7.56
Rickshaw	-0.000029	-16.50		
Taxi	-0.000009	-2.74	-0.62900	-23.75
CNG	-0.000009	-5.05		
Public Bus	-0.000033	-17.06	-0.82900	-16.14
Private Bus	-0.000013	-5.93	-0.35600	-14.62
Car/Jeep (Base Mode)	0.00			
Goodness-of-fit Measures				
ρ^2	0.3638			
$\bar{\rho}^2$	0.36352			
χ^2	9436.70			
Hit-Ratio1(%)	61.49			
Hit-Ratio2(%)	41.58			
$LL(0)$	-12969.6			
$LL(\hat{\beta})$	-8251.3			

Table 5-12 presents the estimation results for the pooled and the segmented models for HBO trips. The alternative specific constants for rickshaw, taxi and CNG are much more positive for the female segment than for the male segment indicating that women prefer these modes to men. The alternative specific constants for public bus and motor cycle are less positive and much more negative for the female segment than for the male segment suggesting that female reluctant to use these modes as compared to their counterparts.

The female group exhibits more sensitivity to travel time than males, but the difference is modest. The magnitude of the cost/income parameter is much more negative for the male segment than for the female segment indicating the higher sensitivity of male to travel cost.

Table 5-12: Estimation Results for Market Segmentation by Gender for HBO Trips

Variables	Pooled Model		Male Segmentation		Female Segmentation	
	Parameter	t-value	Parameter	t-value	Parameter	t-value
Alternative Specific Constants						
Walk	3.78598	32.39	3.63612	20.91	3.71662	23.25
Rickshaw	4.55848	70.30	4.12500	39.48	4.79633	58.54
Taxi	0.77600	13.89	0.49534	4.49	0.90991	13.44
CNG	2.17023	46.41	1.75620	20.62	2.35042	41.61
Public Bus	2.53035	50.17	2.72331	30.67	2.32657	37.27
Motor Cycle	-2.50113	-16.91	-1.70586	-9.19	-3.69313	-11.75
Car/Jeep (Base Mode)	0.00		0.00		0.00	
Generic Variables						
Travel Time (minutes)	-0.07994	-50.46	-0.06773	-31.42	-0.08691	-40.15
Travel Cost (Tk.) / Income (1000's of Tk./month)	-0.12682	-16.25	-0.18912	-12.01	-0.11607	-13.41
Goodness-of-fit Measures						
ρ^2	0.36127		0.39845		0.36463	
$\bar{\rho}^2$	0.36120		0.39827		0.36453	
χ^2	17693.20		7058.74		11398.08	
Hit-Ratio1(%)	52.64		60.39		52.70	
Hit-Ratio2(%)	38.06		42.90		37.88	
$LL(0)$	-24487.5		-8857.8		-15629.7	
$LL(\hat{\beta})$	-15640.9		-5328.4		-9930.6	

5.7 Final Form of MNL Model

The final form of the deterministic part of the utility function of MNL form determined for the modes considered in all four trip purposes is expresses as follows:

MNL Utility Specification for Home Based Work (HBW) Trip purpose Male Segment:

$$V_{Walk} = 2.76109 - 0.0536 \times TT_{Walk}$$

$$V_{Rickshaw} = 2.94389 - 0.0536 \times TT_{Rickshawk} - 0.53149 \times TC_{Rickshaw} / Income$$

$$V_{Taxi} = -0.52604 - 0.0536 \times TT_{Taxi} - 0.53149 \times TC_{Taxi} / Income$$

$$V_{CNG} = 0.52501 - 0.0536 \times TT_{CNG} - 0.53149 \times TC_{CNG} / Income$$

$$V_{Public\ Bus} = 1.71768 - 0.0536 \times TT_{Public\ Bus} - 0.53149 \times TC_{Public\ Bus} / Income$$

$$V_{Private\ Bus} = -0.96445 - 0.0536 \times TT_{Private\ Bus} - 0.53149 \times TC_{Private\ Bus} / Income$$

$$V_{Motor\ Cycle} = -1.30572 - 0.0536 \times TT_{Motor\ Cycle} - 0.53149 \times TC_{Motor\ Cycle} / Income$$

$$V_{Car/Jeep} = -0.0536 \times TT_{Car/Jeep} - 0.53149 \times TC_{Car/Jeep} / Income$$

MNL Utility Specification for Home Based Work (HBW) Trip purpose Female Segment:

$$V_{Walk} = 4.3975 - 0.07915 \times TT_{Walk}$$

$$V_{Rickshaw} = 3.63811 - 0.07915 \times TT_{Rickshawk} - 0.57454 \times TC_{Rickshaw} / Income$$

$$V_{Taxi} = -1.04387 - 0.07915 \times TT_{Taxi} - 0.57454 \times TC_{Taxi} / Income$$

$$V_{CNG} = 0.69885 - 0.07915 \times TT_{CNG} - 0.57454 \times TC_{CNG} / Income$$

$$V_{Public\ Bus} = 1.44206 - 0.07915 \times TT_{Public\ Bus} - 0.57454 \times TC_{Public\ Bus} / Income$$

$$V_{Private\ Bus} = -1.19151 - 0.07915 \times TT_{Private\ Bus} - 0.57454 \times TC_{Private\ Bus} / Income$$

$$V_{Motor\ Cycle} = -2.64624 - 0.07915 \times TT_{Motor\ Cycle} - 0.57454 \times TC_{Motor\ Cycle} / Income$$

$$V_{Car/Jeep} = -0.07915 \times TT_{Car/Jeep} - 0.57454 \times TC_{Car/Jeep} / Income$$

MNL Utility Specification for Home Based Education (HBE) Trip purpose:

$$V_{Walk} = 1.04 - 0.003 \times TT_{Walk} - 0.000074 \times Income - 0.18300 \times FemaleDummy$$

$$V_{Rickshaw} = 3.1 - 0.003 \times TT_{Rickshawk} - 0.77 \times TC_{Rickshaw} / Ln(Income) - 0.000029 \times Income$$

$$V_{Taxi} = -0.579 - 0.003 \times TT_{Taxi} - 0.77 \times TC_{Taxi} / Ln(Income) - 0.000009 \times Income$$
$$- 0.629 \times FemaleDummy$$

$$V_{CNG} = 0.986 - 0.003 \times TT_{CNG} - 0.77 \times TC_{CNG} / Ln(income) - 0.000009 \times Income$$

$$V_{Public\ Bus} = 1.61 - 0.003 \times TT_{Public\ Bus} - 0.77 \times TC_{Public\ Bus} / Ln(Income) - 0.000033 \times Income$$
$$- 0.829 \times FemaleDummy$$

$$V_{Private Bus} = -1.58 - 0.003 \times TT_{Private Bus} - 0.77 \times TC_{Private Bus} / Ln(Income) - 0.000013 \times Income$$
$$- 0.356 \times FemaleDummy$$

$$V_{Car/Jeep} = -0.003 \times TT_{Car/Jeep} - 0.77 \times TC_{Car/Jeep} / Ln(Income)$$

MNL Utility Specification for Home Based Other (HBO) Trip purpose Male Segment:

$$V_{Walk} = 3.63612 - 0.06773 \times TT_{Walk}$$

$$V_{Rickshaw} = 4.125 - 0.06773 \times TT_{Rickshawk} - 0.18912 \times TC_{Rickshaw} / Income$$

$$V_{Taxi} = 0.49534 - 0.06773 \times TT_{Taxi} - 0.18912 \times TC_{Taxi} / Income$$

$$V_{CNG} = 1.7562 - 0.06773 \times TT_{CNG} - 0.18912 \times TC_{CNG} / Income$$

$$V_{Public\ Bus} = 2.72331 - 0.06773 \times TT_{Public\ Bus} - 0.18912 \times TC_{Public\ Bus} / Income$$

$$V_{Motor\ Cycle} = -1.70586 - 0.06773 \times TT_{Motor\ Cycle} - 0.18912 \times TC_{Motor\ Cycle} / Income$$

$$V_{Car/Jeep} = -0.06773 \times TT_{Car/Jeep} - 0.18912 \times TC_{Car/Jeep} / Income$$

MNL Utility Specification for Home Based Other (HBO) Trip purpose Female Segment:

$$V_{Walk} = 3.71662 - 0.08691 \times TT_{Walk}$$

$$V_{Rickshaw} = 4.79633 - 0.08691 \times TT_{Rickshawk} - 0.11607 \times TC_{Rickshaw} / Income$$

$$V_{Taxi} = 0.90991 - 0.08691 \times TT_{Taxi} - 0.11607 \times TC_{Taxi} / Income$$

$$V_{CNG} = 2.35042 - 0.08691 \times TT_{CNG} - 0.11607 \times TC_{CNG} / Income$$

$$V_{Public\ Bus} = 2.32657 - 0.08691 \times TT_{Public\ Bus} - 0.11607 \times TC_{Public\ Bus} / Income$$

$$V_{Motor\ Cycle} = -3.69313 - 0.08691 \times TT_{Motor\ Cycle} - 0.11607 \times TC_{Motor\ Cycle} / Income$$

$$V_{Car/Jeep} = -0.08691 \times TT_{Car/Jeep} - 0.11607 \times TC_{Car/Jeep} / Income$$

