ABSTRACT

RUNEY, ELIZABETH MICHELLE. Destination Choice Modeling of Trip Distribution for the Raleigh-Durham International Airport. (Under the direction of Dr. John R. Stone).

This research develops a sub-model of the Raleigh-Durham International Airport (RDU) for the Triangle Region Travel Demand Model (TRM). The focus of the sub-model is on trip distribution using multinomial logit (MNL) models to explain the relationship between the airport trip makers (air passenger and employees) and destinations of the study area. The MNL models reflect the unique travel patterns of airport trips more than the gravity model by incorporating destination characteristics (number of households and employment type) as well as trip maker characteristics (household income and household size). These characteristics are important to airport trip maker's choice of destination in addition to travel time and travel distance, especially when there are no major competing airports in the area.

RDU airport surveys, RDU airport activity data, and TRM zonal data were used to develop MNL models for the HB, NHB, and Journey-to-Work trip purposes. The airport surveys were the main data sources used in this research and the most challenging to format for trip distribution. Because the surveys were conduced for rail analysis and not for trip distribution, they did not capture enough complete observations trip distribution at the zonal level. Thus, the TAZ destinations were grouped by socio-economic (SE) group segment, and the MNL models were estimated using the Biogeme software. The resulting MNL model probabilities of airport trip makers choosing the SE group segment destinations were applied to the zones of the year 2002 expanded TRM (2002XP TRM) using relative attraction factors, and the trip interchanges between the RDU airport zone and all other zones in the study area were estimated. Finally, the RDU airport sub-model trip interchanges were input into the 2002XP TRM and traffic assignment was estimated using the TransCAD software.

The RDU airport trip interchanges of the sub-model compared to the TRM trip estimates show that the RDU sub-model estimates approximately 2,000 more trips per weekday than the 2002XP TRM. This is reasonable because the sub-model considers both air passenger and airport employee trips, whereas the 2002XP TRM considers only employee trips. Additionally, the distribution of trips show that the RDU airport sub-model estimates more trips at destinations farther away from the RDU airport and more dispersed throughout the study area than the 2002XP TRM. This is reasonable because the RDU airport trip makers' travel farther to get to the airport than they do for other types of trips such as grocery store trips and because most zones have a relatively small number of weekday airport trips. The traffic assignment results of the two methods shows that the RDU airport sub-model traffic volumes are lower compared to the 2002XP TRM estimates and to the year 2002 AADT counts both in the vicinity of the RDU airport and the entire TRM study area. However, calibration of traffic assignment is not in the scope of this study, and additional data sources of the time of day and directional split factors for the RDU airport trips can improve traffic assignment.

The benefit of this research provides a framework and methodology to develop and apply a trip distribution sub-model for unique land uses such as an airport. The destination choice MNL model framework facilitates the modeling of airport trips in travel demand models, and it allows planners to focus limited resources of observed data in order to more precisely distribute airport trips. The RDU airport sub-model provides accurate estimates of RDU airport trips and has potential to provide enhanced traffic assignment and air quality conditions in the Triangle Region. The foregoing results of this research have implications for transportation planning, airport modeling, air quality analysis and land use planning.

Destination Choice Modeling of Trip Distribution for the Raleigh-Durham International Airport

By
Elizabeth M. Runey

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the Degree of Master of Science

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APPROVED BY:

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Dr. Nagui M. Rouphail

____
Dr. Billy M. Williams

____
Chair of Advisory Committee
Dr. John R. Stone

BIOGRAPHY

The author was born in Charleston, South Carolina and was a native of Charlotte, North Carolina. After graduating from the Charlotte Catholic High School, she pursued post-secondary education at North Carolina State University in Raleigh, North Carolina. Upon completion of her Bachelor of Science in Civil Engineering in 2004, the author began working towards a Master of Science Degree in Transportation Engineering at North Carolina State University in Raleigh, North Carolina. The author is currently a consultant with Wilbur Smith Associates in Charleston, South Carolina as a Transportation Analysts. The following work satisfies the final requirement for the degree Master of Science in Civil Engineering.

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LIST OF SYMBOLS

Roman Symbols

A_j	Number of trip attractions in zone j
F_{ij}	Friction factor for zone i to zone j trip interchange
i	Chosen destination by the trip maker n
j	Alternative destinations
J	Universe choice set of all destinations in the study area
J_p	Destinations available to all trip makers of trip purpose p
$J_{p_{SE}}$	Destinations available to trip makers of each SE group segment of trip purpose p
J_{pn}	Observed destinations chosen by trip makers n of trip purpose p
K_{ij}	Adjustment factor for zone i to zone j trip interchange
K	Number of explanatory variables in the utility function
$\dot{K}$	Difference in the number of explanatory variables of two models
LL	Log-likelihood of the MNL model fit to the observed data
LL_R	Maximum log-likelihood of the restricted (null) MNL model
LL_U	Maximum log-likelihood of the unrestricted MNL model
n	Trip Maker
N	Trip Maker Population
N_{ij}	Observed flow between i and j .

$N(\mu_k, \sigma_k)$	Normal distribution as a function of the mean and standard deviation
P_i	Number of trip productions in zone i
p	Trip Purpose
P_{ni}	Conditional probability of trip maker n choosing destination i
T_{ij}	Number of trips between zone i and zone j
$\hat{T}_{ij}$	Estimated flow between i and j .
U_{ni}	Utility of destination i
X^2	Chi-square statistic
X_{ni}	Explanatory variables of observed trip maker n and destination i

Greek Symbols

α_{ni}	Alternative Specific Constant (ASC) of destination i
β_{nk}	Parameters of the k^{th} variable for trip maker n
ε_{ni}	Random error term of unobserved variables
θ	Parameters of the population mixing distribution for the MMNL model
ρ^2	Rho-square statistic
$\rho_a{}^2$	Adjusted Rho-square statistic
γ	Dummy variable used in the log-likelihood calculation

LIST OF ABBREVIATIONS

2002XP	2002 Expanded
AADT	Average Annual Daily Traffic
ASC	Alternative Specific Constant
ATYPE	Area Type
BIO	Bierlaire Optimization algorithm
BIOGEME	Bierlaire Optimization toolbox for GEv Model Estimation
BTS	Bureau of Transportation Statistics
CAMPO	Capital Area Metropolitan Planning Organization
COG	Council of Governments
DCHC	Durham - Chapel Hill – Carrboro Metropolitan Planning Organization
DCM(s)	Destination Choice Model(s)
DOS	Disk Operating System by Microsoft
DOT	Department of Transportation
DU	Dwelling Units
FHWA	Federal Highway Administration
GEN	Gender
HB	Home Based
HBO	Home Based Other
HBW	Home Based Work
HH	Households
HHS	Household Size (Persons per Household) of the Destination

HS	Household Size (Persons per Household) of the Trip Maker
HWY	Highway Employment
IIA	Independent of Irrelevant Alternative
IID	Independent and Identically Distributed
INC	Income Level of Trip Maker
INCRATIO	Income to Car Ratio
IND	Industry Employment
ITE	Institute for Transportation Engineers
J-to-W	Journey – to – Work
LL	Log-likelihood
MAB	Metropolitan Area Boundary
mINC	Median Income of Destination
MNL	Multinomial Logit
MMNL	Mixed Multinomial Logit
MODE	Transportation Mode for Trip Makers of RDU Airport
MPO(s)	Metropolitan Planning Organization(s)
MS	Microsoft
NHB	Non-Home Based
O-D	Origin-Destination
OFF	Office Employment
POP	Population
PRIOR	Trip Maker Location Prior to RDU Airport
RDU	Raleigh-Durham International Airport

RET	Retail Employment
RTP	Research Triangle Park
RUM	Random Utility Maximization
SE	Socio-economic
SER	Service Employment
SIC	Standard Industrial Classification
TDM(s)	Travel Demand Model(s)
TAZ(s)	Traffic Analysis Zone(s)
TRM	Triangle Regional Model
TT	Travel Time to RDU Airport
TTA	Triangle Transit Authority
UBEDS	University Beds

CHAPTER 1 – INTRODUCTION

Chapter 1 discusses the background and issues related to travel demand models and focuses on trip distribution. The chapter describes the importance of trip distribution for unique land uses such as an airport, the scope and objectives of this study, and the report structure.

Background and Problem Statement

The four step travel demand model (TDM) is widely used by many metropolitan planning organizations (MPOs). MPOs use the demand models to help with policy decision-making as well as land-use, transportation, and air quality planning and analysis. The models consist of choices associated with the individual trip maker that correspond to the model steps including (1) Trip Generation: trip frequency, (2) Trip Distribution: trip destination, (3) Mode Choice: travel mode, and (4) Traffic Assignment: trip path. Modeling the choice of destination is an important step of the travel demand model. The purpose of this step is to predict the number of trips from any traffic analysis zone (TAZ) to every other TAZ in the study area. Traditionally, TDMs predict trip destinations using an aggregated gravity method. Most cities, such as Atlanta, Baltimore, Dallas-Fort Worth, and San Francisco use gravity models.

The gravity method is based on attractions of a TAZ such as employment and households and on travel impedance of time, distance, and/or cost between TAZs. This method is easy to understand and straightforward to apply. However, the gravity model does not account for multiple characteristics of trip makers or the way in which those characteristics interact with each other and with the destination (Pozsgay and Bhat, 2001).

Consequently, the gravity method does not represent the varying self-interests of individuals that lead one person to one destination choice and another person to a different destination choice. Furthermore, the gravity method is subjective with the use of special adjustments such as friction factors to represent travelers' sensitivity to travel time and K-factors that try to match the observed travel patterns not predicted by the gravity model.

Another serious concern with distributing trips using the gravity method is that special generators of traffic such as airports, amusement parks, shopping centers, or schools may not be well modeled. Many travel demand models treat these TAZs as special generators with unique trip rates in addition to the usual trip rates based on TAZ employment and related factors. Unique trip rates are calculated in the trip generation step separately from other TAZ trip rates, and these do not affect the usual gravity model trip distribution procedure. However, these unique land uses also have unique trip lengths and trip distribution patterns from other TAZs in the study area. For example, the average airport trip is generally longer than a trip to the grocery store and airport trips are more heavily based on demographic, market, and personal factors rather than travel distance or travel time to the airport, especially when there is only one commercial airport in the region.

When special generator land uses like airports have unique trip lengths and trip distribution patterns as well as unique trip rates, TDMs utilize a sub-model for the land use. The sub-model has a separate trip generation and trip distribution step from the TDM, and it can be fully integrated back into a travel demand model at the mode choice or traffic assignment step. Regression analysis or destination choice models are commonly used as the trip distribution procedure for sub-models instead of the gravity model. Regression analysis offers a simple and straightforward method to model the relationship of several variables, and destination choice methods offer non-linear relationships for the interaction of numerous variables. However, resources such as individual-based survey data specific to the special land use are required and these resources are usually expensive, time consuming, and unavailable. Thus, the usual TDM trip distribution method remains the gravity model method.

The Triangle Regional Model (TRM) models the RDU airport as one TAZ and treats the RDU airport as a special generator with unique trip rates. The unique trip rates for the RDU airport are a function of trip end data from the Triangle Travel Behavior Survey and zonal employment data by trip purpose. However, there is no unique trip distribution model for the RDU airport. The RDU airport zone is treated the same as the other TAZs in the study area using the gravity model for trip distribution. Since the RDU airport trip attractions are based solely on employment data and do not include air passenger trip attractions, the gravity method used to distribute RDU airport trips in prior versions of the TRM may poorly estimate the total ground trips to and from the RDU airport. Fortunately, an air passenger and an airport employee survey are both available for the RDU airport, and an RDU airport sub-model could be developed. An airport sub-model, also referred to as an airport access demand model, generates and distributes trips separately from the rest of the regional demand model. Household surveys are not required for enhanced airport distribution given that they usually do not capture enough airport passenger trips due to the low use of air travel for a household compared to other trip purposes. Thus, the RDU airport survey data and location information provide the necessary resources to develop a destination choice sub-model for the RDU airport.

Scope and Objectives

The specific study area for the research will be the Raleigh-Durham International Airport. The RDU airport is located in Raleigh, North Carolina within seven miles of the Research Triangle Park and within twelve to eighteen miles of many universities and colleges such as North Carolina State University, University of North Carolina at Chapel Hill, Duke University, Shaw University, Meredith College, Peace College, and Wake Technical Community College (**Figure 1-1**). The RDU airport is the only major airport for the Triangle Region of Raleigh, Durham, and Chapel Hill and the closest major airport is located west of Greensboro about 60 miles away.

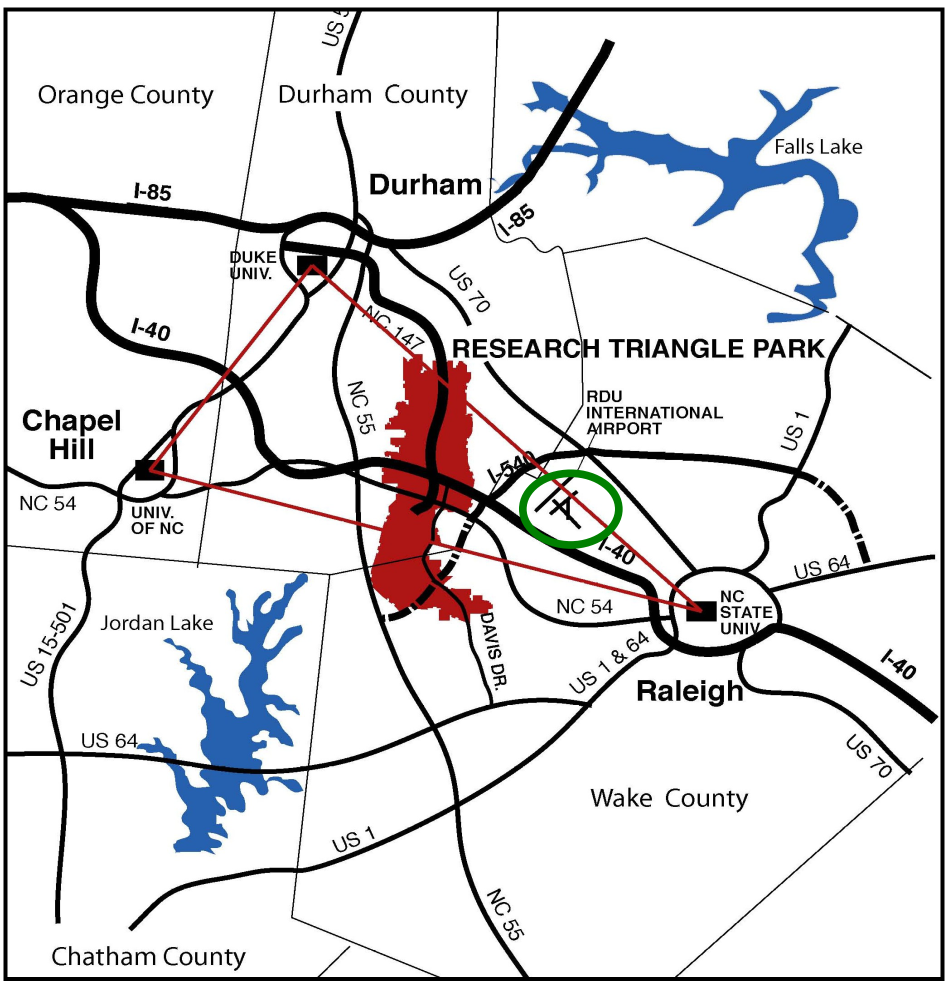


Figure 1-1: RDU Airport Location Map

The greater study area for the research will be the Triangle Region as modeled by the 2002XP Triangle Regional Model (**Figure 1-2**). The 2002XP represents the TRM with a base year of 2002 and an expanded (XP) geographic boundary to cover the revised Capital Area MPO's metropolitan area boundary (MAB). This research will develop a destination choice model for trip distribution of RDU airport trips with the goal of improving estimates of vehicle tips between the RDU zone and all other zones in the TRM study area.

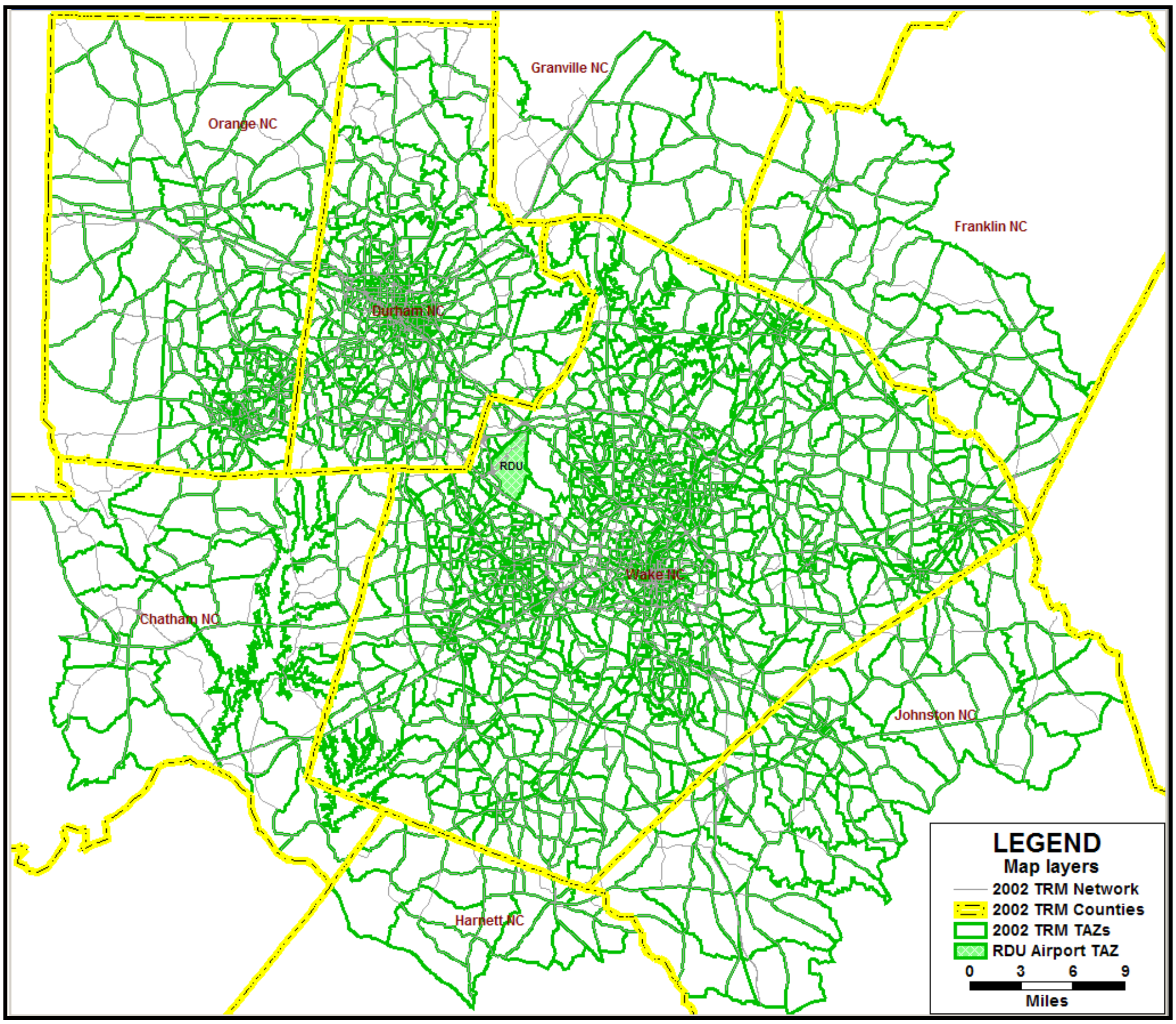


Figure 1-2: TRM Study Area

There are four types of airport access trips to or from the airport that make use of the ground transportation system; 1) air passenger trips, 2) employee trips, 3) airport visitor trips, and 4) cargo trips. This research focuses on air passenger trips and airport employee trips because they represent essentially 100 percent of the peak AM and PM trips. Visitor trips are not considered because the RDU Airport Authority reports on average less than 50 trips per day, which represent less than 0.3 percent of airport trips to the RDU airport. Cargo trips are not considered in this research because these trips operate primarily between 8:00 PM and 7:00 AM, which is outside of the peak AM and PM time periods of the TRM. Furthermore, the TRM has a "Commercial Vehicle" component of the model that better replicates cargo trips distributed throughout the study area.