MNL Utility Specification for Non Home Based Other (NHB) Trip purpose:

$$V_{Walk} = 2.62292 - 0.05968 \times TT_{Walk} - 0.000027 \times Income$$

$$V_{Rickshaw} = 3.30405 - 0.05968 \times TT_{Rickshawk} - 0.19185 \times TC_{Rickshaw} / Income - 0.000022 \times Income$$

$$V_{Taxi} = -0.1776 - 0.05968 \times TT_{Taxi} - 0.19185 \times TC_{Taxi} / Income - 0.000004 \times Income$$

$$V_{CNG} = 1.18874 - 0.05968 \times TT_{CNG} - 0.19185 \times TC_{CNG} / Income - 0.000012 \times Income$$

$$V_{Public\ Bus} = 2.7786 - 0.05968 \times TT_{Public\ Bus} - 0.19185 \times TC_{Public\ Bus} - 0.000037 \times Income$$

$$V_{Private\ Bus} = -1.42109 - 0.05968 \times TT_{Private\ Bus} - 0.19185 \times TC_{Private\ Bus} / Income - 0.000025 \times Income$$

$$V_{Motor\ Cycle} = -0.58066 - 0.05968 \times TT_{Motor\ Cycle} - 0.19185 \times TC_{Motor\ Cycle} / Income - 0.000015 \times Income$$

$$V_{Car/Jeep} = -0.05968 \times TT_{Car/Jeep} - 0.19185 \times TC_{Car/Jeep} / Income$$

5.8 Estimation of NL Model

The MNL models developed so far for different trip purposes are re-examined and evaluated whether these models should be replaced by nested logit models. The basic specification for estimating NL model for particular trip purpose is taken as the final specification (after market segmentation test) of MNL model for corresponding trip purpose with the additional inclusion of travel distance variable as specific and constant terms for the upper nests (Level-2 variables). Although a large number of nests are possible for seven (in HBW and HBO) or eight (in HBE and NHB) alternative modes, the nature of the alternatives allows certain nests to be rejected as implausible (Bhat and Koppelman, 2006). For this reason, five two-level (STRADA defines not more than two levels) potential nesting structures are considered for NL model building. These are shown in Figure 5-1:

- [A]: Motorized – Non-motorized Nests
- [B]: Private – Non-private Nests
- [C]: Motorized private – Motorized non-private – Non-motorized
- [D]: Motorized private – Motorized non-private – Non-motorized private – Non-motorized non-private Nests
- [E]: Private – Public transit – Para transit Nests

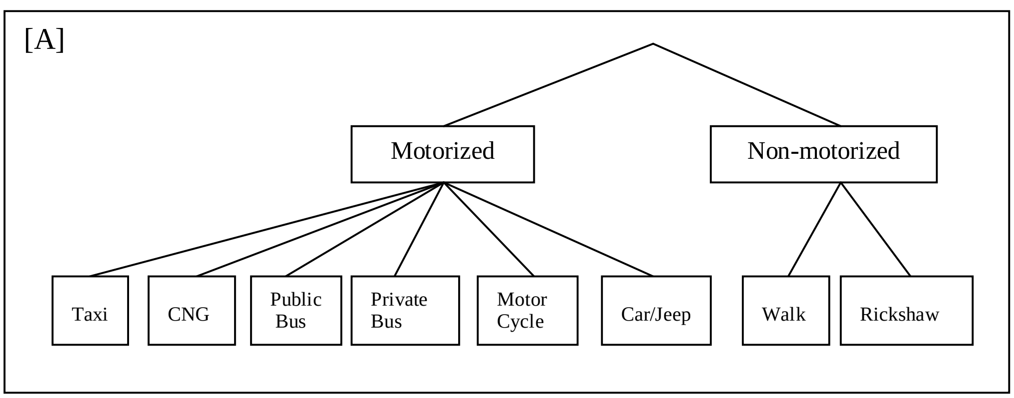


Figure 5-1 [A-E]: Nested Logit Model Structures (contd.)

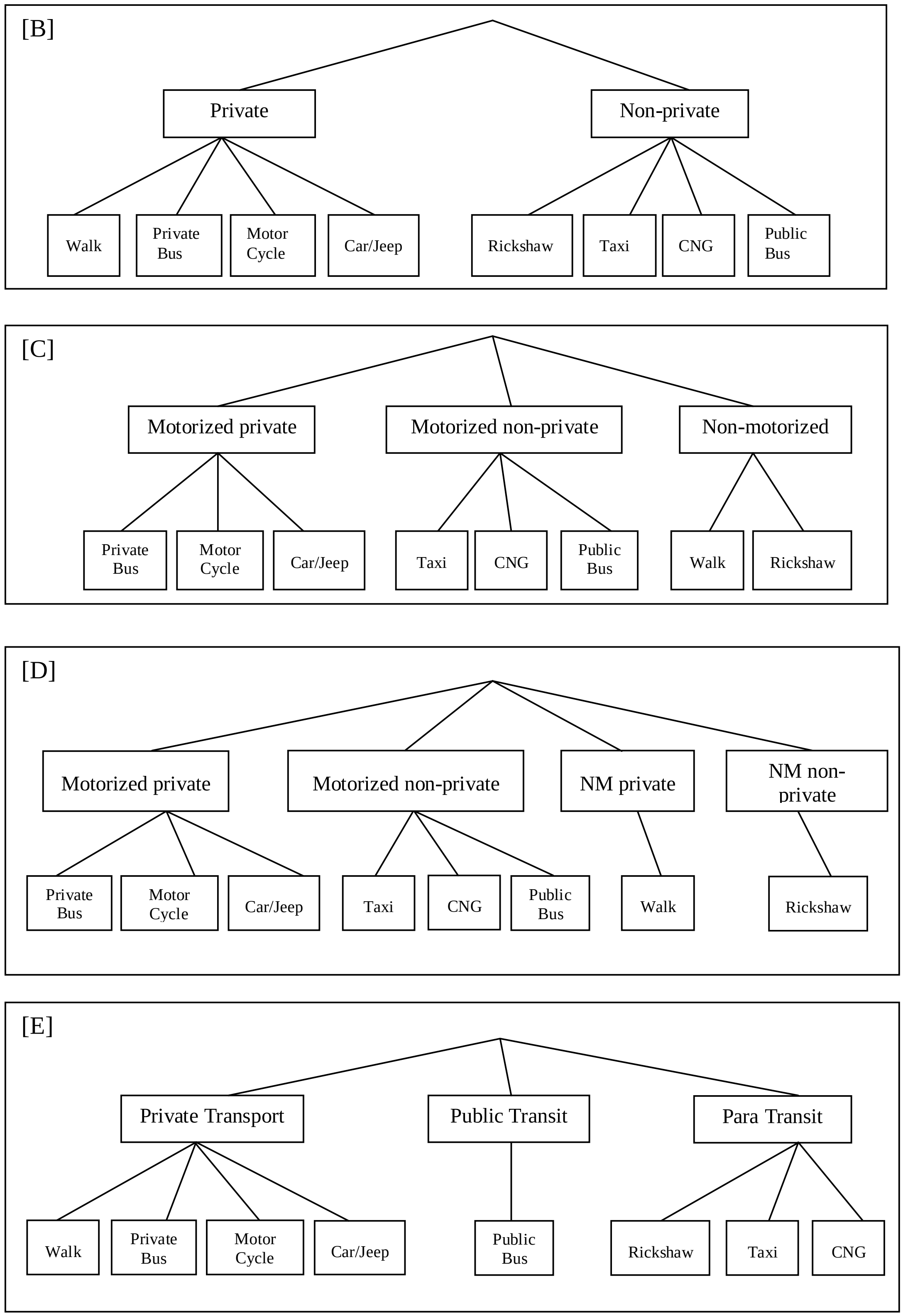


Figure 5-1 [A-E]: Nested Logit Model Structures

In JICA STRADA, when the constant terms are included in the utility specification at both levels of NL model, constants are set up for each Level-2 nest (expressed by node number) except the last and for each level-1 choice (alternative mode) except the last of the same Level-2 nest (STRADA Manual, 2005). For example, the utility specification of nested structure A for HBW purpose can be expressed as:

LEVEL-2

$$V_{Motorized} = \alpha'_{Motorized} + \beta'_1 \times Distance$$

$$V_{Non-motorized} = \beta'_2 \times Distance$$

LEVEL-1

$$V_{Walk} = \alpha_{Walk} + \beta_1 \times TT_{Walk}$$

$$V_{Rickshaw} = \beta_1 \times TT_{Rickshawk} + \beta_2 \times TC_{Rickshaw} / Income$$

$$V_{Taxi} = \alpha_{Taxi} + \beta_1 \times TT_{Taxi} + \beta_2 \times TC_{Taxi} / Income$$

$$V_{CNG} = \alpha_{CNG} + \beta_1 \times TT_{CNG} + \beta_2 \times TC_{CNG} / Income$$

$$V_{Public\ Bus} = \alpha_{Public\ Bus} + \beta_1 \times TT_{Public\ Bus} + \beta_2 \times TC_{Public\ Bus} / Income$$

$$V_{Private\ Bus} = \alpha_{Private\ Bus} + \beta_1 \times TT_{Private\ Bus} + \beta_2 \times TC_{Private\ Bus} / Income$$

$$V_{Motor\ Cycle} = \alpha_{Motor\ Cycle} + \beta_1 \times TT_{Motor\ Cycle} + \beta_2 \times TC_{Motor\ Cycle} / Income$$

$$V_{Car/Jeep} = \beta_1 \times TT_{Car/Jeep} + \beta_2 \times TC_{Car/Jeep} / Income$$

Although λ_k (section 2.3.5, pp. 18-20) can vary over nests reflecting different correlation among unobserved factors within each nest, STRADA constrains the λ_k's to be the same for all nests, indicating that the correlation is the same in each of these nests. Then the conditional and marginal probabilities can be obtained by the following equations:

$$P_n(i \mid k) = \frac{\exp[\lambda_1 . V_{(i|k)n}]}{\sum_{j \in C_n} \exp[\lambda_1 . V_{(j|k)n}]} \tag{5.10}$$

$$P_n(k) = \frac{\exp[\lambda_2 (V_{kn} + \frac{1}{\lambda_1} . IV_{kn})]}{\sum_{l \in K} \exp[\lambda_2 (V_{ln} + \frac{1}{\lambda_1} . IV_{ln}]} \tag{5.11}$$

For each NL model, it is desirable that the nesting parameter λ_2 must lie between 0 and 1; otherwise, the tree structure will not be consistent with the utility maximizing behavior theorem. Based on this assumption, the nested structure is tested whether it is valid. For more than one valid structure, the $\bar{\rho}^2$ value and the significance of λ_2 are taken into consideration in order to select the best nested structure for NL model for each of the four trip purposes.

5.8.1 NL Model for Home Based Work (HBW) Trips

In Table 5-13, the results of testing the defined nested structures for HBW trips male segments are shown to select the best fitted model for further analysis. The model with nested structures A and C are rejected because the parameter of λ_2 for these nests is insignificant (low t-values). The examination of the variables for structure D shows that the parameter of travel time is much more negative relative to MNL model. Nested structure E has an increased substitution of non-private nest of structure B, with para transit and public transit nests whose characteristics are different in respect of fare and travel route. Para transit is undoubtedly more flexible in travel route but with a higher travel cost; whereas public transit is constrained by travel route but costs less. Moreover, structure E has better goodness-of-fit over structure B. With these judgments, we decide to consider nested structure E for further analysis.

Table 5-13: Testing of Nested Structures for HBW Trips Male Segments

Nesting Structure	λ_2	t-value of λ_2	$\bar{\rho}^2$
A	0.00360	0.0078	0.37841
B	0.69728	6.718	0.36827
C	0.003756	2.280	0.37720
D	0.60106	8.832	0.37971
E	0.70616	14.344	0.36888
MNL model			0.36768

In Table 5-14, the results of testing the defined nested structures for HBW trips female segments are shown. The models with nested structures B, C, D are rejected because λ_2 is greater than one. The parameter of λ_2 for nest A is insignificant (much lower t-values). The NL model with nesting structure E has the best goodness-of-fit due to highest

$\bar{\rho}^2$ which is also greater than that for the MNL model. Therefore, the NL model with nesting structure E is considered for further analysis.

Table 5-14: Testing of Nested Structures for HBW Trips Female Segments

Nesting Structure	λ_2	t-value of λ_2	$\bar{\rho}^2$
A	0.00271	0.957	0.38614
B	1.15993	6.034	0.37769
C	1.12395	2.297	0.38293
D	3.00621	4.938	0.39023
E	0.79008	7.708	0.37840
MNL model			0.37672

For both male and female segments, the nested structure E is chosen as the preferred one. Table 5-15 presents the estimation results of the NL model with structure E for the male and female segments of HBW trips. All the level-1 parameters for both the segments are statistically significant. The travel time and cost/income parameters are more negative as compared to those in the MNL model. The alternative specific constant of para transit nest for male segment is significant at 99% confidence level; while that for the female segment is less significant, well below 90% confidence level. The distance parameters specific to private transport nest for males and para transit nest for females are statistically insignificant.

Table 5-15: Estimation Results of NL Model for HBW Trips

Variables	Male Segments		Female Segments	
	Parameter	t-value	Parameter	t-value
LEVEL-1				
Alternative Specific Constants				
Walk	2.87682	24.560	4.89991	13.229
Rickshaw	2.35030	37.376	3.10261	16.567
Taxi	-1.01184	-11.287	-1.69881	-6.705
CNG (fixed)	0.00		0.00	
Public Bus	0.85377	14.623	0.80679	5.537
Private Bus	-1.19260	-13.408	-1.43182	-6.525
Motor Cycle	-1.42645	-18.201	-2.77714	-9.050
Car/Jeep (fixed)	0.00		0.00	
Generic Variables				
Travel Time (minutes)	-0.05481	-30.957	-0.08661	-14.125
Travel Cost (Tk.) / Income (1000's of Tk./month)	-0.63813	-16.721	-0.71924	-7.906
LEVEL-2				
Alternative Specific Constants				
Private Transport Nest	-1.11866	-14.492	-1.02908	-6.230
Para Transit nest	0.26489	2.684	0.22229	1.044
Public Transit Nest (fixed)	0.00		0.00	
Specific Variable – Distance (km)				
Private Transport Nest	-0.00184	-0.181	0.03404	1.544
Para Transit nest	-0.08840	-4.298	-0.00184	-0.054
Public Transit Nest (fixed)	0.00		0.00	
Lambda (λ_2)	0.70616	14.344	0.79008	7.708
Goodness-of-fit Measures				
ρ^2	0.36901		0.37934	
$\bar{\rho}^2$	0.36888		0.37840	
χ^2	13819.55		1946.79	
Hit-Ratio1 (%)	58.46		56.89	
Hit-Ratio2 (%)	39.74		38.51	
$LL(0)$	-18725.2		-2566.0	
$LL(\hat{\beta})$	-11815.4		-1592.6	

5.8.2 NL Model for Home Based Education (HBE) Trips

In Table 5-16, the results of testing the defined nested structures for HBE trips are shown. The model with nesting structure C is rejected because λ_2 is greater than one. The parameter values of λ_2 for all other nests are significant. The NL model with nesting structure D is rejected despite being the best goodness-of-fit because (highest $\bar{\rho}^2$) because it has been found that this model produces counter-intuitive result with positive travel time parameter. Therefore, the NL model with the next higher $\bar{\rho}^2$, that is, nested structure E is considered for further analysis.

Table 5-16: Testing of Nested Structures for HBE Trips

Nesting Structure	λ_2	t-value of λ_2	$\bar{\rho}^2$
A	0.03479	21.200	0.34806
B	0.99897	553.42	0.34830
C	2.49937	21.261	0.39362
D	0.51392	18.005	0.40492
E	0.44584	24.694	0.36510
MNL model			0.36352

Table 5-17 presents the estimation results of the NL model with nested structure E for HBE trips. All the level-1 and level-2 parameters are statistically significant. The travel time and cost/Ln(income) parameters are much less negative relative to those in the MNL model.

Table 5-17: Estimation Results of NL Model for HBE Trips

Variables	Parameter	t-value		
LEVEL-1				
Alternative Specific Constants				
Walk	0.52289	24.934		
Rickshaw	2.79227	40.844		
Taxi	-0.35294	-32.868		
CNG	0.00			
Public Bus	-0.08410	-8.379		
Private Bus	-0.74488	-31.891		
Car/Jeep (Base Mode)	0.00			
Generic Variables				
Travel Time (minutes)	-0.00122	-7.950		
Travel Cost (Tk.) / Ln(Income in Tk./month)	-0.21935	-7.130		
Specific Variables	**Income (Tk./month)**		**Female Dummy**	
Walk	-0.00004	-13.068	0.15237	24.901
Rickshaw	-0.00002	-12.657		
Taxi	-0.00003	-5.703	-0.27368	-30.684
CNG	0.000002	0.943		
Public Bus	-0.00004	-12.009	-1.00781	-37.789
Private Bus	-0.00001	-2.029	-0.40155	-32.990
Car/Jeep (Base Mode)	0.00			
LEVEL-2				
Alternative Specific Constants				
Private Nest	-1.40360	-39.412		
Para Transit Nest	1.48769	41.599		
Public Transit Nest	0.00			
Specific Variable – Distance (km)				
Private Nest	-0.28607	-15.683		
Para Transit Nest	-0.63781	-27.103		
Public Transit Nest	0.00			
Lambda (λ_2)	0.44584	24.694		
Goodness-of-fit Measures				
ρ^2	0.36545			
$\bar{\rho}^2$	0.36510			
χ^2	9479.46			
Hit-Ratio1(%)	61.08			
Hit-Ratio2(%)	42.55			
$LL(0)$	-12969.6			
$LL(\hat{\beta})$	-8229.8			

5.8.3 NL Model for Home Based Other (HBO) Trips

In Table 5-18, the results of testing the defined nested structures for HBO trips male segments is shown. The models with nesting structure A, C, D are rejected because λ_2 is greater than one. The parameter value of λ_2 for nest B is not significant. The $\bar{\rho}^2$ value of nested structure E is greater than that for MNL model. Therefore, the NL model with nesting structure E is considered for further analysis.