The distribution method developed by this research models three airport trip purposes: air passenger home based trips (HB), air passenger non-home based trips (NHB), and airport employee journey-to-work trips (J-to-W). All trips considered in this research are internal trips with both the origin and destination inside the TRM study area. External trips, which are trips with at least one trip end outside the TRM study area, are not considered. The external trips are based on the TRM external-internal trip rates developed from an external station survey (*1997 Triangle Origin-Destination Survey Report*), and they have a separate generation and distribution procedure than internal trips in the TRM. Additionally, the external stations do not have specific demographic, socio-economic, or employment data to link the RDU airport trip makers to the external station. External trips represent about 20 percent of the RDU airport trips according to the RDU Airport Authority.

Traffic assignment of the trips developed in this study using the destination choice model approach is an initial assignment and the TRM is not calibrated with the revised airport trips. This research performs one traffic assignment to the TRM study area using the 2002XP TRM. The 2002XP TRM splits vehicle trips by high and low occupancy vehicles, time of day, and direction prior to assignment. The split of the RDU airport sub-model trips is performed once. Calibration of the vehicle trip split factors and the traffic assignment of the RDU airport sub-model trips are not within the scope of this study.

The specific objectives of this research are as follows:

- To enhance trip distribution for the RDU airport in the TRM by developing an airport sub-model.
- To choose an appropriate destination choice model and calibrate it for the RDU airport travel behavior observed in the Triangle Region.
- To compare the chosen destination choice method with the current gravity method for trip distribution of the RDU airport.
- To develop a framework for the RDU airport destination choice model so that it can be applied to other base years of the TRM such as the 2005 TRM.
- To provide a useful approach for developing an airport trip distribution sub-model that planners and modelers can use as a guide for other airports.

Summary and Report Overview

Chapter 1 describes issues regarding trip distribution and modeling an airport sub-model in a regional TDM. Some of the issues include the limited number of variables considered in traditional distribution methods such as the gravity method and the lack of association between trip maker characteristics and destination characteristics. The goal of this research is to account for the interaction of several characteristics of the airport passengers, employees, and destination zones in the development of a trip distribution airport sub-model and to apply the sub-model to a case study of the RDU airport.

Subsequent chapters lay the foundation for developing an airport trip distribution sub-model. Chapter 2 reviews literature on trip distribution methods and on other area airport models. Also, the second chapter highlights the inadequacies of the gravity model and focuses on the enhanced capabilities of destination choice methods, in particular multinomial logit methods, which is the approach selected for this research. Chapter 3 describes the data sources required to develop and calibrate the distribution model. Chapter 4 presents the multinomial logit model framework, development, and steps to apply the model. Chapter 5 applies the model to a case study of the RDU airport and interprets the modeling results. Finally, Chapter 6 summarizes the findings and recommends improvements for future work.

CHAPTER 2 – LITERATURE REVIEW

The objective of this chapter is to provide a background to the research. The first section of this chapter discusses trip distribution methods including the gravity method and the destination choice methods. The second section highlights trip distribution methods used in travel demand models for cities with airports and focuses on travel demand models that have an airport sub-model. The final section discusses the trip distribution method proposed in this study to distribute the RDU airport trips.

Trip Distribution Methods

There are several methods to distribute trips including growth factor, opportunity, regression, entropy, gravity, and destination choice. However, this research only reviews the gravity method and destination choice method because they are the prevalent methods used to distribute trips in travel demand models. The gravity method is the most commonly used trip distribution method, but studies have found the gravity model to be inadequate (Bhat et al., 1998; Sikdar, 1981; and Todes, 1981), and recent studies show that destination choice methods are used when data is available (Chow et al., 2005; Pozsgay and Bhat, 2001; Bhat and Zhao, 2003; and Steed and Bhat, 2000).

The gravity method is aggregate in nature. It has one model form that uses the Newtonian gravitational force analogy, and it includes factors based on zonal attractiveness, travel time, travel distance, and/or cost impedances. The gravity model is shown below and details of this model is discussed in the following section.

$$T_{ij} = P_i * \left[\frac{A_j F_{ij} K_{ij}}{\sum_{j=1}^{n} (A_j F_{ij} K_{ij})} \right] \quad (2\text{-}1)$$

where,

T_{ij} - Number of trips from zone i to zone j

P_i - Number of trip productions in zone i

A_j - Number of trip attractions in zone j

F_{ij} - Friction factors (represent the spatial separation between zone i and zone j)

K_{ij} - Optional adjustment factors (accounts for socio-economic and other adjustments between zones)

The destination choice method (DCM) is disaggregate in nature. It has several model forms for utility expressions that describe tradeoffs in traveler choices of destination. Compared to the gravity model, the destination choice model accounts for more explanatory variables including traveler behavior, personal characteristics, and zonal measures; and it does not require friction factors or special adjustment factors. Of the different DCM forms, the multinomial logit (MNL) model is the focus of this study. The MNL model has multiple explanatory variables used to describe the choice of destination and it estimates the conditional probability of a trip maker choosing a destination. The MNL model is shown below, and details of this model are explained in the following sections and in Chapter 4 of this thesis.

$$P_{ni} = \frac{e^{U_{ni}}}{\sum_{j \in J_n} e^{U_j}} \quad (2\text{-}2)$$

where,

$P_{ni}(\beta_n)$ - MNL conditional choice probability of destination i for trip maker n

J_n - Choice set of available destinations for trip maker n

U_{ni} - Utility of destination i for trip maker n

$$U_{ni} = \alpha_{ni} + \sum_{k=1}^{K} (X_{nik} * \beta_{nk}) + \varepsilon_{ni} \quad (2\text{-}3)$$

where,

α_{ni} - Alternative specific constant as a function of n

X_{ni} - Explanatory variables

β_{n} - Explanatory variable coefficients

ε_{ni} - Error term

Gravity Method

Metropolitan areas typically use the gravity method because it is simple, easy to understand and calibrate, and does not require hard-to-collect traveler behavior data. The gravity model uses aggregate data at the zonal level and assumes that travel flow is proportional to the zone attractiveness and inversely proportional to travel impedances. The zone attractiveness is a size measure based on the zonal area or number of persons, households, and/or jobs of a TAZ. Travel impedance is a spatial measure based on travel time, travel distance, and/or travel costs using the separation between zones. Therefore, smaller and more spatially distant TAZs are less attractive.

In an attempt to reflect traveler characteristics when using the gravity model, market segment techniques are used to stratify the trip productions by socio-economic variables such as income or auto ownership. For example, the Phoenix, Denver, and Portland regional travel demand models stratify home based work trips by income segments. However, this method still does not recognize the interaction of destinations or the interaction of trip maker characteristics with destination characteristics. The gravity method is unable to model why travelers make a particular destination choice on factors other than travel impedances and opportunities at the destination. Consequently, special land uses, like airports, are not modeled using various personal and destination characteristics that are important to the distribution of special land use trips. Another drawback of the gravity method is that it needs special zone-to-zone adjustment factors like friction factors (F_{ij}) and K-factors (K_{ij}) to force the model to match observed trip patterns. The "force fit" is arbitrary, does not capture the underlying behavior of the trip, and may not transfer to future conditions (Zhao et al., 2004).

<u>*Destination Choice Method*</u>

DCMs represent the state of the art in regional travel demand modeling. Results from a study in Florida show that all urban areas improved trip distribution using destination choice models regardless of the urban size (Chow et al., 2005). Like the gravity method, the destination choice method considers opportunities at the destination and zone-to-zone travel impedances. Unlike the gravity method, destination choice methods use disaggregate data, incorporate numerous variables in the trip decision making process, and do not require any special zone-to-zone adjustment factors. Destination choice models describe a trip maker's choice of destination in probabilistic terms by simultaneously modeling destination characteristics, origin-destination travel conditions, and personal characteristics. Hence, destination choice models reflect travel based on behavioral characteristics that more naturally justify the trip rather than general characteristics of the trip such as trip distance and trip ends at the destination (Zhao et al., 2004). Three main aspects that influence the traveler's choice of destination using DCM include:

- *Attractiveness* of each destination described in land use measures of number of households, population, employment by job category, square footage by land use category, number of establishments by type, special land uses, etc.

- *Travel conditions* between origin-destination pairs measured by travel time, travel distance, or travel costs.
- *Personal characteristics* such as household income, age, gender, household size (persons per household), auto availability, employment, etc.

The family of destination choice models includes probit, general extreme value, logit, and mixed logit models. In the 1960's discrete choice models concentrated on mode choice travel choices using simple binary logit models (Warner, 1962; and Quarmby, 1967). It was not until the 1970's that other travel choices were analyzed using enhanced closed form logit models such as the MNL model (Adler and Ben-Akiva, 1975; Lerman, 1976; and McFadden, 1978). Recently, much attention has focused on mixing the logit models over an observed distribution. One such model is the mixed multinomial logit (MMNL) model, and this model has shown to be advantageous in several studies (McFadden and Train, 2000; Hensher and Greene, 2001; Walker, 2002; Hess et al., 2004; and Gopinath et al., 2004). The MMNL model is the same as the MNL model except that the parameters are randomly distributed over the observed data.

This research investigates the use of the MMNL model for trip distribution of RDU airport trips at the zonal destination level. It was found that the MMNL model estimation required a comprehensive set of observed survey data for all zonal destinations and several complex considerations. The observed dataset for the RDU airport captured less than half of the available TRM study area TAZ destinations by trip purpose. The MMNL models work well when each of the available TRM zone destinations are captured in the observed survey data set, but when most of the destination choice TAZs are not represented in the observed dataset, the MMNL model results in a worse model fit. One way to overcome this issue would be to aggregate the TRM zone destinations (over 2,300 destinations) to socio-economic (SE) group destinations (4 to 10 destinations) per trip purpose. Nevertheless, the complex issues discussed below became more difficult to determine. The SE group destination levels are discussed further in Chapter 4 – Model Development.

The main issue of the MMNL model that had to be considered was if there were to be random parameters, and if so, which parameters should be randomly mixed over the observed data. If there were random parameters, one had to decide which distribution the random parameters would follow (uniform, normal, logarithmic, etc.), which simulated draw generator would be used (pseudo-random number generator, Halton method, Modified Latin Hypercube Sample procedure, etc.) and how many simulated draws would be used in the probability estimation (Hensher and Greene, 2001). These decisions were time consuming and demanding, and it was difficult to make these decisions based on a relatively low number of observations compared to the number of available destinations in the TRM study area. Thus, the MMNL model was determined to be more difficult than necessary for this study, and a simpler and more straightforward approach was found to be best for this study. The approach of this study uses the MNL model to distribute RDU airport trips at the zonal level. It is discussed further in the following section.

Multinomial Logit Model

Currently, the MNL model is the most widely used discrete choice model, and for many years it has provided the fundamental platform for the analysis of discrete choice (Greene and Hensher, 2002). The MNL model is a mathematical logit function that predicts a trip maker's destination choice based on the utility or relative attractiveness of competing destinations that are mutually exclusive. For example, in the TDM mode choice step a trip maker can choose Car or Bus but not both at the same time, and in destination choice, a traveler can choose Office or Restaurant but not both at the same time. The MNL model is a closed-form model with more than two independent choices, and it is assumed that each trip maker's choice destination can be specified using reasonable, deterministic rules. The MNL model structure is shown below. Additional details can be seen in Ben-Akiva and Lerman (1985) and Anderson et al. (1992)

$$P_{ni} = \frac{e^{U_{ni}}}{\sum_{j \in J_n} e^{U_j}} \qquad (2\text{-}2)$$

where,

$P_{ni}(\beta_n)$ - MNL conditional choice probability of destination i for trip maker n

J_n - Choice set of available destinations for trip maker n

U_{ni} - Utility of destination i for trip maker n

$$U_{ni} = \alpha_{ni} + \sum_{k=1}^{K} (X_{nik} * \beta_{nk}) + \varepsilon_{ni} \qquad (2\text{-}3)$$

where,

α_{ni} - Alternative specific constant as a function of trip maker n

X_{ni} - Explanatory variables

β_n - Explanatory variable parameters

ε_{ni} - Error term

The MNL model has been used to capture complex transportation phenomena, such as the choice of mode (Ben-Akiva and Lerman, 1985; Ewing et al., 2004; and Greenwald, 2005), destination (Skinner, 1976; Bhat et al., 1998; Bhat and Zhao, 2003; Zhao, 2004; Li et al., 2004; and Chow et al., 2005), route (Ben-Akiva and Bierlaire, 1999), airport in a multi-airport region (Skinner, 1976; Harvey, 1987; Windle and Dresner, 1995; Pathomsiri and Haghani, 2004; and Hess and Polak, 2004), residential location (McFadden, 1978; and Anas and Chu, 1982), and recreational activities (Pozsgay and Bhat, 2001; and Steed and Bhat, 2000).

According to Maier and Weiss (1989), the MNL model is the most simple and most commonly used discrete choice model, and it has several behavioral advantages, especially for distributing special land use trips, such as airport trips, that have unique travel characteristics. The MNL model captures unique travel patterns by including multiple characteristics of the destinations and of the trip makers that affect the choice of destination. However, there are some concerns regarding the MNL model. The MNL model possesses the Independence from Irrelevant Alternatives (IIA) property. This property states that for each trip maker, the ratio of probabilities between any two choice destinations is entirely independent of the utility of all other destinations. In other words, the trip makers choice of destination is unaffected by the inclusion or exclusion of any other destination. This is a major limiting factor of the MNL model that is not easily verified, and in many situations it is unrealistic and contradictory to the logical notion that one's choices are interdependent. Problems with this assumption are that some destinations can be highly correlated (similar to each other), and this can limit the usefulness in analyzing more complex choice situations. Other concerns of the MNL model are that it must be weighted against such issues as data availability and software availability. Furthermore, there is a wide range of assumptions associated with the MNL model, and there are considerations that must be addressed in order to properly apply the model. Below is a list of the assumptions and considerations of the MNL destination choice model.

Assumptions of the MNL Model

- *Destination*: It is assumed that the elemental destinations aggregated to the TAZ or socio-economic group have similar impedances (time and distance), socio-economic characteristics, and demographic characteristics.
- *Trip Maker*: It is assumed that trip makers have full knowledge of all destination choices in the study area. It is assumed that attitudinal and perception factors do not influence a trip maker's choice destination and that individual choices can be predicted based on limited quantifiable variables.
- *Travel Behavior*: It is assumed that individuals with similar characteristics will also have similar preferences that can be represented by the utility function. Also, it is assumed that trip makers are essentially rational decision-makers who seek to make choices that maximize their utility. This decision is based on the Random Utility Maximization (RUM) theorem and the Consumer Theory. The RUM theory states that a trip maker will make decisions to maximize their well-being, and the Consumer Theory states that a trip maker makes rational decisions that are consistent and transitive. Transitive means that if a person chooses destination "A" over destination "B" and chooses destination "B" over destination "C" then they will choose destination "A" over destination "C".
- *MNL Model*: It is assumed that the relationship between the underlying factors and the choice probability of a trip maker is a logit functional form. The logit function is S-shaped, and it relates more than one independent variable to the probability of making a specific choice. It is assumed that the MNL model utility is composed of deterministic and random components and that the decision process is probabilistic.

- *Error Component*: It is assumed that the random error component of the MNL utility function is independently drawn from a logistic distribution to represent particular taste variation across the trip makers. The error components of the utility function are assumed to be independent and identically distributed (IID) with type I extreme-value distribution (Gumbel, 1958). Independent means that there are no common unobserved factors affecting the utilities of the destinations, and identically distributed means that the variations in unobserved factors affecting the utility are the same across destinations. In other words, there is no correlation between the error components of the utilities, and the variance of the error components are the same for all destinations. Furthermore, it is assumed that the error component represents uncertainty in the model and the assumptions that trip makers have incomplete information and imperfect discrimination capacity of possible destination choices.

<u>Considerations of the MNL Model</u>

- Is there ample observed data to support the modeling needs of a DCM?
- Should the utility function be linear or non-linear (logarithmic, exponential, quadratic, cubic, etc.)?
- What explanatory variables should be used in the utility function? (income, age, gender, employment, travel time, etc.)
- How are the explanatory variables developed or calculated? For example, travel time impedance may be based on free flow or congested network conditions and income of a destination may be based on the median or average household income of the elemental households in the destination.

- Should the observed data destinations be segmented by socio-economic group, and if so, what is the best socio-economic group for each trip purpose? (income, employment type, land use, etc.)
- What software should be used for the analysis? (Biogeme, Alogit, SAS, etc).

These questions regarding the MNL model are addressed for the case study of the RDU airport in Chapter 5 of this report. How the analyst answers the foregoing questions and how comfortable the analyst is with the answers will determine whether the MNL model is used. The decision to use DCMs and its application compared to the standard gravity model is complex. Thus, many planners opt to use the traditional gravity model. However, the potential benefits of using the MNL model are attractive, and more practitioners are moving towards DCMs.

Travel Demand Models for Cities with Airports

Most research regarding airports has focused on airport choice models in a multi-airport region (Skinner, 1976; Harvey, 1987; Pathomsiri and Haghani, 2004; Hess, 2005; and Windel and Dresner, 1995) and ground access mode choice models as described in such reports as the Transportation Research Board E-Circular of *Aviation Demand Forecasting: A Survey of Methodologies* and the Southern California Association of Governments (SCAG) Airport Demand Model Literature Review (Gosling, 2003). However, very little work has been done to model airport trip distribution at the zonal level, which is the focus of this research.

A review of twenty-seven U.S. travel demand models for cities with airports found that only three models use a DCM for trip distribution, and one model uses a combination of the gravity model and the DCM. The remaining twenty-three travel demand models currently use the gravity method to distribute trips and four of these regions plan to enhance to DCM in the future. These results are shown in **Table 2-1**. The implication of these results is that gravity models for trip distribution are the accepted method, but that the state of the art is moving toward destination choice methods. Additionally, **Table 2-1** specifies if the travel demand models have an airport special generator or sub-model and what distribution method is used for the airport trips.

Of the twenty-seven travel demand models, twelve models treat the airports in their region as airport special generators. The airport special generators and the airport agency of the special generators are specified in **Table 2-2**. Most of the airport special generators are develop using unique trip tables or special adjustments of trip rates such as K-factors to control the number of attractions to the airport (Bismark, Denver, and Dallas-Fort Worth). These travel demand models do not have separate trip distribution models for the airports, but some of them use special adjustments for the airport trips and others plan to use a separate distribution procedure for airport trips in the future. For example, the Denver Region Council of Governments makes modifications of the travel impedances used to distribute the airport trips in order to match observed air passenger trip distributions, and the Metropolitan Washington Council of Governments plans to develop an airport access choice model for their next model update (Morgan, 2003).

Table 2-1: Travel Demand Models in Various Metropolitan Areas

Area	TDM Distribution	Airport Model	Airport Distribution
Albuquerque, NM	Gravity	Yes - Special Generator	Gravity
Anchorage, Alaska	Gravity	No	Gravity
Atlanta, GA	Gravity	Yes - Sub-Model	Linear Regression
Baltimore, MD	Gravity	Yes - Special Generator	Gravity
Bismarck, ND	Gravity	Yes - Special Generator	Gravity
Colorado Springs, CO	Gravity	Yes - Special Generator	Gravity
Connecticut State	Gravity	Yes - Special Generator	Gravity
Dallas-Fort Worth, TX	Gravity	Yes - Special Generator	Gravity
Denver, Colorado	Gravity / DCM*	Yes - Special Generator	Gravity-modified airport impedances
Detroit, Michigan	Gravity	No	Gravity
Fargo, North Dakota	Gravity	Yes - Special Generator	Gravity
Houston-Galveston, TX	Gravity	No	Gravity
Los Angeles, CA	Gravity	Yes - Sub-Model	Multinomial Logit model
New Orleans, LA	Gravity	Yes - Sub-Model	Allocation Factors
Ohio/Kentucky/Indiana	Gravity	Yes - Sub-Model	Allocation Factors
Phoenix, AZ	Gravity	No	Gravity
San Diego, CA	Gravity	No	Gravity
San Francisco, CA	Gravity	Yes - Sub-Model	Multinomial Logit model
Seattle, Washington	Gravity / DCM*	Yes - Special Generator	Gravity
Southern California	Gravity / DCM*	No	Gravity
St. Louis, MI	Gravity	No	Gravity
Triangle Region, NC	Gravity / DCM*	Yes - Special Generator	Gravity
Washington, DC	Gravity	Yes - Special Generator**	Gravity-market segments**
Memphis, Tennessee	Gravity & Logit (HBW)	Yes - Special Generator	Gravity
New York	DCM - Logit	No	Logit model
Portland, Oregon	DCM - Logit	Yes - Sub-Model	Multinomial Logit model
Sacramento, CA	DCM - Logit	No	Logit model

* Existing model is Gravity and new model will be Destination Choice.

**Existing model treats the airports as special generators and new model will treat the airports with a sub-model

Table 2-2: Travel Demand Models with Airport Special Generators

Area	Airport	Agency
Albuquerque, NM	Albuquerque International Airport (ABQ)	Mid-Region Council of Governments
Baltimore, MD	Baltimore-Washington International (BWI)	Baltimore Metropolitan Council
Bismarck, ND	Brismarck Municipal Airport (BIS)	Brismarck/Mandan MPO
Colorado Springs, CO	Colorado Springs Airport (COS)	Pikes Peak Area Council of Governments
Connecticut State	Bradley International (BDL)	Capital Region Council of Governments
Dallas-Fort Worth, TX	Dallas-Fort Worth International (DFW)	North Central Texas Council of Governments
Denver, Colorado	Denver International Airport (DIA)	Denver Regional Council of Governments
Fargo, North Dakota	Hector International Airport (FAR)	Fargo/Moorhead MPO
Memphis, Tennessee	Memphis International Airport (MEN)	Memphis Area Transit Authority
Seattle, Washington	SeaTac Airport (SEA)	Puget Sound Regional Council
Triangle Region, NC	Raleigh-Durham International Airport (RDU)	Triangle Regional Model Service Bureau
Washington, DC	Dulles International Airport (IAD) Baltimore-Washington International Airport (BWI) Ronald Regan Washington National Airport (DCA)	Metropolitan Washington COG (MWCOG)

Only six of the twenty-seven travel demand models have an airport sub-model to account for the unique travel patterns of airport trips. The airport sub-models use unique trip tables and allocation techniques to distribute airport trips to the study area zones. The airport sub-models and the airport agency of the sub-models are specified in **Table 2-3**.

Table 2-3: Travel Demand Models with Airport Sub-Models

Area	**Airport**	**Agency**
Atlanta, GA	Hartsfield International Airport (ATL)	Atlanta Regional Commission (ARC)
Los Angeles, CA	Los Angeles International Airport (LAX) Ontario International Airport (ONT) John Wayne-Orange County Airport (SNA) Burbank-Glendale-Pasadena Airport (BUR) Long Beach Airport (LGB) Palm Springs Airport (PSP)	Southern California Association of Governments (SCAG)
New Orleans, LA	Lewis Armstrong Airport (MSY)	Regional Planning Commission (RPC)
Ohio/Kentucky/Indiana	Cincinnati/Northern Kentucky International (CVG)	Ohio-Kentucky-Indiana Regional COG
Portland, Oregon	Portland International Airport (PDX)	Portland Metro
San Francisco, CA	San Francisco International Airport (SFO) Oakland International Airport (OAK) San Jose International Airport (SJC)	Metropolitan Transportation Commission (MTC)

The Atlanta airport sub-model allocates daily enplanements to "ground side" trip ends using linear regression techniques by classifying households by income and total employment. The Los Angeles, California airport sub-model, called the Regional Airport Demand Allocation Model (RADAM), uses the multinomial logit (MNL) model to allocate air passenger and cargo trips between the airports and the study area. The Los Angeles study area is aggregated from 3,827 zones to 100 zones for the RADAM airport model. The New Orleans airport sub-model uses the home based other (HBO) trip ends to allocate air passenger trip ends to the study area zones by weighing the trips by income market segment. The Ohio, Kentucky, Indiana airport sub-model uses separate airport trip tables and allocates the trips to the study area zones using allocation factors of households and employment based on a 1995 socio-economic dataset for the region. The Portland, Oregon airport sub-model uses the MNL model to allocate airport trips to the study area zones, and the airport trips are segmented by air passenger type (resident / non-resident and business / non-business). Finally, the San Francisco, California airport sub-model consists of an airport choice model and an airport ground access mode choice model. The airport model is named ACCESS, and it was developed by Greig Harvey for the Metropolitan Transportation Commission (MTC). The ACCESS program allocates airport trips to the San Francisco region using MNL models segmented by air passenger type (resident / non-resident and business / non-business). Three of the six airport sub-models use the MNL model to distribute airport trips among zones in the study area. Additional details on the airport models are summarized by the Metropolitan Washington Council of Governments (Morgan, 2003).

RDU Airport Trip Distribution Method

The TRM treats the RDU airport as a special generator. The airport trip productions and attractions are based on the total employment of the RDU airport zone and not on the airport air passengers. The distribution of RDU airport trips is treated like all other TAZs in the TRM using the gravity method. However, airports have significantly different trip patterns and trip lengths than other land uses, and many factors such as land use and household characteristics affect airport trip distribution besides the usual trip length (travel time and distance) factors considered by the gravity method.

Given that the state of the art in regional travel demand modeling is moving towards destination choice models because of the documented advantages of destination choice methods, especially for the unique characteristics of airport users, it appears that this research on destination choice models for an airport sub-model is an advantageous area for study. Considering past experiences with destination choice models, the available observed data, limitations, and assumptions of the destination choice models, the MNL destination choice model is best for trip distribution of the RDU airport trips.

Summary

The literature review shows that travel demand models most commonly use the gravity method to distribute trips, but research indicates that destination choice methods such as the MNL model provide advantages in distributing trips. The MNL model uses disaggregate observed data. It is more behavioral than the gravity model, and it accounts for additional factors such as individual characteristics and destination characteristics that affect travel decisions. This is especially true for unique land uses like an airport. However, destination choice models are only superior when sufficient data is available and correct considerations regarding the utility functional form and the utility function variables are accounted for. The literature review on airport sub-models of regional travel demand models is rather limited, but several other studies provide helpful insight for the present work.

Chapter 3 describes the data sources required to develop and calibrate the distribution model. Chapter 4 describes the tools and the framework to develop the MNL model using the data described in this chapter. Chapter 5 applies the framework to a case study of the RDU airport and Chapter 6 reports the conclusions and recommendations of this study.

CHAPTER 3 – DATA SOURCES

This chapter describes the data required to develop and apply a MNL destination choice model. Available data sources and data analysis tools are also discussed in this chapter. Deficiencies in the datasets are identified and means to overcome the shortcomings are proposed.

Data Requirements

Previous studies such as Bhat, et al. (1998) found that the effects of individual characteristics with zonal characteristics and impedance measures are important in developing a destination choice model. Therefore, individual-specific data linked to study area zones and network data are required to develop a MNL model for trip distribution. The primary individual-specific dataset is from survey data of individual trip makers. Surveys provide specific disaggregate information on travelers and their travel behavior in addition to characteristics of the trip choice destinations. The primary zonal and network data is from an existing travel demand model of the study area or from a local MPOs and planning agencies. The zonal data includes data specific to the TAZ destinations such as demographic and socio-economic data and the network data includes local roadway attributes such as link distances and free flow speeds to get travel impedances. Finally, data specific to the special land use of interest such as an airport is required to generate the production and attraction trips to apply the destination choice model. For an airport, the special land use data includes the number of enplaned, deplaned, and transfer passengers, mode split, hours of operation, services provided, etc.

Survey Data

The key component to develop a MNL destination choice model for this study is survey data of RDU airport passengers and airport employees. The trip maker choice behavior allows for model specification and coefficient estimation to yield accurate results (Cambridge Systematics, Inc., 2001). However, resource and funding constraints can make it difficult to obtain survey data specific to a land use and specific to trip distribution. Furthermore, if the survey is not thorough then the additional cost and effort required for the survey may not provide any additional gains over standard trip distribution methods such as the gravity method. For these reasons, most surveys have multiple purposes and users and not all the attribute information may be needed at one time or for each user.

Air Passenger Survey

This study used an air passenger survey of the RDU airport sponsored by the Triangle Transit Authority (TTA). The survey was conducted as part of a rail study to support rail analysis to the RDU airport (PBS&J and NuStats Partners, 2002). The RDU air passenger survey covered five days from Monday, July 15, 2002 to Friday, July 19, 2002 and provided revealed-preference data on RDU air passengers including both visitors and study area residents. There were 23 questions preprogrammed into a Palm Pilot Personal Data Assistant. Surveyors stood at the air carrier's gate area and asked the questions to passengers waiting to board planes, but not to passengers transferring flights or returning from a flight. Only one adult 16 years of age or older per every third traveling party was surveyed. The survey questions captured the location of air passengers prior to their out-bound flight along with household data (income, number of adults, and number of children), personal data (gender, age, and work place), and trip data (trip purpose, mode, number of adult travel companions, and number of child travel companions).

The RDU air passenger survey is used in this study to support the development of a destination choice model by identifying characteristics that link air passengers to the airport and by identifying survey records with non-airport trip ends inside the study area. Of the 1,525 surveyed (non-connecting) passengers, there are 797 records that have geocoding deficiencies and 24 records that have data deficiencies. Thus, these 821 records cannot be used in this study since their non-airport trip ends cannot be determined with the available data. Furthermore, twenty percent (143 observations) of the 704 geocoded passenger records are external to the study area. These records are removed from the sample set resulting in 561 air passenger survey records geocoded internal to the study area.

Since trip purposes vary across passengers, the internal geocoded records are split by trip purpose: home based (HB) trips and non-home based (NHB) trips and MNL models are developed for each purpose. By segmenting the passengers by trip purpose, trip preferences across passengers are more likely to be captured (Pathomsiri and Haghani, 2004). For HB trips, the non-airport trip end is the home zone and for NHB trips the non-airport trip end is locations other than the home such as the air passenger's work place, a shopping center, restaurant, entertainment event, hotel, etc. **Table 3-1** shows the number of internal geocoded air passenger records segmented by trip purpose.

Table 3-1: Internal Geocoded Air Passenger Observations by Trip Purpose

Trip Purpose	Internal Geocoded Observations
HB	359
NHB	202

Airport Employee Survey

This study used an airport employee survey sponsored by the TTA in the development of the RDU airport sub-model. The survey was conducted as part of a rail study to support rail analysis to the RDU airport (PBS&J and NuStats Partners, 2002). The RDU airport employee survey was conducted from Monday, July 22, 2002 to Friday, July 26, 2002. The survey provided revealed-preference data on RDU airport employees who worked for the RDU Airport Authority or who worked for companies located at the airport that provide services and supplies such as air carriers, food services, maintenance, and shipping. The employee survey consisted of a 13 question self-administered questionnaire that was distributed to companies at the airport to give to and to collect from their employees. Only 40 of the 78 companies were able to be contacted either by letter or by personal phone call to participate in the survey and only 20 of the 40 eligible firms agreed to participate in the survey. The largest employer at the RDU airport in July of 2002, American Airlines, refused to participate in the survey and, only 17 percent of the surveyed employees (523 airport employees) returned the survey questionnaires.

The RDU airport employee survey is used in this study to support the development of a destination choice model by identifying characteristics that link airport employees to the airport and by identifying home locations of the airport employees living inside the study area. Some characteristics that link employees to the RDU airport include current mode of transportation to the airport, estimated travel time, trip frequency, need for mid-day transportation, parking location, and demographics. Of the 523 airport employee observations, 112 records are geocode or data deficient and 37 records are external to the

TRM study area. These records are removed from the survey dataset and 374 airport employee observations result with home locations identified internal to the TRM study area.

The only trip purpose for airport employees is "journey-to-work" (J-to-W). These trips link the home with the work place and interim stops do not affect the destination choice. The home is the non-airport trip end and the RDU airport is the work place trip end.

Survey Issues and Remedies

There are two main issues involved with the RDU air passenger and airport employee surveys. The two issues are (1) incomplete data and (2) small observed sample size compared to the study area. The first main issue is that several observation records do not have complete data where all field values are known. For example, some records have unknown or unrecognized destination choice locations and other records have unknown or missing personal characteristics such as household income or household size. Consequently, only the survey observations with complete data field values can be used in the trip distribution MNL models. This results in a significant reduction of the available sample size. **Table 3-2** shows the number of observed survey record and the number of observations with complete survey data (the sample size available for the trip distribution MNL models) by trip purpose. These available sample sizes by trip purpose represent less than 15 percent of the TRM study area TAZs (2,317 TAZs) available for development of the MNL destination choice models.

Table 3-2: Internal Survey Observations and Sample Size by Trip Purpose

Trip Purpose	Survey Observations	MNL Sample Size	% Sample Size
HB	758	359	47%
NHB	757	202	27%
J-to-W	523	374	72%

This issue is extremely difficult to alleviate, especially if other resources and data sources are unavailable. Some research suggests that the sample size have at least 1,000 to 3,000 observations with complete data records specific to the use of the data such as internal trip ends to the study area (Horowitz et al., 1986). To accomplish this number of complete data records, the original dataset (survey data) should collect four or more times the actual sample size. For example, the Metropolitan Transportation Commission (MTC) of the San Francisco, CA region conducted the 1995 Airline Passenger Survey and collected information on over 21,000 departing air-travelers to obtain approximately 5,100 observations to be used in the airport choice MNL model.

The second main issue is that the sample size for each TAZ destination is not large enough to develop statistically valid models. Determining the required sample size depends on (1) the number of possible destination (2) the level of confidence (3) the margin of error tolerated, and (4) the variability in the studied population. However, as a rule of thumb, statisticians historically recommend a sample size of 30 or more observations per destination to provide a statistically valid model. The sample size of 30 is based on the central limit theorem that states that the sampling distribution of any statistic will be approximately normal at a sample size of 30 or more. Because the purpose of the surveys was not intended for distribution of the non-airport trip ends to the TRM study area, most destination TAZs in the study area were not chosen by the observed survey trip makers. Furthermore, most of the TAZ destinations that were chosen in the survey data set are only represented once by the observed trip makers. On average, there were 1.4 survey observations per destination choice TAZ, which is not even close to the recommended 30 sample size.

To overcome the sample size issue of having one or two observations per choice destination instead of over 30 observations, the TAZ choice destinations are grouped by market segmentation of socio-economic (SE) groups. Such groups may be based on income level, employment type, land use, travel impedance, etc. These groups are sets of destination TAZs that are scattered throughout the study area and are not spatially clustered. The SE groups used in this study are based on the trip maker's characteristics of each trip purpose and guidelines used in the TRM. Additionally, the number of observations per segmentation is considered in the development of the SE group segments, with the goal of having at least 30 observations per SE group segment. As a result, the SE group segment destinations may have a sufficient number of survey observations to estimate statistically valid MNL models. This procedure is further explained in Chapter 5. **Table 3-3** shows an example of the income level SE group segments that are used for the HB trip purpose in this study. The HB trip purpose has 359 survey observations and five income group segments. This results in a range of 18 to 159 observations per choice destination.

Table 3-3: Socio-economic Income Group Segments for the HB Trip Purpose

Income Level	Income Description	Income Specification	Observations
1	Low	Income < \$25,000	18
2	Low to Medium	\$25,000 ≤ Income < \$35,000	29
3	Medium	\$35,000 ≤ Income < \$50,000	59
4	Medium to High	\$50,000 ≤ Income < \$80,000	159
5	High	Income ≥ \$80,000	94

Demographic Data by Traffic Analysis Zone

Land use data by TAZ is another key component in developing a destination choice model. TAZs are defined geographic areas that relate travel demand to land use characteristics. In destination choice models, the TAZ represents a small sector of the study area consisting of aggregated elemental destinations and the destination choice model treats each TAZ as a possible destination choice. The TAZ geography and land use data used in this study are provided by the TRM Service Bureau from the 2002XP TRM dated May 15, 2006. The data are in TransCAD software format and require the TransCAD software to view and modify the files. The traffic analysis zone system for the TRM study area is shown in **Figure 3-1**.

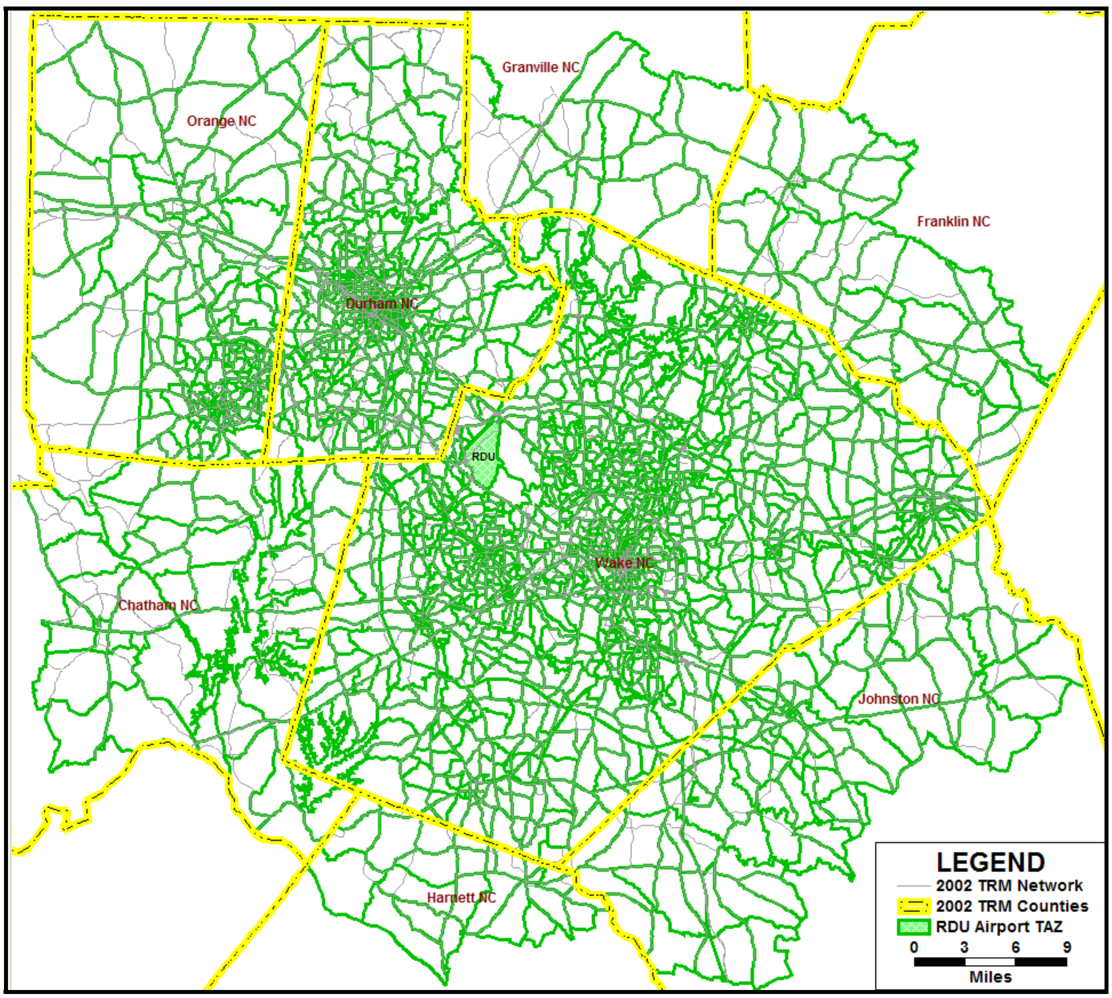


Figure 3-1: TRM 2002XP Traffic Analysis Zones

There are 2,317 internal zones (within the TRM study area) and 72 external zones (location where traffic enters and exits the TRM study area). In this study, only the internal zones are considered as possible destination choices since the external zones of the TRM use a separate model to distribute external-external and external-internal trips. Additionally, the external zones do not have associated demographic data to be used in the MNL model estimation. However, each of the 2,317 internal zones has demographic data such as households, population, median income, employment, etc. as listed in **Table 3-4**. Most of the TRM study area zonal data are from the local MPOs (CAMPO and DCHC) and the land use employment data are segmented by Standard Industrial Classification (SIC) code.

Table 3-4: Traffic Analysis Zone Attributes

Field Name	Attribute Description
ATYPE	Area Type
HH	Households
POP	Population
mINC	Median Income
HHS	Average Household Size
INCRATIO	Income : Car Ratio
IND	Industry Employment
RET	Retail Employment
HWY	Highway Employment
OFF	Office Employment
SER	Service Employment
DU	Dwelling Units
UBEDS	University Beds

Additionally, impedance matrices of travel time and travel distance are obtained from the TRM Service Bureau for each zonal pair. The zonal pairs used in this study are the RDU airport zone paired with all other internal TAZs in the 2002XP TRM study area. The impedances are based on the 2002XP TRM highway network link distance and free flow travel conditions between the RDU airport zone and all other TAZs in the study area. See **Appendix A** for a table of TAZ data including travel times and distances between the RDU airport and all other TAZs in the study area.