Table 5-18: Testing of Nested Structures for HBO Trips Male Segments

Nesting Structure	λ_2	t-value of λ_2	$\bar{\rho}^2$
A	1.05943	1.500	0.40932
B	0.01961	1.697	0.40086
C	9.21756	6.337	0.41558
D	1.54153	5.563	0.41503
E	0.44152	8.406	0.40222
MNL model			0.39827

In Table 5-19, the results of testing the defined nested structures for HBO trips female segments is shown. The model with nesting structure C is rejected because λ_2 is greater than one. The parameter values of λ_2 for nests A, B and D are insignificant. Between the rest two nests, the NL model with nesting structure E has the best goodness-of-fit because of highest $\bar{\rho}^2$ which is also greater than that for the MNL model. Therefore, the NL model with nesting structure E is considered for further analysis.

Table 5-19: Testing of Nested Structures for HBO Trips Female Segments

Nesting Structure	λ_2	t-value of λ_2	$\bar{\rho}^2$
A	0.02132	2.166	0.36853
B	0.49335	2.712	0.36468
C	17.85260	12.704	0.37310
D	0.12116	1.045	0.37512
E	0.48402	8.921	0.36816
MNL model			0.36453

For both male and female segments, the nested structure E is chosen as the preferred one. Table 5-15 presents the estimation results of the NL model with structure E for the male and female segments of HBW trips. All the level-1 parameters for both the segments except alternative specific constant for public bus in the male segment are statistically significant. The travel time parameter is slightly more negative and travel cost/income parameter is much more negative relative to those in the MNL model. The distance parameter relative to nests at level-2 for male group is less significant

Table 5-20: Estimation Results of NL Model for HBO Trips

Variables	Male Segments		Female Segments	
	Parameter	t-value	Parameter	t-value
LEVEL-1				
Alternative Specific Constants				
Walk	4.92636	17.347	4.42010	21.164
Rickshaw	2.71780	29.995	2.73264	42.130
Taxi	-1.11419	-13.128	-1.31707	-26.096
CNG	0.00		0.00	
Public Bus	0.06116	0.4958	0.92238	12.083
Motor Cycle	-2.09592	-11.2898	-4.05975	-12.063
Car/Jeep	0.00		0.00	
Generic Variables				
Travel Time (minutes)	-0.08492	-24.538	-0.10005	-39.686
Travel Cost (Tk.) / Income (1000's of Tk./month)	-0.50409	-9.261	-0.34146	-8.909
LEVEL-2				
Alternative Specific Constants				
Private Nest	-4.92255	-7.6171	-3.14176	-8.664
Para transit Nest	0.06116	0.4958	2.21937	6.227
Public Transit Nest	0.00		0.00	
Specific variable – Distance (km)				
Private Nest	0.01257	0.555	0.04294	2.367
Para transit Nest	-0.04043	-1.539	0.01518	0.990
Public Transit Nest	0.00			
Lambda (λ_2)	0.44152	8.406	0.48402	8.921
Goodness-of-fit Measures				
ρ^2	0.40249		0.36832	
$\bar{\rho}^2$	0.40222		0.36816	
χ^2	7130.26		11513.36	
Hit-Ratio1(%)	60.52		52.34	
Hit-Ratio2(%)	42.65		37.95	
$LL(0)$	-8857.7		-15629.6	
$LL(\hat{\beta})$	-5292.6		-9872.9	

5.8.4 NL Model for Non Home Based (NHB) Trips

In Table 5-21, the results of testing the defined nested structures for NHB trips are shown. None of the models can be rejected since λ_2 value is within the desirable range and also the parameters of λ_2 for all nests are significant. The NL model with nesting structure A has the best goodness-of-fit because of highest $\overline{\rho}^2$ despite low λ_2 value; but $\overline{\rho}^2$ for this NL model is less than that for MNL model. Therefore, this model cannot reject the MNL model for NHB trips which lead to the conclusion that NL model is not supported over MNL model for NHB trips.

Table 5-21: Testing of Nested Structures for NHB Trips

Nesting Structure	λ_2	t-value of λ_2	$\overline{\rho}^2$
A	0.09681	15.668	0.32027
B	0.88440	204.244	0.29402
C	0.39461	11.179	0.25450
D	0.16560	10.085	0.26369
E	0.30824	12.625	0.28628
MNL model			0.32269

5.9 Final Form of NL Model

The final form of the deterministic part of the utility function of NL form determined for the modes considered in all four trip purposes is expresses as follows:

NL Utility Specification for Home Based Work (HBW) Trip purpose Male Segment:

Level-1:

$$V_{Walk} = 2.87682 - 0.05481 \times TT_{Walk}$$

$$V_{Rickshaw} = 2.35030 - 0.05481 \times TT_{Rickshawk} - 0.63813 \times TC_{Rickshaw} / Income$$

$$V_{Taxi} = -1.01184 - 0.05481 \times TT_{Taxi} - 0.63813 \times TC_{Taxi} / Income$$

$$V_{CNG} = -0.05481 \times TT_{CNG} - 0.63813 \times TC_{CNG} / Income$$

$$V_{Public\ Bus} = 0.85377 - 0.05481 \times TT_{Public\ Bus} - 0.63813 \times TC_{Public\ Bus} / Income$$

$$V_{Private\ Bus} = -1.1926 - 0.05481 \times TT_{Private\ Bus} - 0.63813 \times TC_{Private\ Bus} / Income$$

$$V_{Motor\ Cycle} = -1.42645 - 0.05481 \times TT_{Motor\ Cycle} - 0.63813 \times TC_{Motor\ Cycle} / Income$$

$$V_{Car/Jeep} = -0.05481 \times TT_{Car/Jeep} - 0.63813 \times TC_{Car/Jeep} / Income$$

Level-2:

$$V_{Private\ Transport} = -1.11866 - 0.00184 \times Distance$$

$$V_{Para\ Transit} = 0.26489 - 0.0884 \times Distance$$

NL Utility Specification for Home Based Work (HBW) Trip purpose Female Segment:

Level-1:

$$V_{Walk} = 4.89991 - 0.08661 \times TT_{Walk}$$

$$V_{Rickshaw} = 3.10261 - 0.08661 \times TT_{Rickshawk} - 0.71924 \times TC_{Rickshaw} / Income$$

$$V_{Taxi} = -1.69881 - 0.08661 \times TT_{Taxi} - 0.71924 \times TC_{Taxi} / Income$$

$$V_{CNG} = -0.08661 \times TT_{CNG} - 0.71924 \times TC_{CNG} / Income$$

$$V_{Public\,Bus} = 0.80679 - 0.08661 \times TT_{Public\,Bus} - 0.71924 \times TC_{Public\,Bus} / Income$$

$$V_{Private\,Bus} = -1.43182 - 0.08661 \times TT_{Private\,Bus} - 0.71924 \times TC_{Private\,Bus} / Income$$

$$V_{Motor\ Cycle} = -2.77714 - 0.08661 \times TT_{Motor\ Cycle} - 0.71924 \times TC_{Motor\ Cycle} / Income$$

$$V_{Car/Jeep} = -0.08661 \times TT_{Car/Jeep} - 0.71924 \times TC_{Car/Jeep} / Income$$

Level-2:

$$V_{Private\ Transport} = -1.02908 + 0.03404 \times Distance$$

$$V_{Para\ Transit} = 0.22229 - 0.000184 \times Distance$$

NL Utility Specification for Home Based Education (HBE) Trip purpose:

Level-1:

$$V_{Walk} = 0.52289 - 0.00122 \times TT_{Walk} - 0.00004 \times Income + 0.15237 \times FemaleDummy$$

$$V_{Rickshaw} = 2.79227 - 0.00122 \times TT_{Rickshawk} - 0.21935 \times TC_{Rickshaw} / Ln(Income) - 0.00002 \times Income$$

$$V_{Taxi} = -0.35294 - 0.00122 \times TT_{Taxi} - 0.21935 \times TC_{Taxi} / Ln(Income) - 0.00003 \times Income - 0.27638 \times FemaleDummy$$

$$V_{CNG} = -0.00122 \times TT_{CNG} - 0.21935 \times TC_{CNG} / Ln(income) + 0.000002 \times Income$$

$$V_{Public\ Bus} = -0.0841 - 0.00122 \times TT_{Public\ Bus} - 0.21935 \times TC_{Public\ Bus} / Ln(Income) - 0.00004 \times Income$$
$$-1.00781 \times FemaleDummy$$
$$V_{Private\ Bus} = -0.74488 - 0.00122 \times TT_{Private\ Bus} - 0.21935 \times TC_{Private\ Bus} / Ln(Income) - 0.00001 \times Income$$
$$-0.40155 \times FemaleDummy$$
$$V_{Car/Jeep} = -0.00122 \times TT_{Car/Jeep} - 0.21935 \times TC_{Car/Jeep} / Ln(Income)$$

Level-2:

$$V_{Private\ Transport} = -1.40360 - 0.28607 \times Distance$$

$$V_{Para\ Transit} = 1.48769 - 0.63781 \times Distance$$

NL Utility Specification for Home Based Other (HBO) Trip purpose Male Segment:

Level-1:

$$V_{Walk} = 4.92636 - 0.08492 \times TT_{Walk}$$

$$V_{Rickshaw} = 2.71780 - 0.08492 \times TT_{Rickshawk} - 0.50409 \times TC_{Rickshaw} / Income$$

$$V_{Taxi} = -1.11419 - 0.08492 \times TT_{Taxi} - 0.50409 \times TC_{Taxi} / Income$$

$$V_{CNG} = -0.08492 \times TT_{CNG} - 0.50409 \times TC_{CNG} / Income$$

$$V_{Public\ Bus} = 0.06116 - 0.08492 \times TT_{Public\ Bus} - 0.50409 \times TC_{Public\ Bus} / Income$$

$$V_{Motor\ Cycle} = -2.09592 - 0.08492 \times TT_{Motor\ Cycle} - 0.50409 \times TC_{Motor\ Cycle} / Income$$

$$V_{Car/Jeep} = -0.08492 \times TT_{Car/Jeep} - 0.50409 \times TC_{Car/Jeep} / Income$$

Level-2:

$$V_{Private\ Transport} = -4.92255 + 0.01257 \times Distance$$

$$V_{Para\ Transit} = 0.06116 - 0.04043 \times Distance$$

NL Utility Specification for Home Based Other (HBO) Trip purpose Female Segment:

$$V_{Walk} = 4.4201 - 0.10005 \times TT_{Walk}$$

$$V_{Rickshaw} = 2.73624 - 0.10005 \times TT_{Rickshawk} - 0.34146 \times TC_{Rickshaw} / Income$$

$$V_{Taxi} = -1.31707 - 0.10005 \times TT_{Taxi} - 0.34146 \times TC_{Taxi} / Income$$

$$V_{CNG} = -0.10005 \times TT_{CNG} - 0.34146 \times TC_{CNG} / Income$$

$$V_{Public\ Bus} = 0.92238 - 0.10005 \times TT_{Public\ Bus} - 0.34146 \times TC_{Public\ Bus} / Income$$

$$V_{Motor\ Cycle} = -4.05975 - 0.10005 \times TT_{Motor\ Cycle} - 0.34146 \times TC_{Motor\ Cycle} / Income$$

$$V_{Car/Jeep} = -0.10005 \times TT_{Car/Jeep} - 0.34146 \times TC_{Car/Jeep} / Income$$

Level-2:

$$V_{Private\ Transport} = -3.14176 + 0.04294 \times Distance$$

$$V_{Para\ Transit} = 2.21937 + 0.01518 \times Distance$$

5.10 Recommended Model Form

Based on the above results, the nested logit model can be recommended with nested structure of private transport (walk, private bus, motor cycle, car/jeep) – para transit (rickshaw, taxi, CNG) – public transit (public bus) in determining the choice of travel mode for HBW, HBE and HBO trips. It should be noted that HBW and HBO trips are segmented on gender. The MNL model is recommended for NHB trips.

5.11 Comparison of Model Output with Results of Other Relevant Studies

Hasan (2007) developed an MNL model based on the STP HIS data. The utility specification of the model developed by him includes alternative specific constants, travel time and travel cost variables for auto rickshaw, transit and rickshaw modes only. In our present study, we have considered eight modes and the other variables are – travel time, travel cost/income or travel cost/Ln(income) and/or income. Since Hasan’s study dealt with only three modes, it is not reasonable to compare the coefficients of the variables. Moreover, in our study we have determined that travel cost interacted with income in the form of either travel cost/income or travel cost/Ln(income) is more explicable than travel cost only to determine the utility of modes.

5.11 Additional Analysis for Model Estimation with BIOGEME

Since a comparison cannot be made for the model output in our present study, we have made an additional analysis for model estimation using BIOGEME. BIerlaire Optimization toolbox for GEv Model Estimation (BIOGEME) is a freeware package designed for the development of research in the context of discrete choice models in general, and of Generalized Extreme Value models in particular (McFadden, 1978). The results with the BIOGEME are shown in Appendix D.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 General

Mode choice behavior is a fundamental element of travel behavior that has significant implications for transportation planning. Along with estimates of public transit ridership and the use of alternative modes of transportation, the effectiveness of policies regarding introduction of a new transit system or improvement of the existing one depends on studies of mode choice behavior and modal split models. These are the critical determinants of the probability of what factors will act behind the shifting of people from one mode to the other and also the probability of the number of people may actually change their travel mode.

The dual concern of this study is with the identification of mode choice determinants and the formulation of a mode choice model. The data available to BUET from the household interview survey (HIS) conducted for Strategic Transport plan (STP) in 2004 is used in the study material. Mode choice behavior is analyzed with respect to users' socio-economic characteristics. In this regard, modal share is demonstrated in bar graphs to draw a comparative figure in the use of modes among the different sets of attributes. Model share of individual group is illustrated in pie charts to determine the use of modes by each group. A multinomial logistic regression is applied to show the overall effects of the selected attributes on mode selection.

The mode choice model is developed based on two approaches- multinomial logit (MNL) and nested logit (NL) for each of the four trip purposes, home based work (HBW), home based education (HBE), home based other (HBO) and non home based (NHB). The development of the MNL model starts with a basic specification of utility function which includes travel time, travel cost and household income. The impact of the generic variables as well as specific variable to the utility equation is shown to verify the suitability of their incorporation in the utility specification. Two alternative specifications of the utility function based on interaction of travel cost with income such as cost/income and cost/Ln(income) are explored. The underlying principle behind this formulations is that a unit of cost is less important with increasing income.

The NL model is developed to overcome the limitation of the IIA (independence from Irrelevant Alternatives) property of MNL model. The NL model is aimed at to examine whether people's choice vary over one particular alternative or the same group of alternatives. In this regard, six different nested structures are considered in the study to check their reasonableness and find the most significant and best-fitted one in context of the travelers of Dhaka.

6.2 Major Findings of the Study

1. The highest proportion of trips made by the residents of Dhaka are for home based other purpose such as shopping, medical, social, recreational etc. The major portion of trips for all purposes is made by households consisting four members. Women usually take part in more education and home base other trips.

2. Rickshaw is the most significant mode of transport. It shares 36% of trips for all purposes. Major portion of rickshaw trips are attributed to home based education and home base other non-work trips. Public bus is also significant mode of transport contributed to 32% of trips for all purposes among which 38% bus trips are taken up for HBW trip purpose and 35% for HBO trip purpose. Motorized para transit services such as CNG and taxi are most frequently used for HBO trips.

3. Household income is the most important factor which influences choice of travel mode. People of all groups except high income group mostly use public bus for HBW trips and rickshaw for HBE trips, where the use of CNG for HBO trips increase with income. The share of walk trips is mostly attributed to people under low income group. The use of car/jeep is naturally credited to people with high income level.

4. Gender has also significant effect on mode choices – women are more likely to use rickshaws whatever be the purpose of the trip, while men highly use rickshaw

for education trips. Women show much less propensity to use public bus and strongly disagree in using motor cycle.

5. Travel cost interacted with household income is found to have better goodness-of-fit rather than travel cost or income considered alone in the utility equation of mode choice model.

6. The characteristics of the same group of vehicles such as private transport, para transit and public transit act primarily behind the choice of modes as compared to the choice of mode considering individual characteristics which is evident from the nested logit model.

6.3 Limitations of the Study

1. The study considers the data of 4,825 households from the STP HIS data set of 6,035 households. Both the numbers are lacking representative samples because it is a usual practice to collect survey data from 1% households in the study area which would be more than 10,000 HHs in the DCC area during the period the survey was conducted.