Special Land Use Data

Characteristics specific to the special land use of interest, the RDU airport, are required to apply the destination choice model. The RDU Airport Authority is the best source of information regarding RDU airport activity data such as enplanements, deplanements, transferring air passengers, travel characteristics, and employee characteristics. Historic data of the RDU airport were evaluated to determine the impact of the 9-11 terrorist attack on the RDU airport activity. The RDU airport activity data for the year 2002 were not noticeably affected by the terrorist attacks. The year 2002 annual enplanements, deplanements, and transfer passengers are used to generate the number of daily ground trips produced by RDU air passengers (**Table 3-5**). This number is determined by subtracting the percent of air passengers that have connecting flights from the enplanements and deplanements and dividing this number by 365 days in a year. The RDU Airport Authority reports that 4 percent of the RDU air passengers connect from one flight to another without leaving the airport via ground transportation. This transfer percent is based on activity reports from the airlines and data from the U.S. Department of Transportation (USDOT) Bureau of Transportation Statistics (BTS). The USDOT BTS information is used because several of the airlines do a substandard job of distinguishing connections from locally boarding passenger (enplanements) and locally terminating passengers (deplanements).

Table 3-5: Raleigh-Durham International Airport Activity Data

Year 2002	RDU Airport Authority			Daily Ground Person Trips
	Air Person Trips	Transfers at 4%	Ground Person Trips	
Enplanements	4,133,046	165,322	3,967,724	10,870
Deplanements	4,108,207	164,328	3,943,879	10,805
Total	8,241,253	329,650	7,911,603	21,676

The RDU Airport Authority estimates that there were 4,300 to 5,000 employees with identification badges in year 2002. These employees worked in shifts starting at 5:00 AM and 1:30 PM and many employees also worked on weekends. To determine the average number of employees that work at the RDU airport on an average weekday, some assumptions must be made. It is assumed that all airport employees live internal to the Triangle Region. It is assumed that on average all employees with identification badges make a trip to the RDU airport on an average day. Given that most of the employees work in shifts, if half these employees work the AM shift and the other half of the employees work the PM shift, then on average all the employees make a trip to the airport on an average weekday. Additionally, since several of the employees work on the weekends as well as the weekday, it is assumed that less employees work during the week than the actual number of employees with identification badges. Therefore, this study chooses to use the estimate of 4,300 employees with identification badges instead of 5,000 employees. Furthermore, the RDU Airport Authority estimates that one-third of the employees with identification badges (1,433 employees) work at the RDU airport on an average weekday.

Summary

Several data sources are needed to develop and apply a MNL model. Air passenger and airport employee survey data are the most important information for developing a MNL model, and acquiring such data can be challenging. Additionally, zonal demographic data and highway network data are required for developing a MNL destination choice model and this data can be simple to obtain if a travel demand model for the study area is readily available. Finally, airport specific data for airport passengers such as enplanements, deplanements and percent transfers and airport specific data for airport employees such as number of employees and employee work shifts are required to apply the destination choice model. This chapter described such data for the RDU airport based on a 2002 passenger survey, a 2002 employee survey, a 2002 base year travel demand model for the Triangle Region, and 2002 RDU Airport Authority statistics. The survey data was found to have several incomplete observed records, and to require SE grouping as the destination choice level. The RDU airport activity data was found to require modifications of trip generation for average daily weekday trips that access ground transportation. Chapter 4 describes the tools and the framework to develop the MNL model using the data described in this chapter. Chapter 5 applies the framework to a case study of the RDU airport and Chapter 6 reports the conclusions and recommendations of this study.

CHAPTER 4 – MODEL DEVELOPMENT

Chapter 4 discusses the framework of the multinomial logit (MNL) model for destination choice. This chapter starts with application tools available to estimate a MNL model. Chapter 4 presents terms and definitions of the model concept, the utility function properties and development, and the estimation procedure. The chapter ends with a list of steps used to estimate a MNL model.

MNL Model Application Tools

In order to implement a destination choice model such as the MNL model, special software packages must be used. Prior to the 1980's analysts used software packages such as Limdep, Alogit, and Blogit to estimate discrete choice models. As the analysis tools developed, Nlogit (Limdep) and Alogit became the most widely used tools for destination choice models. Today, other advanced software such as SAS, Biogeme (Hielow), Hlogit, and DCM (Ox) offer user-friendly tools to estimate destination choice models.

After considering several analysis tools, the BIerlaire Optimization toolbox for GEv Model Estimation (Biogeme) was chosen for this study. It is a discrete choice estimation software package developed by Michel Bierlaire and it has been used as an analysis tool in several studies (Gopinath et al., 2004; Hess, 2005; and Frejinger and Bierlaire, 2006). The software is free and it has a supportive Yahoo users group. The software does not limit the number of choice alternatives or the number of parameters estimated in the discrete choice models. The most recent version of Biogeme is version 1.4 with two advanced applications, Biosim and Bioroute. Biosim is a simulation application developed by Denis Bolduc that simulates discrete choice models and performs sample enumerations for the choice probabilities. Bioroute is a route choice application that uses a highway network and origin-destination pairs to create explicit enumeration of travel paths. The Biosim application is used in this study to determine the choice probability of each observation choosing their chosen destination. The Bioroute application is not used in this study.

Biogeme estimates both closed-form models such as the MNL model and open-form models such as the MMNL model. This research focuses on closed-form destination choice models. Biogeme has many computational advantages for estimating closed-form destination choice models and it offers a variety of options to the users of the software regarding model type (binary probit, multinomial logit, nested logit, cross-nested logit, and generalized extreme value), model form (linear or nonlinear), and optimization algorithm to estimate the log-likelihood (BIO, CFSQP, SOLVOPT, and DONLP2). This research uses the Biogeme closed-form MNL model with the BIO optimization algorithm.

Terms and Definitions

Destination choice is the choice between discrete alternative destinations. The MNL model is a discrete choice model that can analyze the choice of destination dependent on the type of destination and the personal characteristics of the traveler. The MNL model seeks to maximize the destination choice utilities for trip makers and it determines the probability of trip makers choosing one destination over another.

Trip Maker

The trip maker is the individual decision-making traveler. Each record from the observed data set indicates choices of a trip maker. The data represents the trip maker's personal characteristics such as age, gender, education, income, job description, etc and chosen destination (non-airport trip end). The trip maker is denoted by $n = 1 \ldots N$ where n is the individual and N is the population sample size.

Trip Purpose

The trip purpose is the type of trip made by the trip maker. The individual trip makers are segmented by trip purpose and distribution models are developed for each trip purpose. It is recognized that trip purpose specific models lead to better interpretations of travel behavior and are more efficient than models not specific to trip purpose (Bhat and Zhao, 2003). There are three airport trip purposes listed below. The trip purposes are denoted by $p = 1 \ldots 3$.

1. Air Passenger Home Based (HB)
2. Air Passenger Non-Home Based (NHB)
3. Airport Employee Journey-to-Work (J-to-W)

Choice Destinations

The destination choices are the available non-airport trip end locations that a trip maker considers during the choice process. The destinations are considered as elemental destinations by the trip maker such as the location of an individual's home, business, school, etc. However, in the situation of large study areas such as the Triangle Region, the elemental destinations must be aggregated to TAZs or to SE group segments in order to estimate the MNL model. The reason for this is due to observed data issues of estimating a MNL model with few observations per destinations, and due to the difficulty in defining exactly what constitutes the elemental destination (Pozsgay and Bhat, 2001; and Chow et al., 2004). The destinations (TAZs or SE group segments) are denoted as $j = 1 \ldots J$ where J is the total number of potential destinations for trip makers. The actual chosen destination by the trip maker is represented by "i".

When elemental destinations are aggregated to the zonal level, it is assumed that the elemental destinations within the TAZ have similar socio-economic and demographic characteristics. Ideally, one does not want to aggregate destinations, especially if the aggregation is more than at the zonal level. However, some circumstances require the need for further aggregation than at the zonal level. Such circumstances occur when the sample size of the observed data is too small and when the observed data set does not capture most of the TAZs in the study area. In this situation the elemental destinations are aggregated to a SE group segment based on a common SE market such as income level, land use, employment type, etc. Using this method, the destination choice is the SE group segment and there are usually five to ten destination choices per trip purpose instead of over two-thousand destination choices with zonal aggregation. This method is further discussed in the next section.

Available Choice Destinations

The available choice destinations are the set of destinations available to a trip maker. There are three sets of available choice destinations for trip makers (**Figure 4-1**): (1) the universal destination choice set, (2) the universal destination choice set by trip purpose, and (3) the observed destination choice set by trip purpose. The first available choice set of destinations is the universal choice set. This choice set consists of all destinations ($j = 1 \ldots J$) as available choice destinations to all trip makers and it is denoted as J. The second set of destinations available to trip makers is universal choice set split by trip purpose and this is denoted as J_p. This choice set reflects that not all destinations are available for trip makers of different trip purposes. For example, HB trips would not have TAZs with zero households as an available destination and NHB trips would not have TAZs with zero employment as an available destination. This choice set is useful when applying the DCM probabilities to the entire study area and it is explained further in Chapter 5, the case study of the RDU airport. The third set of available choice destinations is the observed choice set by trip purpose. This is the set of observed destinations obtained from the survey data and it is denoted as J_{pn}. This choice set reflects the only destinations used in estimating the DCM. This means that if a TAZ destination is chosen by an observed trip maker, then that TAZ is available in the DCM estimation. On the other hand, if a TAZ is not chosen by an observed trip maker, then that TAZ is not considered in the DCM estimation.

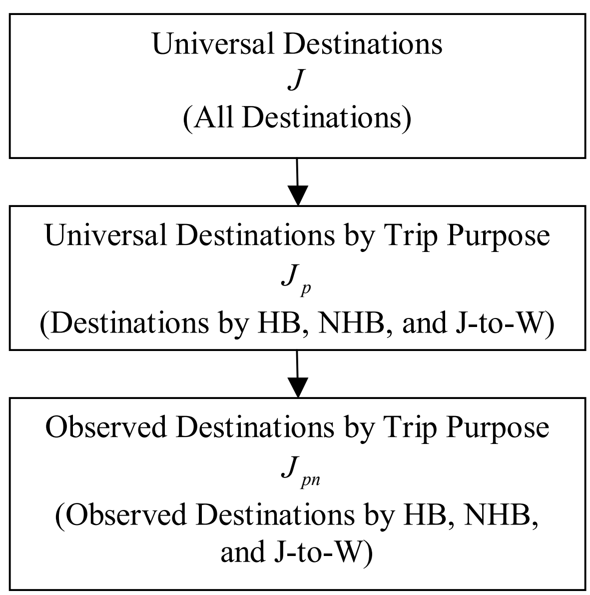


Figure 4-1: Available Destination Choice Sets

Since the DCM estimation is limited to the observed choice set by trip purpose, it is important for the observed data to capture all possible destinations of trip makers for each trip purpose. However, sometimes the observed data sets do not capture most destinations in the study area. Consequently, there may be a large number of destinations that are not in J_{pn}, are not considered in the DCM estimation, and do not have an estimated choice probability of being chosen by a trip maker. This is especially the case when there are thousands of available TAZ destinations (FDOT MTF, 2001). In an effort to overcome this issue, some studies use an observation repetition procedure (Bhat et al., 2003; and Pozsgay and Bhat, 2001). In this method, each observation is repeated a number of times, usually five to ten times. The repeated records are the exact same as the actual record except for the choice of destination. The destination choice for each repeated record is replaced randomly by a different but very similar destination TAZ from the study area that is most likely to be chosen by the trip maker. This procedure increases the number of TAZs considered in J_p and the number of destination choice probabilities estimated. Another method used to overcome this limitation, which is the method chosen in this study, is to group the trip makers and the destination TAZs by SE group segments. The SE group segments are not geographically clustered but they are based on a common SE variable such as income or employment type. Even though less explanatory power is obtained when TAZs are aggregated, research has shown this method to be the best way to yield reasonable forecasts when relatively small observed data is available (Horowitz et al., 1986). This method assumes that different trip makers have different choice processes and that the homogeneous groups account for population heterogeneity. The choice set in this method decreases from thousands of available destinations to less than ten destinations per trip maker.

Decision Rule

The decision rule is the underlying theory of destination choice models. Destination choice models use the Random Utility Maximization (RUM) theory to evaluate the choice set for each trip maker. Under this methodology, an individual's decision is based on maximizing his or her well-being by comparing the relative attractiveness of competing destinations (Ben-Akiva and Lerman, 1985). The attractiveness is represented by a utility function that accounts for personal preferences, destination characteristics, and unobserved variations in the population. Using this theorem, the destination with the highest utility is seen as the most attractive destination for a trip maker. The theorem form is mathematically shown below.

$$U_{ni}(X_i, \beta_n, \varepsilon_{ni}) \geq \max_{j=1,\ldots,J_{pn}} U_{ni}(X_j, \beta_n, \varepsilon_{nj}) \qquad (4\text{-}1)$$

where,

U_{ni} - Utility function of chosen destination i for trip maker n.
X, β, ε - Functions of the utility explained in the next section.
J_{pn} - Available set of choice destinations for trip maker n

Utility Function Development

The utility function consists of variables describing characteristics of the destination and characteristics of the trip maker. There is a unique utility for each observed destination choice involving a deterministic component and a random or error component. The deterministic component represents the observed data and the random or error component represents uncertainty. The uncertainty accounts for incomplete or unavailable information about the unobserved destinations and individuals, model measurement errors, and the assumptions that the trip maker has perfect discriminatory capability (Ben-Akiva and Bierlaire, 1999).

Variables

Variables are constraints that govern an individual's choice of destination based on maximizing his or her preferences. The value of the variables determines the "tipping point" in the distribution of preferences where trip makers would switch from one destination choice to another. The variables may include travel impedance factors, personal factors and destination attraction factors. Impedance factors are a measure of accessibility or of spatial separation between zones such as travel time, travel distance, and travel cost. The in-vehicle travel time used in this study is a function of the highway distance and the free flow speed of the highway network from the RDU airport zone to all other destination zones in the 2002XP TRM study area. The travel time is calculated as follows.

$$TravelTime = (\frac{Length}{FreeFlowSpeed}) * 60 \qquad (4\text{-}2)$$

Personal factors are observed characteristics of the trip maker including gender, employment type, household size (persons per household), household income, etc. Destination factors are the observed characteristics specific to each TAZ or SE group segment such as the number of households, population, employment by SIC code classification, median income, area type, and availability of services and infrastructure such as transit. The variables considered in this study to develop the utility function are listed in **Table 4-1** and these variables hold true over time so that future data sets can be applied to recalibrate the MNL model.

Table 4-1: Observed Utility Variables

Personal Characteristics	Destination Characteristics
Gender (GEN) Household Size (HS) Income Level (INC) Location Prior Airport (PRIOR) Transportation Mode (MODE)	Travel Time to RDU (TT) Average HH Size (HHS) Median Income Level (mINC) # Households (HH) # Service Employment (SER) # Office Employment (OFF) # Highway Employment (HWY) # Dwelling Units (DU) # University Beds (UBeds)

Utility Structure

The utility structure of the MNL model can be linear or non-linear. A linear utility implies that the marginal change of variables is independent of the existing variables and that the change in a trip maker's choice of destination is the same as the variables increase or decrease. A non-linear utility implies that the marginal change in a trip maker's choice of destination is not the same as the variables increase or decrease. **Figure 4-2** shows the linear, exponential, and logarithmic functions on a linear scale. The utility structure consists of a deterministic (measurable) part and a stochastic (random error) part. The deterministic part of the utility describes the attractiveness of destination choice i for trip maker n and the random error part of the utility adjusts the deterministic part with regard to uncertainty such as individual judgments and possible errors in observations or measurements. The random error part of the MNL utility function depends on the assumption that it is independent and identically Gumble distributed (Ben-Akiva and Lerman, 1985). This assumption should be verified after the MNL models are estimated.

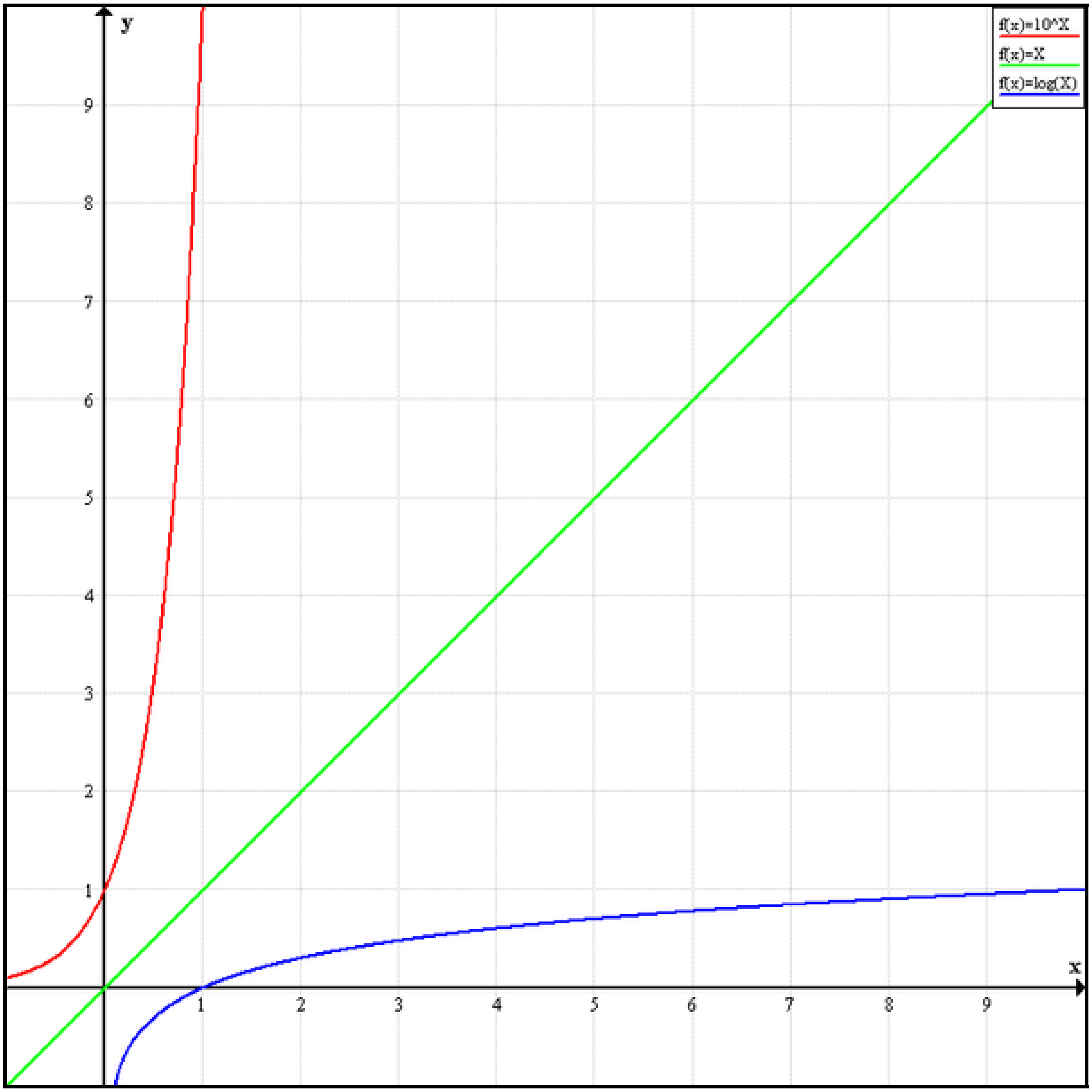


Figure 4-2: Linear, Exponential, and Logarithmic Functions on a Linear Scale

The utility structure determines the attractiveness of choice destination i for trip maker n. The utility is estimated for each observed destination of the trip purpose choice set J_{pn}. The utility function for the MNL model includes parameters (β) of the observed variables (X_{ni}). The standard utility is:

$$U_{ni} = \alpha_{ni} + \sum_{k=1}^{K} (X_{nik} * \beta_{nk}) + \varepsilon_{ni} \tag{4-3}$$

where,

α_{ni} - Alternative Specific Constant (ASC) that indicates the effect of a destination with a fixed coefficient. This accounts for unobserved factors that can not be modeled such as convenience, reliability and safety. One ASC is fixed at a value of one to represent a reference destination that all other destinations are scaled to. The remaining ASC values are estimated by the model. The ASC values move estimated results closer to observed demand at the aggregate level and they help explain what the existing model is not able to adequately address (Cambridge Systematics Inc., 2001).

X_{nik} - Explanatory variables of observed destination characteristics (travel time, number of households, median income, employment, etc) and observed trip maker characteristics (gender, income level, employment type, etc.)

K - Number of explanatory variables used in the utility function.

β_{nk} - Coefficient of the k^{th} observed variable (X_{nik}) that represents the effect of the variable.

ε_{ni} - Random error term that represents the unobserved characteristics of the trip maker's preferences for destination i that are not included in the model. The error term is independently and identically distributed (IID) with type I extreme-value Gumbel distribution across individuals and destination zones (Gumbel, 1958).

Choice Probability Estimation

The choice probability for the MNL models can be calculated precisely since it is closed-form in nature. The choice probabilities are based on the maximum likelihood estimation of the MNL model. The log-likelihood function is estimated based on the optimization algorithm BIerlaire's Optimization (BIO). BIO is specifically adapted for the Biogeme software and it is a trust-region algorithm. Specific details on the BIO optimization algorithm are shown in the Biogeme user guide ("An introduction to BIOGEME Version 1.3) by Michel Bierlaire, 2005.

Choice Probability Function

The choice probability function is the MNL choice probability of destination i being chosen by trip makers of trip purpose p. The probability is based on the utility of the choice destination versus the aggregate utility of all available destinations for the trip maker. The standard logit choice probability of the MNL model is:

$$P_{ni}(i \mid J_p) = \frac{e^{U_{ni}}}{\sum_{j \in J_p} e^{U_j}} \quad (4\text{-}4)$$

where,

$P_{ni}(i \mid J_p)$ - Conditional probability of trip maker n choosing destination i from destination choice set J_p

U_{ni} - Utility of the choice destination i for trip maker n

U_j - Utility of destination j for trip maker n

J_p - Set of available destinations j for trip maker n

Log-Likelihood

The log-likelihood (LL) is the likelihood of the MNL model fit of the observed survey data. It is the sum of the logarithm of the choice probabilities for each observed trip maker and it can be used to check the model estimates. In this study, the LL is calculated using the BIO optimization algorithm in Biogeme. Goodness-to-fit statistics such as the log-likelihood ratio test help to compare different models underlying choice process, and determine if utility adjustments should be made in order to identify the best model fit for the observed data. This statistical test takes the ratio of the maximum value of the likelihood function under parameter constraints to the likelihood function under no parameter constraints. The maximum (final) log-likelihood is when the parameter estimates of the MNL model maximize the LL. The mathematical formula of the LL is:

$$LL = \sum_{j=1}^{J_p} (\gamma) \log P_{ni} \tag{4-5}$$

where,

LL - Likelihood of model fit to the observed data
J_p - Available set of observed destination choices of trip purpose p
γ - Dummy variable indicating if the destination is the actual chosen alternative (1) or if the destination is not chosen (0).
P_{ni} - Conditional probability of trip maker n choosing destination i from choice set J_p

Model Estimation Steps

The process to estimate the MNL models include setup of observed trip maker data and destination data, development and application of the MNL models in Biogeme, and evaluation of the models by trip purpose. The general steps to estimate the MNL models are listed below and more detailed specification of each step as well as the application of the MNL models to the RDU airport is presented in Chapter 5, the RDU airport case study. **Figure 4-3** shows a flowchart of the model estimation process.

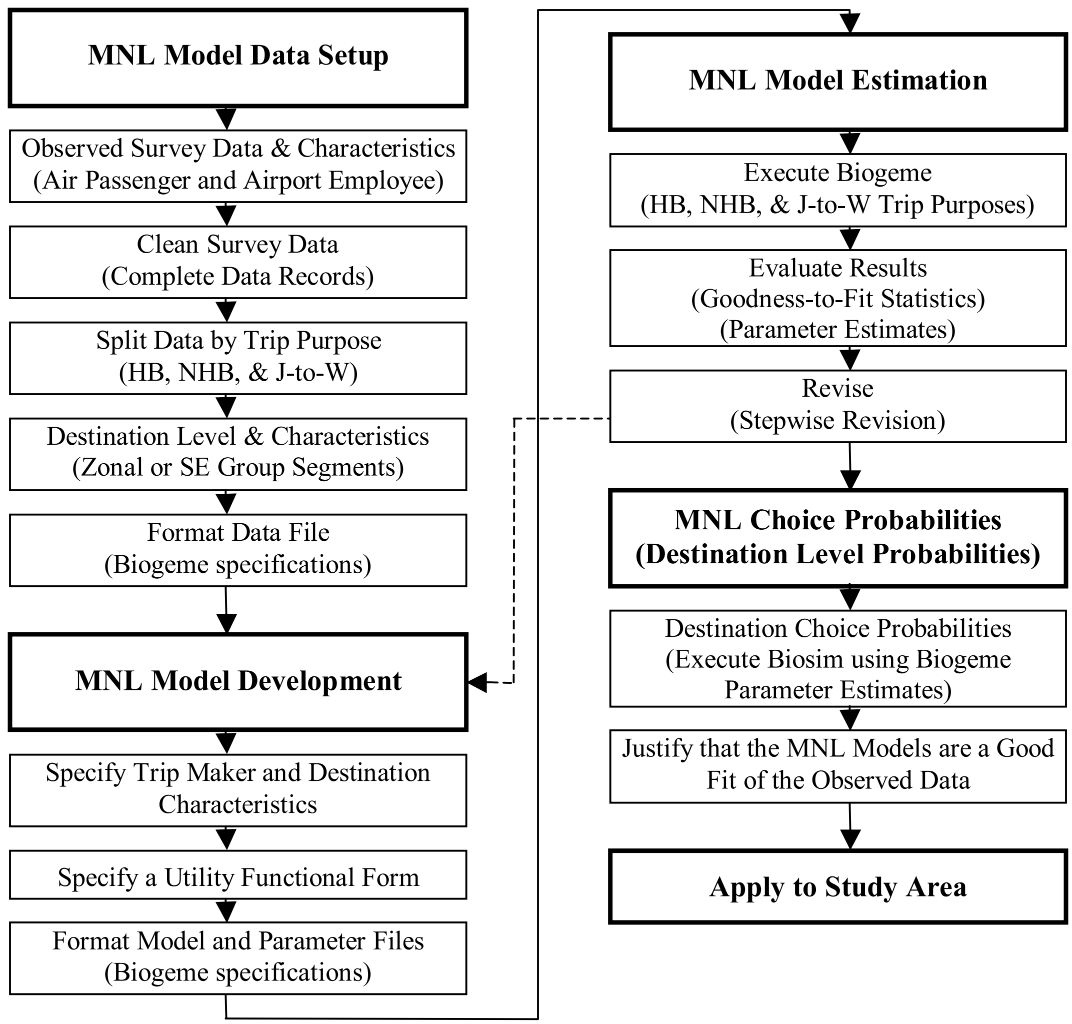


Figure 4-3: Flowchart of the RDU Airport MNL Model Estimation

<u>*MNL Model Data Setup (using MS Excel and TransCAD)*</u>

1. Obtain observed data such as surveys on individual characteristics of the airport air passengers and employees (PBS&J and NuStats Partners, 2002).

2. Identify the relevant observed trip maker characteristics from the survey (**Table 4-1**) and remove all records that have incomplete information. Incomplete information includes missing values of personal attributes or unidentifiable choice destination

locations. Also, one can use scatter plots of the observed data to determine if there are any outlying values that may skew the MNL model estimation. If there are outlying data then they should be removed from the observed data set.

3. Split the data file by trip purpose (HB, NHB, and J-to-W) and create a new observed data file for each trip purpose (Each trip purpose has a separate excel worksheet of observed data).

   (The following steps are performed for each trip purpose.)

4. Geocode the choice destinations from the observed survey data to the TAZs in the study area. Extract out all records external to the study area since this study is limited to internal trip ends only.

5. Based on the geocoded choice destinations, determine if most of the TAZs are captured in the observed data sets (**Figure 4-4**). If so (right side figure), then the choice destinations should remain aggregated to the zonal level. If not (left side figure), then the choice destinations should be aggregated to the SE group segment. This process is described in the proceeding steps.

   (Since the aggregation level is at the SE group level in the RDU airport application, the remainder of the model estimation steps will follow with the SE group method.)

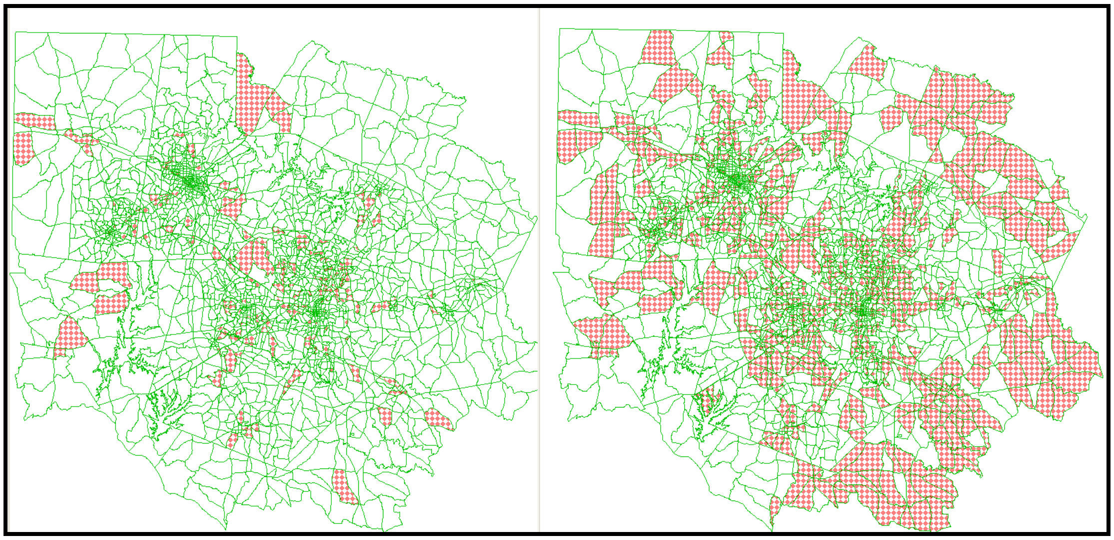


Figure 4-4: Geocoded Choice Destinations

6. The first step to aggregate the observed choice destinations to the SE group segments is to determine the SE group specifications, such as the number of segments and the bounds for each segment. This should be based on available data and study area definitions. For example, the TRM defines income by five levels and the specification is shown below in **Table 4-2**.

Table 4-2: TRM Income SE Group Segment Specification

Income Level	Income Description	Income Specification
1	Low	Income < \$25,000
2	Low to Medium	\$25,000 ≤ Income < \$35,000
3	Medium	\$35,000 ≤ Income < \$50,000
4	Medium to High	\$50,000 ≤ Income < \$80,000
5	High	Income ≥ \$80,000

7. Determine the study area TAZs that match each SE group segment. These TAZs are the available destination TAZs of each SE group segment by trip purpose (J_p). First,

the TAZs by trip purpose are determined and second, the TAZs by SE group segment are determined. For example, the HB and J-to-W trip purposes only consider TAZs with household or dwelling unit data to be available TAZ destinations and not TAZs without household or dwelling unit data. The NHB trip purpose only considers TAZs with employment data are considered to be available TAZ destinations and TAZs with no employment data to be available TAZ destinations and not TAZs without employment data. Then, the available TAZs by trip purpose are split by SE group segment as specified in step six. For example, the "Income Level 1" SE group segment of the HB trip purpose has available destination TAZs with household and dwelling unit data and a median income of less than $25,000. Note that the TAZs in the SE group destinations are not spatially clustered and not every TAZ is available for each trip purpose.

8. Based on the TAZs that make up the SE group segment, identify the destination characteristics that affect the choice of destinations. Then, average the TAZ characteristic values for each SE group segment and add them to the observed data file. The characteristics of the SE group segments are an average of the individual TAZ characteristics that make up the SE group segmentation. Possible destination characteristics are shown in **Table 4-3.**

Table 4-3: Destination Characteristics of the SE Group Segments

Destination Characteristics	
Travel Time Travel Distance Industry Employment Retail Employment Highway Employment Office Employment Service Employment	Households Population Income Average Household Size Dwelling Units University Beds

9. Match the SE group segments defined in step six to the observed choice destinations from the survey dataset. Create a field named "Choice" in the excel data table and populate the field with the SE group segment destination that matches the observed trip maker's choice destination. In other words, establish which SE group segment has the observed TAZ destination as one of its available TAZ destinations determined in step seven. The observed choice destination is defined by the "Choice" field which is the SE group segment destination.

10. Justify that the observed data records within each SE group segment have similar characteristics. This study uses scatter plots of the observed survey and destination data to remove any records that have outlying data from the average. This can easily be performed in MS Excel and it is recommended to make a separate plot for each characteristic of the SE group segment.

11. Format the data file according to the DCM software (Biogeme) specifications (Bierlaire, 2005).

MNL Model Development (using MS Excel)

Note that the MNL model development steps are a trial and error process that uses a stepwise method of testing various characteristics and model forms to determine the best model fit of the observed data. The model fit is evaluated based on results from the "MNL Model Estimation" steps discussed in the following section of this chapter.

12. Determine which characteristics of the trip maker and of the destination are to be used in the MNL model to describe the trip maker's choice of destination. Also, verify that there is no major correlation between variables.

13. Determine what utility form (linear or non-linear) is the best model fit to describe the choice destinations as a function of the trip maker and destination characteristics. The linear utility forms are the simplest. The non-linear logarithmic utility form is more complex to estimate but some non-linear forms such as logarithmic is best used when there is a wide range of data help to form the data into a more manageable range.

14. Format the MNL model file according to the Biogeme software guidelines including specification of the parameters, utility, expressions, segmentation groups, model type, etc. (Bierlaire, 2005).

15. Specify a parameter file associated with the MNL model that includes the optimization algorithm, output display levels, missing value specification, etc. (Bierlaire, 2005).

MNL Model Estimation (using a text editor and the Biogeme software)

16. Export the data file, model file, and parameter file from MS Excel as space delimitated or tab delimitated file (.prn) and open the file in a text editor such as TextPad or Emacs. If the Biogeme software is used, save the text files as UNIX format and save the data file, model file, and parameter file with a .dat, .mod, and .par file extension, respectively.

17. Verify that all data is correctly converted from MS Excel format to text format and that no data is lost or truncate in the process. Additionally, if Biogeme is used, verify that a space or tab separates all words or numbers in each row of the files and that each row in the data file contains the same number of values.

18. Once Biogeme is downloaded from the website www.roso.epfl.ch/Biogeme, it is executed using a DOS terminal. The data file (.dat), MNL model file (.mod), and parameter file (.par) are specified and the outputs are reported (**Figure 4-5**).

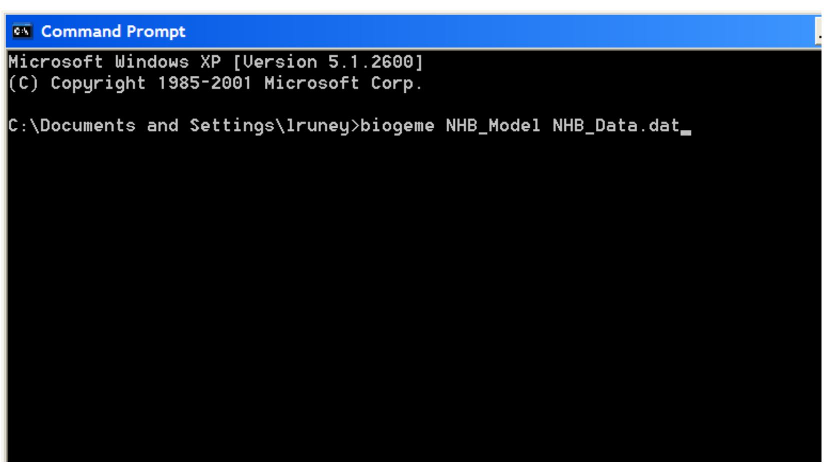


Figure 4-5: Execution of Biogeme in a MS DOS Terminal for the NHB Model

19. The output files provide statistical results of the data and of the model used in the MNL model estimation, including the utility function form and parameter statistics. The data statistics output file (.sta file extension) gives the mean, minimum, and maximum values of each variable. Additionally, this file presents the number of total observations used in the model estimation and the number of observations per choice destination. The model statistics output file (.rep file extension) provides goodness-to-fit statistics such as the final log-likelihood, log-likelihood ratio test, and the adjusted Rho-square estimates to help determine if the model is a good fit for the observed data. Additionally, the file provides the parameter estimates and parameter t-statistics to help determine which variables are significant in the MNL model estimation.

If the model statistical results or parameter estimates (size and sign) are not satisfactory, then the utility is revised in a stepwise process by changing utility form and/or the utility function variables. The stepwise approach removes and adds variables of the MNL model based on the resulting goodness-to-fit test statistics and t-values. Then, the MNL model development and estimation steps are repeated until the output estimates and statistics are acceptable and the best model fit for the observed data is obtained according to the goodness-to-fit statistics such as those shown in (**Appendix B**).

MNL Choice Probability Estimation for SE Group Segments (using the Biosim application)

20. Once the parameters of the final utility function are estimated in Biogeme, then the probability of each observed trip maker choosing their choice destination can be determined using the Biosim application. The Biogeme output file with a .res

extension is renamed to _res.mod and this file is used as the Biosim model input file to get the estimated choice probabilities. The same data file and parameter file used in the MNL model parameter estimation (Biogeme application) can be used in the MNL choice probability estimation (Biosim application).

21. Similar to **Figure 4-4** the Biosim application is executed in a DOS terminal with the input data file (.dat), estimated MNL utility parameter file (_res.mod), and parameter file (.par). The Biosim application estimates the choice probabilities using the following equation:

$$P_{ni}(i \mid J_p) = \frac{e^{U_{ni}}}{\sum_{j \in J_p} e^{U_j}} \tag{4-6}$$

where,

$P_{ni}(i \mid J_p)$ - Probability of trip maker n choosing SE group segment i from SE group destination choice set J_p

U_{ni} - Utility of the chosen SE group segment i for trip maker n

U_j - Utility of SE group segment j for trip maker n

J_p - Set of available choice SE group segments j for trip maker n

22. The enumeration output file (.enu) from the Biosim application provides each observations destination choice probability. The average of the trip maker destination choice probabilities by SE group segment provides the overall choice probability that a trip will be made from the airport to each SE group segment.

23. Finally, the resulting overall choice probabilities should be verified to meet the IID assumption of the MNL model error components and that the MNL models are a

good model fit of the observed data. The estimated choice probabilities should be compared to the observed choice probabilities and a residual plot of the models should be checked that the predicted choice probabilities are independent (no trend to the plotted data points) and identically distributed (data points are contained in a horizontal band around zero residual).

Additionally, the IIA property of the MNL models should be tested to meet the assumption that the relative probability of choosing between two destinations is unaffected by the inclusion or exclusion of additional choice destinations. Two common tests of the IIA property are the Hausman test proposed by Hausman and McFadden (1984) and the Small and Hsiao (1985) exact test. The Hausman test involves the comparison of the model estimates using all choice destinations (unrestricted model) to the model estimates using one less choice destination (restricted model) and verifying that the parameters of the restricted model are approximately the same as those of the unrestricted model. The Small and Hsiao's exact test compares that the maximum log-likelihood of the restricted model is approximately the same as the maximum log-likelihood of the restricted model using parameters estimated from the unrestricted model.

Once the overall choice probabilities of the SE group segment destination are verified, they can be applied to the TRM study area zones using zonal relative attraction factors as discussed in the next chapter (Chapter 5). Then, the resulting zonal choice probabilities can be applied to the generated RDU airport person trips to get the person trips between the RDU airport and all other zones in the study area by trip purpose. Next, the person trips can be converted to vehicle trips using vehicle occupancy rates and a trip table matrix of origin-destination trip interchanges between the RDU airport and all other zones in the TRM study area can be created. Finally, the trip matrix can be incorporated into the TRM travel demand model for traffic assignment.

Summary

Chapter 4 presents the framework for the MNL model by defining the model concept, utility function, and estimation procedure. This chapter provides a framework of the MNL destination choice model, including steps of data setup, model development and model estimation. Chapter 5 applies the framework to a case study of the RDU airport and compares the results with the gravity procedure currently used for the RDU airport in the 2002XP TRM. Chapter 6 provides conclusions and recommendations for future work.