2. The survey data is taken from 19 wards of DCC. This obviously does not represent equal proportion of socio-economic groups in the study area.

3. A more logical approach for model development in the context of developing country where socio-economic profile varies widely is to segregate the trips first by income group and then by purpose. Because of small number of data to represent all socio-economic groups, we have developed the model based on trip purpose only.

4. In the present study, HH income is grouped based on STP and DHUTS studies. But there was no guideline or procedure as to how to define income groups as low, middle and high and this is reflected between the differences in selecting income ranges in both the studies.

5. Detail information on travel cost by different modes of transport is not available in the data set. Other information such as comfort level, possibility of choice of other modes etc., if included in the survey data, can be applied in the mode choice model which will increase its power of applicability in different situations.

6.4 Recommendation for Future Research

1. The major research opportunity with the mode choice model proposed in the study is to exploit it as a sub-model in developing travel demand model and forecasting future traffic.

2. The performance of the model structure developed in the study can be tested by applying to other data set with the present prevailing condition of Dhaka's traffic, particularly to the DHTUS data when available.

3. The individual model elements can be further enhanced with the incorporation of new variables such as comfort level, land use data, demographic information etc.

4. As the use of personal motorized vehicle (motor cycle, private car) is increasing in Dhaka, the more survey data of the users of these modes may make the mode choice model stronger to perform.

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APPENDIX A

STP Modal Split Model Form

U (auto network mode) = B * time + C * cost

U (transit mode) = A + B* time + C * cost

Table A-1: Parameters of Modal Split Model in UTP Model in STP

	LIG	MIG	HIG
A	2.8499	1.4869	0.2242
B	0.0113	0.0014	0.0016
C	0.0013	0.0003	0.0008

DHUTS Modal Split Model Form

Table A-2: Parameters of Modal Split Model (Step 1) in DHUTS

Mode	Variable	LIG		MIG		HIG	
		Parameter	t-value	Parameter	t-value	Parameter	t-value
Walk	Distance	-0.29	-201.76	-0.47	-289.60	-0.64	-304.53
Rickshaw	Distance	0.15	48..57	0.23	32.92	0.30	20.75
Other	Distance	0.39	16.58	0.46	11.76	0.56	6.47

Table A-3: Parameters of Modal Split Model (Step 2) in DHUTS

Mode	Variable	LIG		MIG		HIG	
		Parameter	t-value	Parameter	t-value	Parameter	t-value
Car	Ge - cost	-0.12	-0.10	-0.39	-0.27	-3.42	-2.15
	Constant	-1.01	-1.21	-0.99	-2.28	-0.37	-2.07
Bus	Ge - cost	-0.19	-0.20	-0.10	-0.14	-2.04	-1.90
	Constant	2.27	7.09	1.43	8.20	0.19	1.25
Auto - Rickshaw	Ge - cost	-0.18	-0.29	-0.19	-0.27	-2.39	-2.16
	Constant	0.00		0.00		0.00	

APPENDIX B

Table B-1: Number of Registered Vehicles in Dhaka (1994 – 2009)

Year	UP TO 1994	1995	1996	1997	1998	1999	2000	2001**	2002	2003	2004	2005	2006	2007	2008	2009
Type of Vehicles																
Motor Car	36998	6923	8386	6528	4984	4330	2452	5560	5542	6163	4734	5633	7403	10244	13749	17654
Jeep/St.Wagon/Microbus	17937	1556	1387	1492	1438	1371	910	1579	2911	1810	2114	3303	4548	4372	5077	6803
Taxi	787	25	35	14	102	215	348	762	2101	4980	523	514	266	0	0	10
Bus	269	145	73	58	184	224	202	453	632	374	779	728	949	1082	1144	914
Minibus	2009	324	167	397	300	215	242	831	1924	1051	368	118	75	77	107	112
Truck	9775	802	615	834	1681	855	1635	890	1127	2128	1437	1104	1480	830	1642	3180
Auto-rickshaw/Auto-tempo	8359	7301	4615	1902	1689	682	1881	75	2616	7996	2344	139	230	121	155	1144
Motor-Cycle	61478	4427	4027	5346	4992	5330	8768	8590	9102	7239	7872	12879	16284	17303	23713	22093
Others	2063	878	828	310	196	1326	819	1825	1012	3930	1300	2361	2728	2913	2550	4868
Total	139675	22381	20133	16881	15566	14548	17257	20565	26967	35671	21471	26779	33963	36942	48137	56778

** 26,429 Two-Stroke Three-wheeler (Auto-rickshaw/Auto-tempo) removed in 2000 from Dhaka.

APPENDIX C

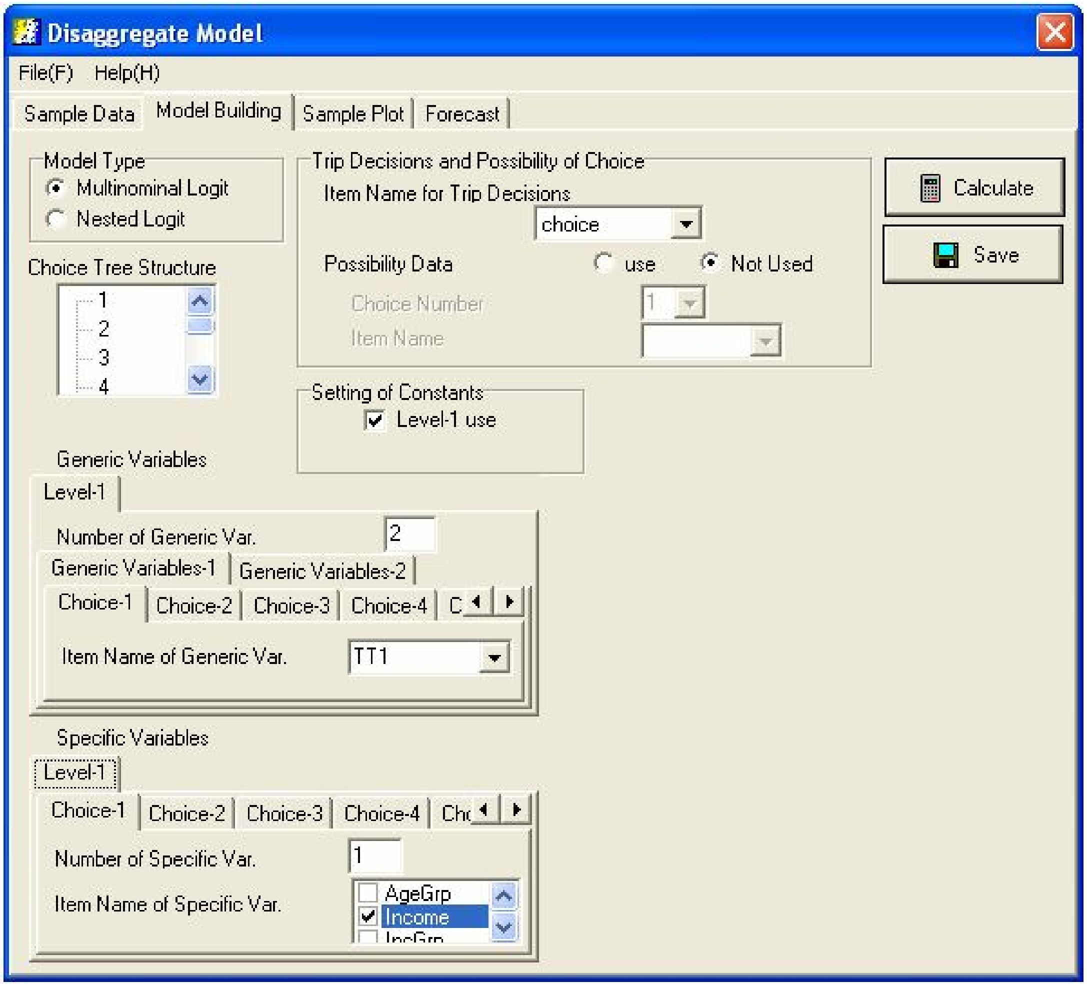

Figure C-1: Screen Shot of Model Building of JICA STRDA (Input of Variables)