CHAPTER 5 – CASE STUDY: RALEIGH - DURHAM INTERNATIONAL AIRPORT

Chapter 5 applies the MNL destination choice model to distribute airport trips of the RDU airport. A sub-model to the 2002XP TRM is developed for the RDU airport and the trip distribution results from the sub-model are compared to the trip distribution results of the gravity model in the 2002XP TRM. This chapter starts with a brief background of the RDU airport. Then, the RDU airport sub-model is developed including generating and distributing airport trips. Distribution of airport trips is the main focus of this chapter. Trip distribution for the RDU airport involves development and estimation of MNL models for each trip purpose, expansion of the MNL model probability estimates to all 2002XP TRM TAZs by socio-economic group segment, and estimation of trip interchanges between the RDU airport and the TAZs in the study area. Finally, the chapter ends with validation checks of the trip distribution results obtained by the MNL destination choice model compared to those obtained from the 2002XP TRM gravity model.

Background

The RDU airport is the only major airport in the Triangle Region. It is a medium size hub and ranks 43rd among other U.S. airports in total annual enplanements. Additionally, the RDU airport is the 37th largest origination and destination travel market in the U.S. (Raleigh-Durham Airport Authority, 2005). This market refers to the number of passengers who begin or end their trips at the RDU airport.

The 2002XP TRM represents the RDU airport as one TAZ out of the 2,317 total TAZs in the study area and it is treated as an airport special generator. The airport trip productions and attractions are based on the total employment of the RDU airport and not on the airport air passengers. The RDU airport trips estimated in the 2002XP TRM do not include air passenger trips and this may cause the total trips to and from the RDU airport zone to be incorrectly estimated. The 2002XP TRM estimates 3,800 total employees for the RDU airport with 94 percent of the employees having service job types. According to the TRM these employees generate 18,250 average weekday person trips and 15,800 average weekday vehicle trips between the RDU airport zone and all other TAZs in the TRM study area. The total trips are low compared to the average weekday vehicle trips developed from the *Institute for Transportation Engineers Trip Generation Manual.* Using the ITE trip rate of 13.4 trips per employee for a commercial airport, the 3,800 RDU airport employees generate 50,900 average weekday person trips and 28,300 average weekday vehicle trips (ITE, 2003). The ITE trip generation manual estimates seem high for average weekday trips at the RDU airport. Thus, this research of the RDU airport sub-model is relevant to provide another means to generate the RDU airport trips and distribute them to the study area.

Trip distribution for the RDU airport zone is treated like all other TAZs in the 2002XP TRM study area using the gravity method. However, the RDU airport passenger trips have significantly different trip patterns and trip lengths than other land uses in the TRM study area. Many factors such as employment and household characteristics affect the RDU airport trip distribution besides the usual trip length (travel time and distance) factors considered by the gravity method. Thus, the proposed RDU airport sub-model for the 2002XP TRM considers airport employee trips and air passenger trips based on 2002 socio-economic data and 2002 air passenger and employee survey data.

Trip Generation

The first step of the airport sub-model generates the airport ground access person trips of the RDU airport. The ground access trips are those person trips that arrive to and depart from the RDU airport via ground transportation. These trips are generated for both air passengers and airport employees of the RDU airport. The air passenger trips are generated using RDU airport flight activity data and the airport employee trips are generated using information about the companies working at the RDU airport. Both of these data sources are provided by the RDU Airport Authority.

Air Passenger Trips

The average weekday air passenger trips are determined based on the RDU airport activity data such as the number of enplaned, deplaned, and transfer passengers. This information is obtained from the RDU Airport Authority records of historical airport activity data, which can be accessed from the RDU Airport Authority website and from the expertise of the RDU Airport Director, Mr. John Brantley (http://www.rdu.com/aboutrdu/stats.htm). **Table 5-1** shows the annual RDU airport activity data for the year 2002.

Table 5-1: Annual RDU Airport Activity Data

Annual Enplanements	Annual Deplanements	Annual Percent Transfer
4,133,046	4,108,207	4.0%

The annual enplanements represent the number of air passenger trips that are attracted to the RDU airport (i.e. those passengers arriving to the airport from the study area zones to depart the airport via flight). The annual deplanements represent the number of air passenger trips that are produced by the RDU airport (i.e. those air passengers arriving to the airport via flight and departing the airport via vehicle to be distributed to the Triangle Region). The number of enplaned and deplaned passengers includes transferring passengers, which are those passengers who transfer from an arriving flight to a departing flight and do not access ground transportation at the RDU airport. To represent the air passengers leaving the RDU airport via ground transportation (i.e. air passenger ground access trips), the percent transferring passengers are removed from the total enplanements (**Table 5-2**).

Table 5-2: Annual RDU Airport Air Passenger Ground Trips

Year 2002	RDU Airport Authority		
	Air Person Trips	Transfers at 4%	Ground Person Trips
Enplanements	4,133,046	165,322	3,967,724
Deplanements	4,108,207	164,328	3,943,879
TOTAL	8,241,253	329,650	7,911,603

Additionally, since this study is limited to internal trip ends within the 2002XP TRM, the airport air passengers traveling by ground transportation to and from a destination external to the study area are removed from the total enplanements and deplanements. The number of RDU air passengers who originate or terminate at a destination external to the TRM study area for year 2002 was 20 percent based on RDU Airport Authority estimates. Similarly, the percent external trips captured in the observed air passenger survey for the RDU airport is 20 percent. The external trips are removed from the total ground access person trips to give the annual ground access person trips that are internal to the TRM study area (**Table 5-3**).

Table 5-3: Annual RDU Airport Air Passenger Internal Ground Trips

Year 2002	RDU Airport Authority				
	Air Person Trips	Transfers at 4%	Ground Person Trips	External Trips at 20%	Internal Ground Person Trips
Enplanements	4,133,046	165,322	3,967,724	793,545	3,174,179
Deplanements	4,108,207	164,328	3,943,879	788,776	3,155,103
TOTAL	8,241,253	329,650	7,911,603	1,582,321	6,329,282

Next, the internal ground person trips are converted from annual trips to average daily trips for RDU air passengers. The total average daily ground trips are assumed to be the total annual ground trips divided by 365 days in a year. Additionally, the daily ground trips are assumed to be equivalent to the average weekday trips. **Table 5-4** shows the conversion of annual enplanements and deplanements to daily internal ground access trips for air passengers of the RDU airport. There are approximately 17,300 average daily person trips of the RDU air passengers only, which corresponds to the TRM estimate discussed previously, not the ITE estimate.

Table 5-4: Daily RDU Airport Air Passenger Ground Access Trips

Year 2002	RDU Airport Authority					Daily Internal Ground Person Trips
	Air Person Trips	Transfers at 4%	Ground Person Trips	External Trips at 20%	Internal Ground Person Trips	
Enplanements	4,133,046	165,322	3,967,724	793,545	3,174,179	8,696
Deplanements	4,108,207	164,328	3,943,879	788,776	3,155,103	8,644
TOTAL	8,241,253	329,650	7,911,603	1,582,321	6,329,282	17,340

The airport daily ground access trips are balanced so that the number of trip attractions is equal to the number of trip productions. This method assumes that the number of airport ground access trips leaving the RDU airport for the TRM study area (proportional to deplanements) is equal to the number of ground access trips arriving at the RDU airport from the TRM study area (proportional to enplanements). Thus, the daily RDU airport trip productions and trip attractions are equal to half of the total daily ground access person trips. In this study, the 17,340 daily internal ground access trips result in 8,670 produced trips and 8,670 attracted trips for the RDU air passengers.

The daily trips are split by air passenger trip purpose: home based (HB) and non-home based (NHB). Segmenting the trips by purpose preserves consistency with the MNL model estimates since different MNL models are developed for each trip purpose in the trip distribution step of the airport sub-model. The air passenger trip purpose split is based on the TTA Air Passenger survey of the RDU airport. The survey shows that HB trips equal to 58 percent of the total observations and NHB trips equal to 42 percent of the total observations. The daily ground trips by trip purpose are calculated by multiplying the total trips (17,340 trips) by the percent of observed trips for each trip purpose (**Table 5-5**). The airport air passenger daily trip attractions are assumed the same as the airport air passenger daily trip productions for each trip purpose.

Table 5-5: Daily RDU Airport Air Passenger Trips by Trip Purpose

Trip Purpose	Survey Percent	Daily Productions
HB	58%	10,057
NHB	42%	7,283
TOTAL	100%	**17,340**

Airport Employee Trips

The transportation consulting firm PBS&J and the data collection firm NuStats Partners report that in year 2002 there were 78 companies listed on the RDU airport inventory working directly or indirectly for the RDU airport (PBS&J and NuStats Partners, 2002). The RDU Airport Authority reports that there were approximately 4,300 employees working on site at the RDU airport in the year 2002 and that approximately one-third of the airport employees (1,433 employees) worked at the RDU airport on an average weekday in year 2002. The number of airport employees used in this research, 1,433 employees, is approximately 2,360 less than the 2002XP TRM estimate of total employment at the RDU airport. The number of employees generated by the RDU airport sub-model represents approximately 19,200 person trips per weekday using the ITE trip rate of 13.4 trips per employee and this estimate seems more reasonable than the 50,900 person trips per weekday estimated using the 2002XP TRM number of employees (3,800 employees).

This research assumes that the 1,433 employees of the RDU airport is a direct representation of the average daily employee trip attractions. As with the airport air passenger trips, the airport employee trip attractions are assumed to be equal to the airport employee trip productions. Thus, the trip attractions are doubled to get 2,866 average daily employee trips to and from the RDU airport. This is reasonable because on an average weekday, airport employees make a trip to the airport (trip attraction) for work and they make a trip from the airport (trip production) back to their home. This research does not consider trip chaining or intermediate stops between the RDU airport zone and the home zone for airport employee trips. The employee trips are modeled as journey-to-work (J-to-W) trips where only the RDU airport trip end and the home trip end are considered and mid-day trips made during work hours (such as a lunch trip) or intermediate trips between work and home (such as picking up children from school) are not considered. **Table 5-6** shows the daily J-to-W employee trips as well as HB and NHB air passenger trips for the RDU airport.

Table 5-6: Total Daily RDU Airport Trips by Trip Purpose

Trip Purpose	Daily Trips
HB	10,057
NHB	7,283
J-to-W	2,866
TOTAL	20,206

Trip Distribution

Trip generation estimates the RDU airport productions and attractions, but not the non-airport trip ends. Thus, the RDU airport daily trips must be allocated to the non-airport trip ends. As discussed in Chapter 4, the gravity model trip distribution method is replaced by the MNL model destination choice distribution approach. MNL models distribute the non-airport trip ends to homes and business in the Triangle Region. The MNL model describes each trip maker's choice of destination location in probabilistic terms using individual (personal income, gender, household size, etc.) and destination characteristics (employment type, median household income, number of households, average household size, travel time to RDU, etc.). Separate MNL models are developed for each airport trip purpose (HB air passenger trips, NHB air passenger trips, and J-to-W airport employee trips) and the MNL models are used to determine the probability that a trip maker selects a given TAZ destination in the 2002XP TRM study area.

However, due to data constraints, the MNL model approach cannot be directly applied to zonal distribution of the RDU airport trips. Simply stated, there are too many TAZ possibilities for a distributed trip and there are too few RDU airport air passenger and employee survey dataset records to calibrate the DCM model by TAZ. So, the TRM zones are categorized by SE group income level or land use type for each trip purpose. Then, the

MNL models probability distributions of the RDU airport trips by SE group segment are estimated and calibrated using the Biogeme software. The resulting choice probabilities are applied to the corresponding 2002XP TRM TAZs using a relative attraction factor and the vehicle trip interchanges between the RDU airport and the TRM study area zones are determined. Details of the MNL model dataset, TAZ pre-processing, Biogeme analysis, and choice probability application to TRM TAZs are explained below. **Figure 5-1** shows a flowchart of the overall process.

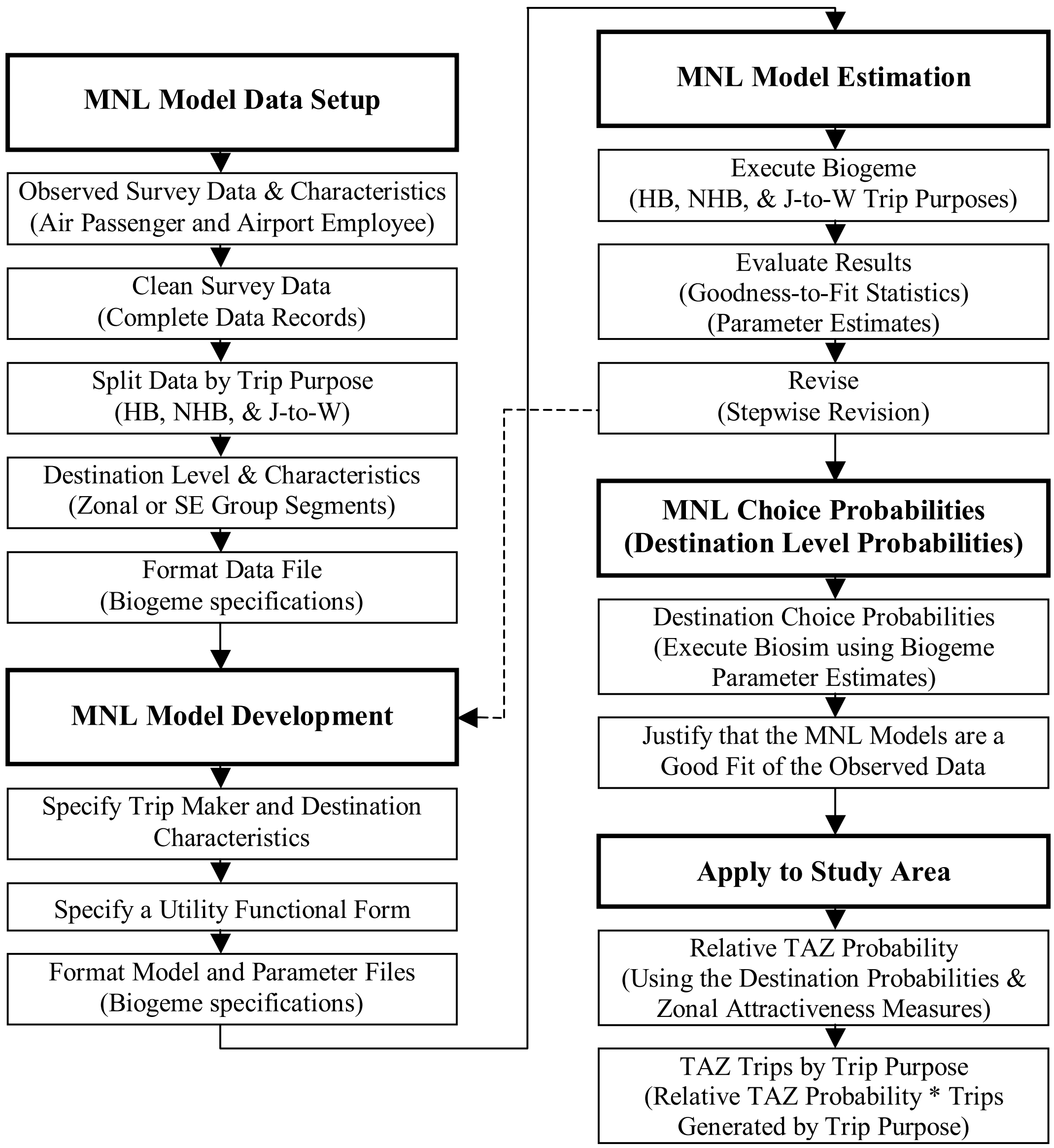


Figure 5-1: Flowchart of the RDU Airport Trip Distribution Process

The model estimation steps presented in Chapter 4 of this report are applied to the RDU airport case study. First, observed survey data and destination data are used to develop data files and the MNL model files in MS Excel. Then, the TRM study area TAZs are categorized by SE group segment. Next, the files are converted to the Biogeme software specifications and a stepwise procedure calibrates the MNL models characteristics and utility function forms. Once the best models are fitted to the observed data by trip purpose, the results are input into the Biosim application and the overall choice probabilities of the SE group segments are obtained. In MS Excel, the estimated probabilities are applied to the TRM study area zones by trip purpose using a relative attraction factor. For example, the HB trip purpose uses an attraction factor based on the number of housing units in a zone (the higher the number of housing units in a zone, the higher the probability of an airport HB trip destination). Then, the relative TAZ probabilities are applied to the RDU airport trips estimated in the trip generation step of the RDU airport sub-model. This results in the number of person trip interchanges between the RDU airport zone and all other zones in the TRM study area for each trip purpose. The person trip interchanges can be converted to vehicle trip interchanges using vehicle occupancy factors, and the origin-destination vehicle trip interchanges between the RDU zone and all other zones in the 2002XP TRM study area are determined. The following steps perform the MNL destination choice model for the RDU airport.

MNL Model Data Setup (using MS Excel and TransCAD)

1. The observed data used in this case study is survey data of RDU airport air passengers and employees; the *Airport Rail Link Study Passenger Survey* and the *Airport Rail Link Study Employee Survey* (PBS&J and NuStats Partners, 2002). **Appendix C** shows the questions asked to the RDU airport air passengers and airport employees from the surveys.

2. Given that the surveys were conducted for the purpose of rail analysis to the RDU airport, there are several fields in the survey dataset that are not relevant to this particular study. Such characteristics are flight number, flight duration, if the trip maker has used heavy rail in the past three months, and if the trip maker pays to park at the airport. Thus, the irrelevant data fields are removed from the observed dataset, leaving only the relevant observed data regarding destination choice. The relevant observed trip maker characteristics from each survey are presented in **Table 5-7** and the questions that correspond to these characteristics are shown in **Appendix C** highlighted in red italics font.

Table 5-7: Relevant Survey Data Trip Maker Characteristics

Air Passenger Characteristics	Airport Employee Characteristics
Complete Home Address	Complete Home Address
Connecting Flight	Work Days per Week
Resident / Non-Resident	Adults per Household
Business / Leisure	Children per Household
Household Size	Household Income
Household Income	Gender
Gender	Job Description
Location Prior to RDU	Make Mid-Day Trips
Prior Location Address	Mode of Travel to Work
Trip Length (in days)	Stop Prior to Work
Number of Companions	Estimated Travel Time
Travel Destination	

The survey observations that have incomplete information such as missing values of personal attributes or unidentifiable choice destination locations are removed from the dataset. The air passenger data results in 704 complete observations and the airport employee data results in 411 complete observations (**Table 5-8)**.

Table 5-8: Number of Complete Survey Observations

	Number of Survey Observations	Number of Complete Survey Observations
Air Passenger Survey	1,525	704
Airport Employee Survey	523	411

3. The 704 air passenger observations are split by two trip purposes (HB and NHB) and the 411 airport employee observations are considered as one trip purpose (J-to-W). The air passenger split between HB and NHB is based on the trip maker's location prior to the RDU airport. **Table 5-9** shows the number of complete observations by trip purpose. Separate observed data files are created for each trip purpose in MS Excel (HB_Data.xls, NHB_Data.xls, and JtoW_Data.xls).

Table 5-9: Number of Complete Survey Observations by Trip Purpose

Trip Purpose	Number of Complete Survey Observations
HB	460
NHB	244
J-to-W	411

The sample size by trip purpose represents less than 5 percent of the daily HB and NHB trips and less than 15 percent of the daily J-to-W trips estimated in the trip generation step of the sub-model. Also, the sample size by trip purpose represents less than 20 percent of the 2002XP TRM study area zones (2,317 zones), which results in 80 percent of the TAZ destinations not represented in the observed survey dataset. Furthermore, almost all of the TAZ destinations that are represented in the survey dataset are only represented once and no TAZ is observed 30 or more times in the surveys. Therefore, the MNL model parameter and probability estimates are not statistically valid for TAZ level estimation due to the low observed sample size per TAZ. A means to overcome this issue is discussed below.

Research suggests that the original survey dataset should collect four or more times the actual sample size desired for zonal destination choice trip distribution (Horowitz et al., 1986; MTC, 1995; and MWCOG, 2002). Therefore, if the sample size for most destination TAZs by trip purpose were to be approximately 30 observations, then the 2,317 zones of the 2002XP TRM would most likely need an observed dataset of approximately 50,000 to 60,000 trip makers of the RDU airport for zonal trip distribution. This number allows for survey and coding errors such as missing data or incomplete information and it allows for the sample size of each choice destination to be large enough (ideally, greater than 30 observations) to estimate the RDU trips by zone. **Table 5-10** shows a comparison of the RDU airport and other regional airport survey observations and sample size for model estimation. Additionally, the table shows two examples of observed survey data that would be ideal for zonal destination levels.