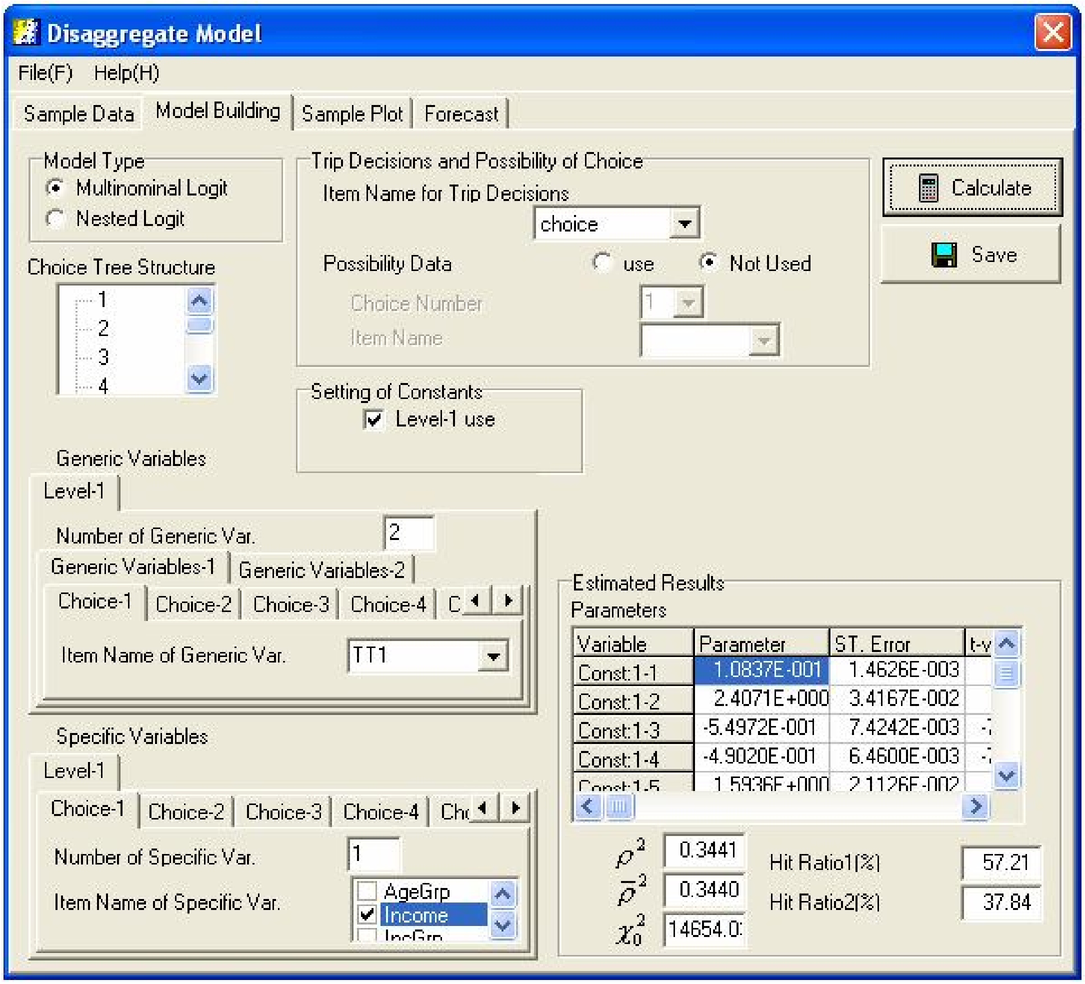

Figure C-2: Screen Shot of Model Building of JICA STRDA (Model Output)

APPENDIX D

```
                   Model: Multinomial Logit
                   Sample file: model-male-HBW.dat
Number of estimated parameters: 9
        Number of observations: 9005
         Number of individuals: 9005
           Null log-likelihood: -18725.371
            Cte log-likelihood: -13588.636
           Init log-likelihood: -18725.371
          Final log-likelihood: -11838.820
         Likelihood ratio test: 13773.101
                    Rho-square: 0.368
           Adjusted rho-square: 0.367
           Final gradient norm: +3.520e-002
                    Diagnostic: Convergence reached...
                    Iterations: 11
                      Run time: 00:06
           Variance-covariance: from analytical hessian

Utility parameters
******************
Name  Value   Std err   t-test p-val Rob. std err Rob. t-test Rob. p-val
----  -----   -------   ------ ----- ------------ ----------- ----------
ASC1  2.76    0.111     24.95  0.00  0.157        17.57       0.00
ASC2  2.94    0.0651    45.21  0.00  0.0879       33.48       0.00
ASC3  -0.526  0.0923    -5.70  0.00  0.0946       -5.56       0.00
ASC4  0.525   0.0633    8.29   0.00  0.0650       8.07        0.00
ASC5  1.72    0.0560    30.65  0.00  0.0716       24.00       0.00
ASC6  -0.965  0.0771    -12.51 0.00  0.0943       -10.22      0.00
ASC7  -1.31   0.0782    -16.70 0.00  0.0834       -15.65      0.00
ASC8  0.000   --fixed--
BETA1 -0.0536 0.00163   -32.89 0.00  0.00279      -19.22      0.00
BETA2 -0.532  0.0217    -24.45 0.00  0.0369       -14.40      0.00

Utility functions
*****************
1      Alt1    one     ASC1 * one + BETA1 * TT1 + BETA2 * cost_inc_1
2      Alt2    one     ASC2 * one + BETA1 * TT2 + BETA2 * cost_inc_2
3      Alt3    one     ASC3 * one + BETA1 * TT3 + BETA2 * cost_inc_3
4      Alt4    one     ASC4 * one + BETA1 * TT4 + BETA2 * cost_inc_4
5      Alt5    one     ASC5 * one + BETA1 * TT5 + BETA2 * cost_inc_5
6      Alt6    one     ASC6 * one + BETA1 * TT6 + BETA2 * cost_inc_6
7      Alt7    one     ASC7 * one + BETA1 * TT7 + BETA2 * cost_inc_7
8      Alt8    one     ASC8 * one + BETA1 * TT8 + BETA2 * cost_inc_8
```

```
                   Sample file: model-male-HBW-NL-3.dat
                         Model: Nested Logit
Number of estimated parameters: 11
        Number of observations: 9005
         Number of individuals: 9005
           Null log-likelihood: -18725.371
            Cte log-likelihood: -13588.636
           Init log-likelihood: -18725.371
          Final log-likelihood: -11825.813
         Likelihood ratio test: 13799.116
                    Rho-square: 0.368
           Adjusted rho-square: 0.368


Utility parameters
******************
Name  Value   Std err   t-test p-val Rob. std err Rob. t-test Rob. p-val
----  -----   -------   ------ ----- ------------ ----------- ----------
ASC1  2.71    0.127     21.25  0.00  0.168        16.15       0.00
ASC2  3.08    0.103     30.03  0.00  0.126        24.56       0.00
ASC3  -2.47   0.544     -4.54  0.00  0.977        -2.53       0.01
ASC4  -0.697  0.353     -1.98  0.05  0.623        -1.12       0.26       *
ASC5  1.60    0.0899    17.77  0.00  0.112        14.22       0.00
ASC6  -1.35   0.129     -10.49 0.00  0.179        -7.52       0.00
ASC7  -1.71   0.163     -10.47 0.00  0.213        -8.03       0.00
ASC8  0.000   --fixed--
BETA1 -0.0530 0.00161   -32.86 0.00  0.00272      -19.46      0.00
BETA2 -0.679  0.0384    -17.68 0.00  0.0594       -11.43      0.00


Model parameters
******************
Name   Value Std err    t-test(0) p-val(0) t-test(1) p-val(1) Rob. std err Rob. t-test(0)
Rob. p-val(0) Rob. t-test(1) Rob. p-val(1)
----  ----- -------   --------- -------- --------- -------- ------------ ------------- --
----------- -------------- -------------
NESTA  0.784 0.0737     10.64      0.00      -2.93      0.00      0.101          7.77
0.00         -2.14          0.03
NESTB  0.591 0.0612     9.65       0.00      -6.69      0.00      0.111          5.34
0.00         -3.70          0.00
NESTC  1.00   --fixed--  9.65       0.00      -6.69      0.00      0.111          5.34
0.00         -3.70          0.00


Utility functions
*****************
1       Alt1    one     ASC1 * one + BETA1 * TT1 + BETA2 * cost_inc_1
2       Alt2    one     ASC2 * one + BETA1 * TT2 + BETA2 * cost_inc_2
3       Alt3    one     ASC3 * one + BETA1 * TT3 + BETA2 * cost_inc_3
4       Alt4    one     ASC4 * one + BETA1 * TT4 + BETA2 * cost_inc_4
5       Alt5    one     ASC5 * one + BETA1 * TT5 + BETA2 * cost_inc_5
6       Alt6    one     ASC6 * one + BETA1 * TT6 + BETA2 * cost_inc_6
7       Alt7    one     ASC7 * one + BETA1 * TT7 + BETA2 * cost_inc_7
8       Alt8    one     ASC8 * one + BETA1 * TT8 + BETA2 * cost_inc_8
```

```
                   Sample file: model-HBE.dat
                         Model: Multinomial Logit
Number of estimated parameters: 18
        Number of observations: 6665
         Number of individuals: 6665
           Null log-likelihood: -12969.491
            Cte log-likelihood: -9257.960
           Init log-likelihood: -12969.491
          Final log-likelihood: -8222.778
         Likelihood ratio test: 9493.426
                    Rho-square: 0.366
           Adjusted rho-square: 0.365
```