Table 5-10: Comparison Regional Air Passenger Surveys

Agency	Zones	Survey Observations	Sample Size
Metropolitan Washington COG	2,000	48,000	19,000
Metropolitan Transportation Commission	3,827 aggregated to 100 zones	21,000	5,100
Triangle Region - Actual Survey	2,317	1,525	704 *
Triangle Region - Example 1	2,317	50,000	20,000
Triangle Region - Example 2	2,317 aggregated to 100 zones	20,000	5,000

*This is the resulting sample size for complete air passenger observations and not the sample size used in the MNL model estimation. The sample size used in the MNL model estimation has outlying data records removed.

(The following steps were performed for each trip purpose.)

4. The observed destinations from the survey data are geocoded to the TRM study area using the trip maker's prior location address. Any destination external to the study area is extracted from the observed records. **Table 5-11** shows the number of external observations and the resulting number of internal observations to the TRM study area by trip purpose. The number of internal observations is the sample size of the observed data for the MNL model estimation. **Figure 5-2** displays the geocoded choice destinations by trip purpose that are internal to the study area. Note that the sample size is getting smaller with the reduction of external trips and this should be considered when developing the number of observations to collect in the airport surveys.

Table 5-11: Internal Observations by Trip Purpose

Trip Purpose	Number of Complete Survey Observations	External Observations	**Internal Observations**
HB	460	101	**359**
NHB	244	42	**202**
J-to-W	411	37	**374**

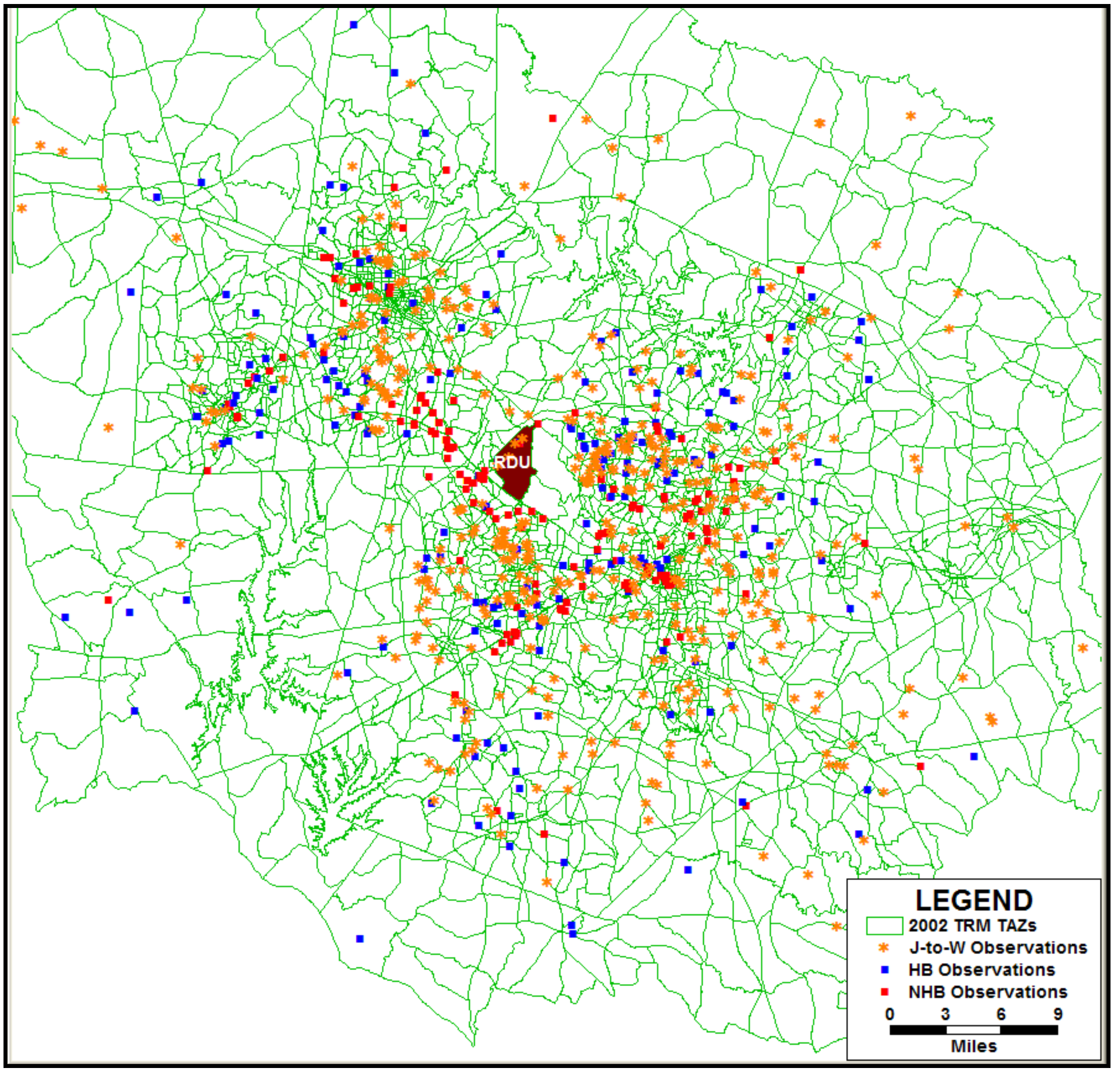


Figure 5-2: Geocoded Internal Observations by Trip Purpose to the TRM Study Area

5. **Figure 5-2** shows that the RDU airport employee and air passenger survey observations are scattered throughout the 2002XP TRM study area. However, when the observed destinations are aggregated to the corresponding TAZ, most of the TRM zones are not represented by the observed data, especially when one trip purpose is displayed such as the NHB trip purpose (**Figure 5-3**). Because there are few TAZs represented in the survey data by trip purpose, the observed destinations are aggregated to the SE group segment in order to model the entire 2002XP TRM study

area for each trip purpose. The SE group segments represent the choice destinations of the MNL models. The process of defining the SE group segments and aggregating the observed TAZs to each SE group segment is discussed in the proceeding steps.

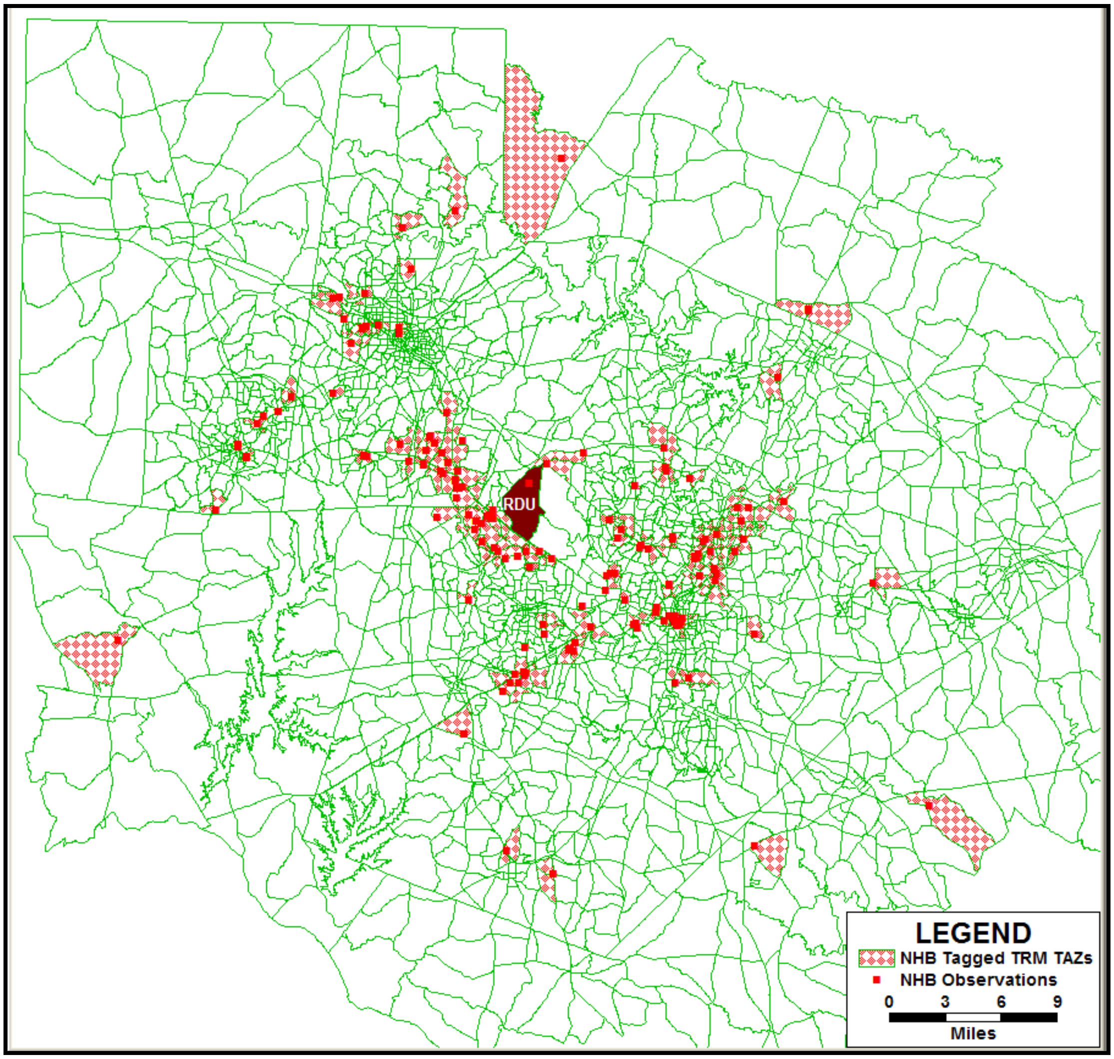


Figure 5-3: Geocoded NHB Choice Destinations Linked to TRM TAZs

6. The SE group specifications are determined based on definitions and guidelines used in the TRM. The TRM definitions help determine the number of segments per SE

group and the value bounds for each segment. The SE group segment names, descriptions, and specifications are presented in **Table 5-12**.

Table 5-12: SE Group Segments by Trip Purpose

SE Group	SE Group Segment	Name	Description	Specification (mINC is Median Income)
Income Level (HB)	1	INC 1	Destination TAZ - Low INC	mINC < \$25,000
	2	INC 2	Destination TAZ - Low to Medium INC	\$25,000 ≤ mINC < \$35,000
	3	INC 3	Destination TAZ - Medium INC	\$35,000 ≤ mINC < \$50,000
	4	INC 4	Destination TAZ - Medium to High INC	\$50,000 ≤ mINC < \$80,000
	5	INC 5	Destination TAZ - High INC	mINC ≥ \$80,000
Land Use Type (NHB)	1	LU 1	Service - Hotels	Land use is SER
	2	LU 2	Office - Professional work places & low travel time	Land use is OFF & TT ≤ 21 min from RDU
	3	LU 3	Office - Professional work places & high travel time	Land use is OFF & TT >21 min from RDU
	4	LU 4	Highway - Restaurants & Ubeds - Universities	Land use is HWY & Ubeds
Income Level (J-to-W)	1	INCTT 1	Destination TAZ - Low and Low to Medium INC	mINC < \$35,000
	2	INCTT 2	Destination TAZ - Medium INC & low travel time	\$35,000 ≤ mINC < \$50,000 & TT < 25 min
	3	INCTT 3	Destination TAZ - Medium INC & high travel time	\$35,000 ≤ mINC < \$50,000 & TT ≥ 25 min
	4	INCTT 4	Destination TAZ - Medium to High INC & low travel time	\$50,000 ≤ mINC < \$80,000 & TT < 25 min
	5	INCTT 5	Destination TAZ - Medium to High INC & high travel time	\$50,000 ≤ mINC < \$80,000 & TT ≥ 25 min
	6	INCTT 6	Destination TAZ - High INC	mINC ≥ \$80,000

7. The 2002XP TRM zones are linked to the SE group segments based on the specifications defined in **Table 5-12**. These zones are the choice set of available TAZ destinations for each SE group segment by trip purpose. First, the TAZs available for each trip purpose are determined (J_p). The available TAZ destinations for the HB and J-to-W trip purpose are those TAZs with household or dwelling unit data. TAZs with no household or dwelling unit data are not available destinations for the HB and J-to-W trip purpose. The available TAZ destinations for the NHB trip purpose are those TAZs with employment data. TAZs with no employment data are not available destinations for the NHB trip purpose. Next, the TAZs available for each SE group segment are determined by trip purpose ($J_{p_{SE}}$). For example, the available TAZ destinations for the "Income Level 1" SE group segment of the HB trip purpose are

those TAZs with household and dwelling unit data and a median household income of less than $25,000. The available TAZ destinations for the "Land Use Type 1" SE group segment of the NHB trip purpose are those TAZs with employment data, in particular high service (SER) employment. Note that the TAZs designated in the SE group segments are not spatially clustered and not every TAZ in the 2002XP TRM study area is available for each trip purpose. **Figure 5-4** shows a color theme map of SE group segments of Income Level for the HB trip purpose. **Figure 5-5** shows a flow chart of the TAZ choice set process for the SE group segments by trip purpose.

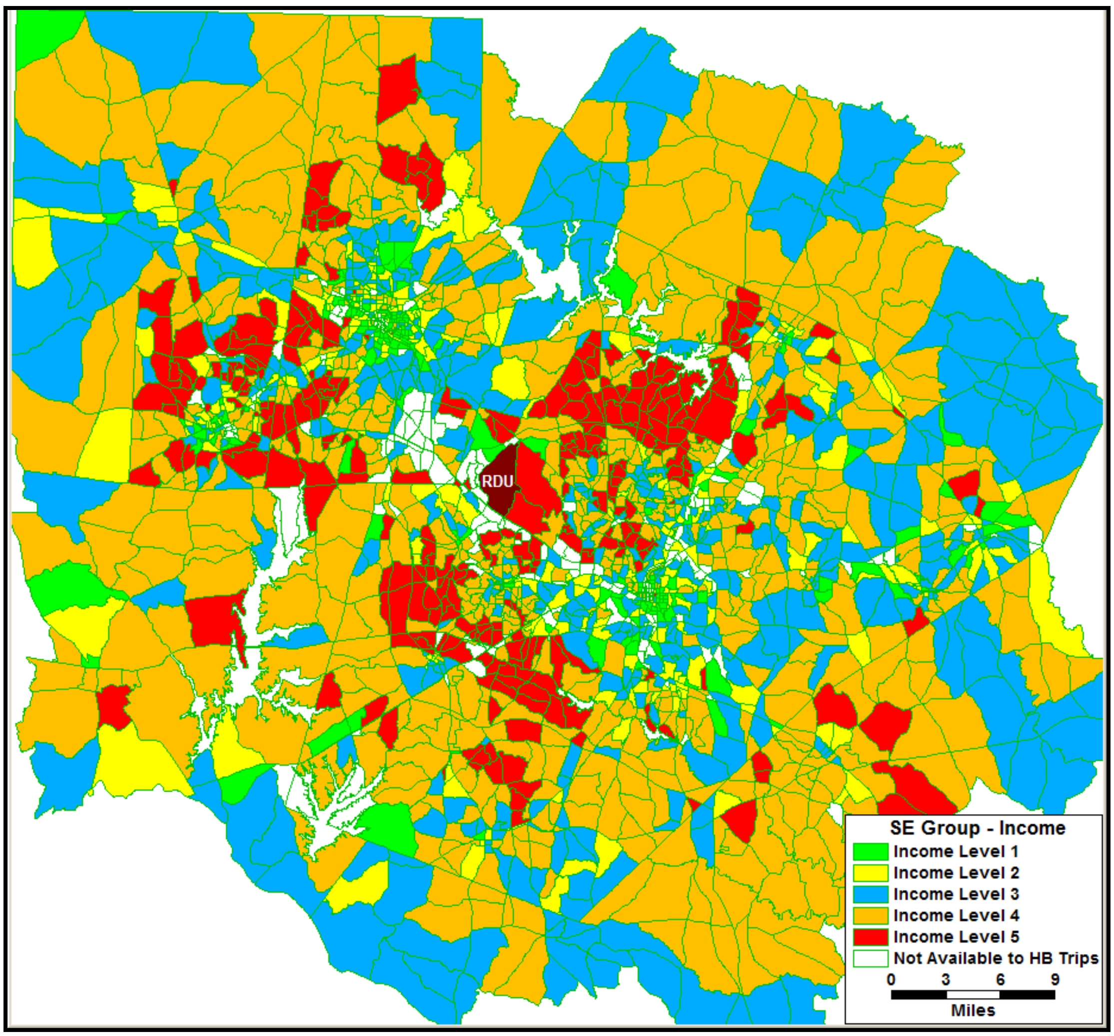


Figure 5-4: TAZs by Income SE Group Segments for HB Trips

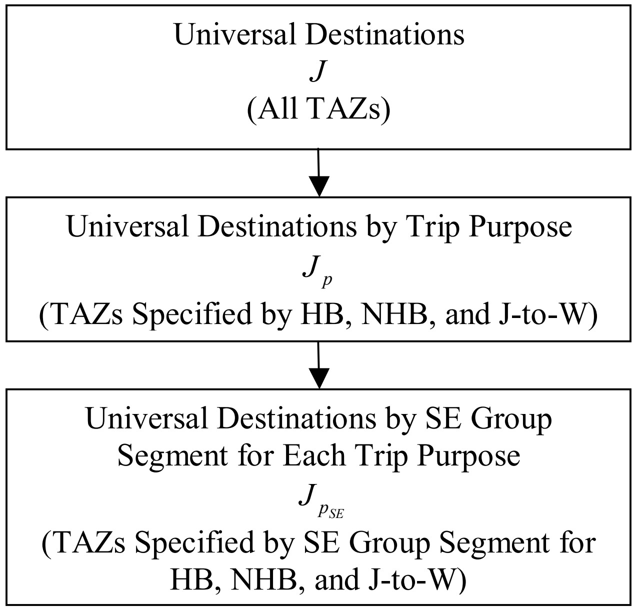


Figure 5-5: Available TAZ Choice Set for SE Group Segments by Trip Purpose

8. The destination characteristics of the SE group segments are determined by averaging the characteristics of all TAZs that are linked to the SE group segment. These characteristics are added to the observed data file for each trip purpose. The relevant destination characteristics that may be used in the MNL models estimation are identified for each trip purpose in **Table 5-13** and the average values of the characteristics for each SE group segment are shown in **Table 5-14**.

Table 5-13: Destination Characteristics of the SE Group Segments

HB	NHB	J-to-W
Travel Time	Travel Time	Travel Time
Households	Total Employment	Households
Dwelling Units	Industry Employment	Dwelling Units
Average Household Size	Retail Employment	Average Household Size
Median Income	Highway Employment	Median Income
	Office Employment	
	Service Employment	

Table 5-14: Values of the Destination Characteristics for the SE Group Segments

HB

Characteristic	SE Group Segment	Average Values
Travel Time (minutes)	1	28.50
	2	29.50
	3	33.24
	4	32.52
	5	26.41
Households	1	208
	2	261
	3	258
	4	278
	5	240
Dwelling Units	1	179
	2	229
	3	255
	4	287
	5	243
Median Income	1	$17,003
	2	$30,241
	3	$42,919
	4	$61,244
	5	$106,071
Average Household Size	1	2.3
	2	2.2
	3	2.4
	4	2.5
	5	2.7

NHB

Characteristic	SE Group Segment	Average Values
Travel Time (minutes)	1	27.18
	2	17.86
	3	29.63
	4	28.30
Service Employment	1	313
	2	274
	3	213
	4	272
Office Employment	1	105
	2	177
	3	180
	4	74
Highway Employment	1	43
	2	49
	3	34
	4	101
Other Employment	1	174
	2	216
	3	126
	4	199
Total Employment	1	634
	2	716
	3	553
	4	646

J-to-W

Characteristic	SE Group Segment	Average Values
Travel Time (minutes)	1	29.10
	2	20.40
	3	37.20
	4	20.55
	5	36.89
	6	26.37
Households	1	239
	2	370
	3	224
	4	341
	5	255
	6	240
Dwelling Units	1	208
	2	371
	3	220
	4	354
	5	262
	6	243
Median Income	1	$24,652
	2	$42,181
	3	$43,147
	4	$62,954
	5	$60,614
	6	$106,071
Average Household Size	1	2.2
	2	2.3
	3	2.5
	4	2.4
	5	2.6
	6	2.7

9. The observed choice destinations of the survey data are linked to the SE group segments based on the specifications in **Table 5-12.** A field named [Choice] is inserted into observed data table to represent the SE group segment chosen by the observed trip maker (**Appendix D**). **Table 5-15** displays the number of observed TAZ destinations compared to the number of possible TAZ destinations by SE group segment. **Figure 5-6** shows the observed choice destinations matched to the SE group segments for the HB trip purpose.