Utility parameters
****

Name	Value	Std err	t-test	p-val		Rob. std err	Rob. t-test	Rob. p-val	
ASC1	1.70	0.149	11.39	0.00		0.191	8.92	0.00	
ASC2	3.24	0.0896	36.16	0.00		0.126	25.74	0.00	
ASC3	-0.108	0.237	-0.46	0.65	*	0.252	-0.43	0.67	*
ASC4	0.871	0.101	8.63	0.00		0.0868	10.03	0.00	
ASC5	2.02	0.105	19.25	0.00		0.129	15.69	0.00	
ASC6	-1.04	0.147	-7.09	0.00		0.159	-6.54	0.00	
ASC7	0.000	--fixed--							
BETA_TT	-0.00298	0.000220	-13.50	0.00		0.000444	-6.70	0.00	
BETA_cost	-0.675	0.0236	-28.63	0.00		0.0268	-25.16	0.00	
BETA_fem_1	-0.398	0.102	-3.91	0.00		0.104	-3.82	0.00	
BETA_fem_3	-1.59	0.345	-4.61	0.00		0.344	-4.62	0.00	
BETA_fem_5	-0.948	0.0617	-15.37	0.00		0.0600	-15.81	0.00	
BETA_fem_6	-0.376	0.129	-2.91	0.00		0.130	-2.90	0.00	
BETA_inc_1	-8.38e-005	5.85e-006	-14.31	0.00		8.27e-006	-10.12	0.00	
BETA_inc_2	-2.93e-005	2.02e-006	-14.56	0.00		3.92e-006	-7.48	0.00	
BETA_inc_3	-9.74e-006	4.71e-006	-2.07	0.04		5.74e-006	-1.70	0.09	*
BETA_inc_4	-5.11e-006	1.63e-006	-3.13	0.00		1.24e-006	-4.13	0.00	
BETA_inc_5	-3.37e-005	2.26e-006	-14.90	0.00		3.82e-006	-8.83	0.00	
BETA_inc_6	-1.42e-005	2.68e-006	-5.31	0.00		3.62e-006	-3.93	0.00	
BETA_inc_7	0.000	--fixed--							

Utility functions
****

1	Alt1	one	ASC1 * one + BETA_TT * TT1 + BETA_cost * cost_ln_inc_1 + BETA_inc_1 * income + BETA_fem_1 * sex
2	Alt2	one	ASC2 * one + BETA_TT * TT2 + BETA_cost * cost_ln_inc_2 + BETA_inc_2 * income
3	Alt3	one	ASC3 * one + BETA_TT * TT3 + BETA_cost * cost_ln_inc_3 + BETA_inc_3 * income + BETA_fem_3 * sex
4	Alt4	one	ASC4 * one + BETA_TT * TT4 + BETA_cost * cost_ln_inc_4 + BETA_inc_4 * income
5	Alt5	one	ASC5 * one + BETA_TT * TT5 + BETA_cost * cost_ln_inc_5 + BETA_inc_5 * income + BETA_fem_5 * sex
6	Alt6	one	ASC6 * one + BETA_TT * TT6 + BETA_cost * cost_ln_inc_6 + BETA_inc_6 * income + BETA_fem_6 * sex
7	Alt7	one	ASC7 * one + BETA_TT * TT7 + BETA_cost * cost_ln_inc_7 + BETA_inc_7 * income

```
                   Sample file: model-male-HBO.dat
                            Model: Multinomial Logit
Number of estimated parameters: 8
        Number of observations: 4552
         Number of individuals: 4552
           Null log-likelihood: -8857.783
            Cte log-likelihood: -6106.573
           Init log-likelihood: -8857.783
          Final log-likelihood: -5328.411
         Likelihood ratio test: 7058.744
                   Rho-square: 0.398
           Adjusted rho-square: 0.398
```

```
Utility parameters
******************
Name     Value   Std err   t-test p-val Rob. std err Rob. t-test Rob. p-val
----     -----   -------   ------ ----- ------------ ----------- ----------
ASC1    3.64    0.188        19.33  0.00  0.223        16.33       0.00
ASC2    4.12    0.111        37.10  0.00  0.149        27.73       0.00
ASC3    0.495   0.110        4.49   0.00  0.111        4.48        0.00
ASC4    1.76    0.0880       19.96  0.00  0.0906       19.39       0.00
ASC5    2.72    0.0895       30.44  0.00  0.106        25.76       0.00
ASC6    -1.71   0.177        -9.64  0.00  0.181        -9.41       0.00
ASC7    0.000   --fixed--
BETA1   -0.0677 0.00266      -25.42 0.00  0.00436      -15.52      0.00
BETA2   -0.189  0.0167       -11.29 0.00  0.0229       -8.25       0.00
```

```
Utility functions
*****************
1      Alt1    one     ASC1 * one + BETA1 * TT1 + BETA2 * cost_inc_1
2      Alt2    one     ASC2 * one + BETA1 * TT2 + BETA2 * cost_inc_2
3      Alt3    one     ASC3 * one + BETA1 * TT3 + BETA2 * cost_inc_3
4      Alt4    one     ASC4 * one + BETA1 * TT4 + BETA2 * cost_inc_4
5      Alt5    one     ASC5 * one + BETA1 * TT5 + BETA2 * cost_inc_5
6      Alt6    one     ASC6 * one + BETA1 * TT6 + BETA2 * cost_inc_6
7      Alt7    one     ASC7 * one + BETA1 * TT7 + BETA2 * cost_inc_7
```

```
                    Sample file: model-NHB.dat
                         Model: Multinomial Logit
Number of estimated parameters: 16
        Number of observations: 2934
         Number of individuals: 2934
           Null log-likelihood: -6101.081
            Cte log-likelihood: -4583.846
           Init log-likelihood: -6101.081
          Final log-likelihood: -4106.322
         Likelihood ratio test: 3989.519
                    Rho-square: 0.327
           Adjusted rho-square: 0.324
```

```
Utility parameters
******************
Name        Value      Std err   t-test p-val   Rob. std err Rob. t-test Rob. p-val
----        -----      -------   ------ -----   ------------ ----------- ----------
ASC1        3.75       0.331     11.34  0.00    0.399        9.41        0.00
ASC2        3.35       0.148     22.56  0.00    0.243        13.79       0.00
ASC3        -0.667     0.134     -4.96  0.00    0.136        -4.91       0.00
ASC4        0.921      0.110     8.41   0.00    0.119        7.75        0.00
ASC5        2.84       0.138     20.53  0.00    0.221        12.85       0.00
ASC6        -0.776     0.318     -2.44  0.01    0.314        -2.47       0.01
ASC7        -0.500     0.181     -2.77  0.01    0.192        -2.60       0.01
ASC8        0.000      --fixed--
BETA_TT     -0.0656    0.00373   -17.59 0.00    0.00477      -13.76      0.00
BETA_cost   -0.124     0.0292    -4.26  0.00    0.0369       -3.37       0.00
BETA_inc_1  -6.13e-005 1.32e-005 -4.64  0.00    1.74e-005    -3.52       0.00
BETA_inc_2  -1.98e-005 2.85e-006 -6.97  0.00    6.97e-006    -2.85       0.00
BETA_inc_3  1.58e-006  1.20e-006 1.32   0.19  * 9.73e-007    1.62        0.10       *
BETA_inc_4  -5.99e-006 1.90e-006 -3.16  0.00    2.28e-006    -2.62       0.01
BETA_inc_5  -3.69e-005 3.35e-006 -11.02 0.00    6.42e-006    -5.75       0.00
BETA_inc_6  -4.43e-005 1.36e-005 -3.26  0.00    1.03e-005    -4.30       0.00
BETA_inc_7  -1.56e-005 4.93e-006 -3.16  0.00    4.52e-006    -3.45       0.00
BETA_inc_8  0.000      --fixed--
```

```
Utility functions
*****************
1       Alt1    one     ASC1 * one + BETA_TT * TT1 + BETA_cost * cost_inc_1 + BETA_inc_1 *
income
2       Alt2    one     ASC2 * one + BETA_TT * TT2 + BETA_cost * cost_inc_2 + BETA_inc_2 *
income
3       Alt3    one     ASC3 * one + BETA_TT * TT3 + BETA_cost * cost_inc_3 + BETA_inc_3 *
income
4       Alt4    one     ASC4 * one + BETA_TT * TT4 + BETA_cost * cost_inc_4 + BETA_inc_4 *
income
5       Alt5    one     ASC5 * one + BETA_TT * TT5 + BETA_cost * cost_inc_5 + BETA_inc_5 *
income
6       Alt6    one     ASC6 * one + BETA_TT * TT6 + BETA_cost * cost_inc_6 + BETA_inc_6 *
income
7       Alt7    one     ASC7 * one + BETA_TT * TT7 + BETA_cost * cost_inc_7 + BETA_inc_7 *
income
8       Alt8    one     ASC8 * one + BETA_TT * TT8 + BETA_cost * cost_inc_8 + BETA_inc_8 *
income
```