Table 5-15: 2002XP TRM TAZs by SE Group Segment

SE Group	SE Group Segment	Observed Survey TAZ Choice Destination	Possible TRM 2002XP Choice Destinations
Income Level (HB)	1	18	198
	2	29	271
	3	59	541
	4	159	728
	5	94	316
	TOTAL	**359**	**2,054**
Land Use Type (NHB)	1	50	1,441
	2	66	225
	3	66	1,089
	4	20	1,069
	TOTAL	**202**	**3824 ***
Income Level (J-to-W)	1	50	469
	2	61	128
	3	63	413
	4	72	196
	5	74	532
	6	53	316
	TOTAL	**374**	**2,054**

* Land Use SE Group Segments overlap TRM 2002XP TAZs

The SE group segment approach is an innovation to deal with small data sets. The approach shows that for 15 SE group segments with 30 observations each, the required sample size is a minimum of 450 observations. If a survey was conducted specifically to RDU airport trip distribution of internal airport trips, then the airport surveys would need to capture at least 1,800 airport trip makers who have internal destinations to the 2002XP TRM study area. The number of survey observations is approximated based on the assumption of capturing four times the sample size in the observed survey to account for survey and measurement error recommended by Horowitz et al. (1986). The comparison of regional air passenger surveys in step 3 (**Table 5-10**) can be referenced as an additional comparison using the SE group segment aggregation level.

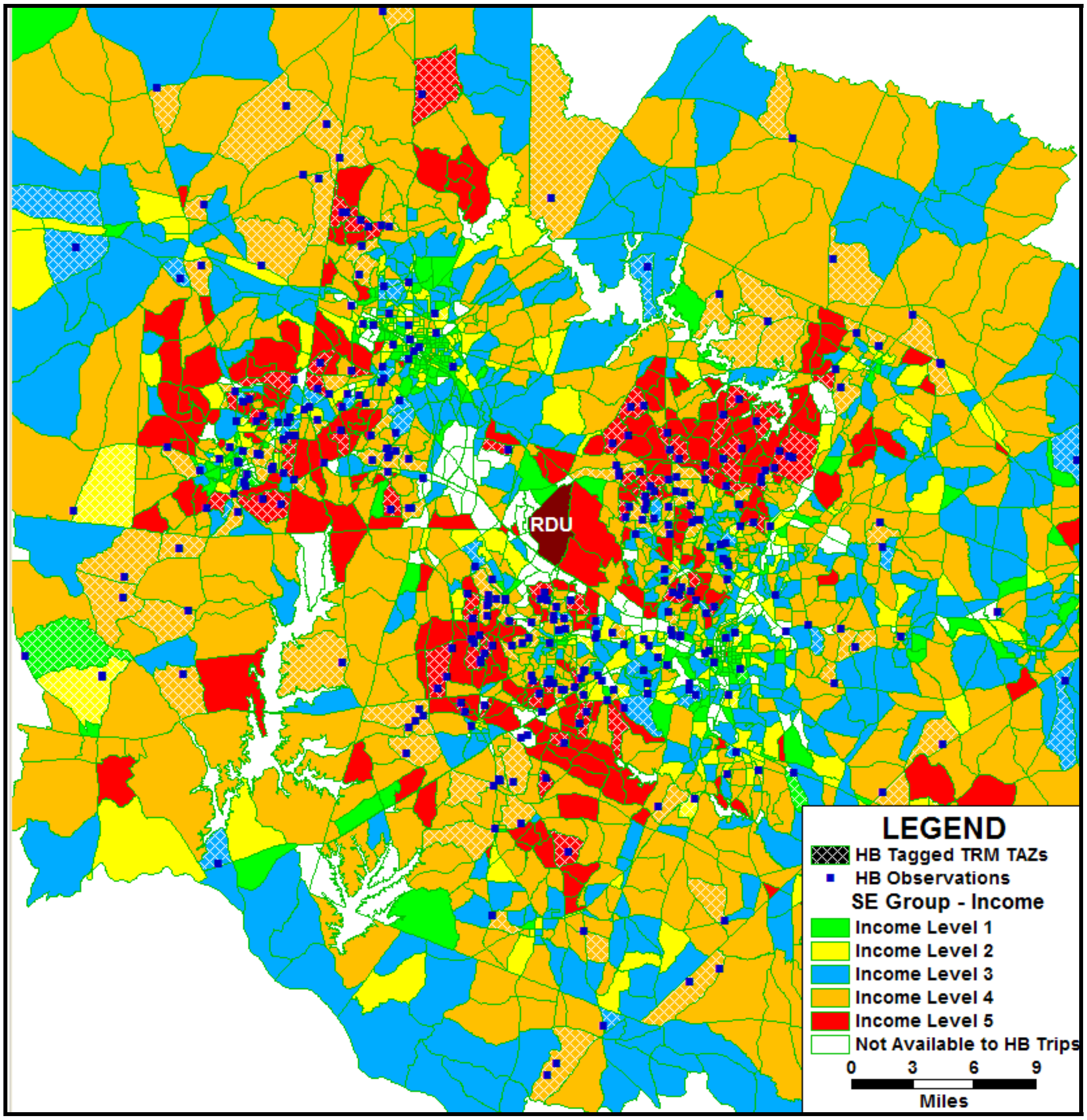


Figure 5-6: Observed Destinations Linked to the HB Income SE Group Segments

10. Once the relevant trip maker characteristics, TAZ destination characteristics, and the SE group segment characteristics are determined, the next step is to justify the assumption that the observed data records within each SE group segment have similar characteristics. This study uses scatter plots of the observed trip maker and destination data to remove any records that have outlying data. For example, a scatter plot of the median household income for observed data records of the HB trip purpose

is shown in **Figure 5-7**. This figure illustrates that there are some data records that have outlying median income characteristics. The most significant outliers in this figure are the highest three income values of Income Level 5. Therefore, these observed records are removed from the dataset because they do not fit with the similar characteristics of Income Level 5. The scatter plot and removal of outlying characteristics is performed for all characteristics of each trip purpose (**Appendix E**).

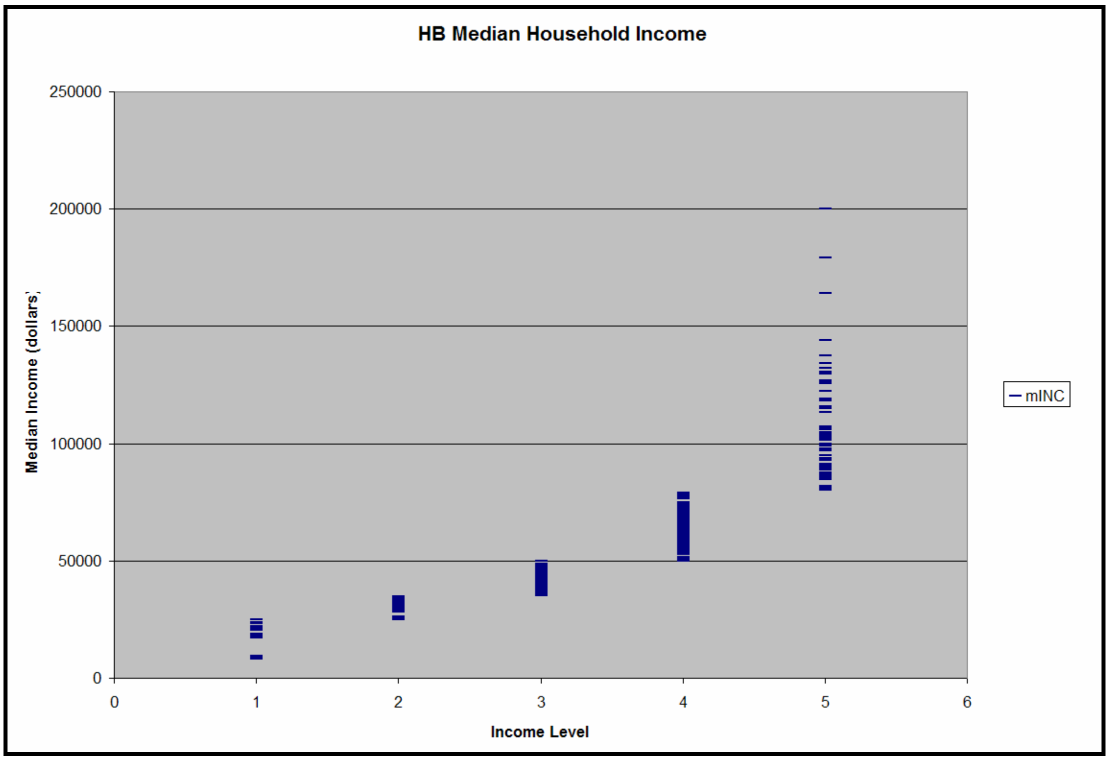


Figure 5-7: Scatter Plot of Median Income for Observations of the HB Trip Purpose

Due to the removal of outlying data records, the number of observations is reduced even further. Consequently, a few of the SE group segments have a sample size of less than 30 observations. **Table 5-16** shows the number of complete observation records with and without outlying data. Ideally, a sample size of thirty or more is required to reflect normal distribution of the model data. For those SE group segments with an observed sample size of less than thirty, “Q-Q” plots are used to check for normal distribution of the characteristics. The “Q-Q” plots order the observed data characteristics against the corresponding normal quantiles. Normal distribution of the data is indicated if the points generally follow a straight line. **Table 5-16** shows that normality is to be checked for the HB SE group segments 1 and 2 as well as for the NHB SE group segment 4 because the sample size is less than thirty observations. **Figure 5-8** shows the “Q-Q” plot of the median household income (mINC) characteristic for the HB SE group segment 2. The remaining “Q-Q” plots can be referenced in **Appendix E**.

Table 5-16: Observations With and Without Outlying Data by SE Group Segment

SE Group	SE Group Segment	Observations with Outlying Data	Observations without Outlying Data
Income Level (HB)	1	18	16
	2	29	28
	3	59	57
	4	159	149
	5	94	90
	TOTAL	359	340
Land Use Type (NHB)	1	50	38
	2	66	57
	3	66	59
	4	20	14
	TOTAL	202	168
Income Level (J-to-W)	1	51	39
	2	61	60
	3	63	62
	4	72	70
	5	74	72
	6	53	49
	TOTAL	374	352

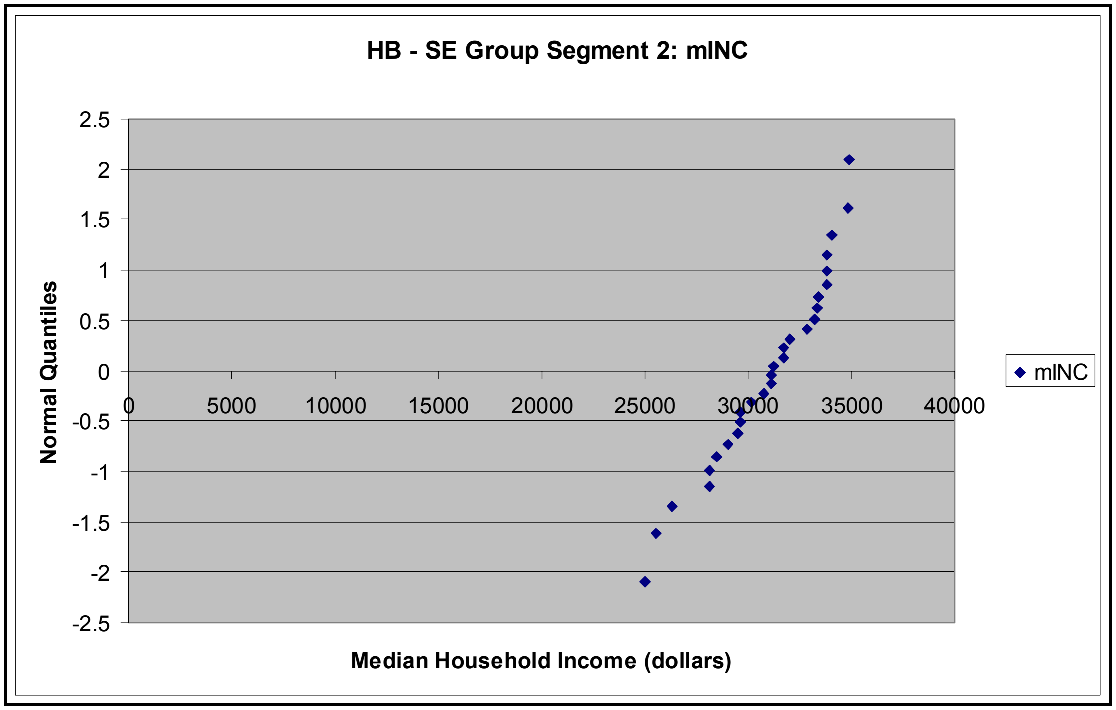


Figure 5-8: "Q-Q" Plot of Median Income for the HB SE Group Segment 2

Results from the "Q-Q" plots show that the HB characteristics generally follow a normal distribution (the plots show approximately a straight line), but a few of the NHB characteristics do not follow a straight line. These characteristics are service employment, office employment, and other (industry and retail) employment. Therefore, other forms of these characteristics are tested for normal distribution such as the interaction, square root, or log transformation of the values. **Figure 5-9** shows the "Q-Q" plot of service employment compared to the "Q-Q" plot of the log transformation of service employment for the NHB SE group segment 4. The figure shows the data points of the log transformation to be approximately linear (normally distributed). The interaction and log transformation of office employment is also normally distributed, but the log transformation of other employment is not normally distributed (**Appendix E**). Thus, the service and office employment characteristics can only be used in the MNL model estimation as the interaction or log transform of the data and the other employment characteristic can not be used in the model estimation since it violates the MNL model assumption of normal distribution.

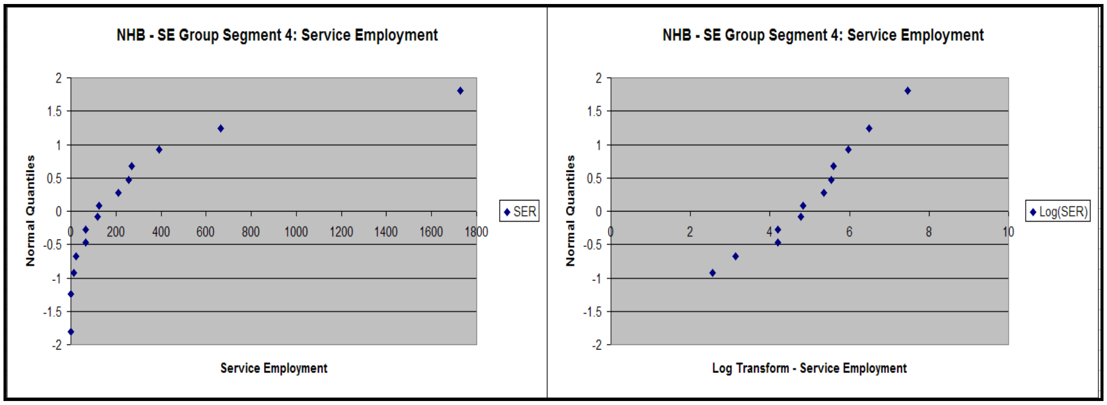


Figure 5-9: Comparison of the Service Employment "Q-Q" Plot and Log Transform Service Employment "Q-Q" Plot for the NHB SE Group Segment 4

11. Once the data characteristics and values are determined, the trip maker characteristics, TAZ destination characteristics, and SE group segment destination characteristics are combined in one data table by trip purpose. The trip purpose data files are formatted according to the Biogeme software specifications; the first row of the data file corresponds to the labels of the available data fields and each subsequent row corresponds to an observation. Additionally, each row must have a data value for each data field (**Appendix F**).

MNL Model Development (using MS Excel)

12. The characteristics used in the MNL models are chosen from a set of relevant characteristics specified in **Table 5-7** for the individual trip maker and from **Table 5-**

13 for the destinations. If any of the characteristics are highly correlated, such as travel time and travel distance, then one of the correlated characteristics is removed from the model. Also, any characteristic that does not provide a good measure of the choice of destination is removed from the model. For example, characteristics such as "connecting flight", "work days per week", and "job description" are important in developing the RDU airport sub-model, but they are not needed for the MNL model estimation. **Table 5-17** shows the significant characteristics that could be used in the MNL model estimation along with their corresponding abbreviations.

Table 5-17: Possible Characteristics of the MNL Models

Trip Maker Characteristics	Characteristic Abbreviation	Destination Characteristics	Characteristic Abbreviation
Location Prior to RDU	PRIOR	Travel Time	TT
Resident / Non-Resident	Res / N-Res	Industry Employment	IND
Business / Leisure	Bus / N-Bus	Retail Employment	RET
Trip Length (in days)	DAYS	Highway Employment	HWY
Household Size	HS	Office Employment	OFF
Household Income	INC	Service Employment	SER
Gender	GEN	Households	HH
Number of Companions	COMP	Population	POP
Travel Destination	DEST	Median Income	mINC
Job Description	J DESC	Average Household Size	HHS
Estimated Travel Time	Time	Dwelling Units	DU

13. The utility form of the MNL models are tested based on the relationships between the available characteristics used in the MNL model. The simplest utility form is linear-in-parameters and other utility forms are logarithmic, exponential, quadratic, etc. However, estimating non-linear models are notoriously difficult (Chen and Hou,

2006). The model results from the different utility forms such as the log-likelihood ratio test, chi-square test, adjusted Rho-square statistic, etc. are evaluated and the utility form is refined until the best goodness-to-fit statistics are obtained. The stepwise calibration process of running the MNL models and evaluating the results is described further in the next section of this chapter (*MNL Model Estimation*). Some forms of the utility function tested are shown in **Table 5-18.**

Table 5-18: Utility Function Forms of the MNL Model

Form Type	Example Utility Function
Linear	ASC + β*X + β*Y + β*Z
Logarithmic	ASC + β*X + β*Y + β*log (Z)
Exponential	ASC + β*X + β*Y + β*exp (Z)
Polynomial	ASC + β*X + β*Y^2 + β*Z^3
Quadratic	ASC + β*X^2 + β*Y^2 + β*Z^2 + β*XY + β*YZ + β*XZ

14. The MNL model files are formatted in MS Excel according to the Biogeme software specifications. Biogeme requires a description of the model, identification of the destination choice field name ([Choice]) that is used in the corresponding data file, a list of the estimated parameters and their value bounds, the utility function for each destination choice, expressions of the utility function, and specification of the destination choice model type (MNL). The expressions section is used to state the availability of the choice destination (Av_# = 1) and to define any characters or words not specified in the parameters section of the model file. **Figure 5-10** shows the MNL model file for the NHB trip purpose that was used in this research. The final MNL model files for each trip purpose can be referenced in **Appendix F**.

```
[ModelDescription]
"RDU Airport MNL Model for NHB trips"

[Choice]
Choice

[Beta]
//       Name      Value      LowerBour UpperBour Status    (0=variable, 1=fixed)
ASC_1           0  -1.00E+00 1.00E+00        1
ASC_2           0  -1.00E+00 1.00E+00        0
ASC_3           0  -1.00E+00 1.00E+00        0
ASC_4           0  -1.00E+00 1.00E+00        0
B_OFF3          0  -1.00E+00 1.00E+00        0
B_EMP3          0  -1.00E+00 1.00E+00        0
B_TT3           0  -1.00E+00 1.00E+00        0

[Utilities]
//       ID       Name       Avail    linear-in-parameterexpression(beta1*x1+beta2*x2+)
       1 NHB_1    Av_1       ASC_1 * one + B_OFF3 * OFF3_1 + B_EMP3 * EMP3_1 + B_TT3 * TT3_1
       2 NHB_2    Av_2       ASC_2 * one + B_OFF3 * OFF3_2 + B_EMP3 * EMP3_2 + B_TT3 * TT3_2
       3 NHB_3    Av_3       ASC_3 * one + B_OFF3 * OFF3_3 + B_EMP3 * EMP3_3 + B_TT3 * TT3_3
       4 NHB_4    Av_4       ASC_4 * one + B_OFF3 * OFF3_4 + B_EMP3 * EMP3_4 + B_TT3 * TT3_4

[Expressions]
one = 1
Av_1 = 1
Av_2 = 1
Av_3 = 1
Av_4 = 1
$LOOP {zz 1 5 1} OFF3_zz = OFF_zz * OFF
$LOOP {zz 1 5 1} EMP3_zz = EMP_zz * EMP
$LOOP {zz 1 5 1} TT3_zz = TT_zz * TT

[Model]
$MNL
```

Figure 5-10: MNL Model File for the NHB Trip Purpose

15. Along with a data file and a model file, each trip purpose has a parameter file that specifies the parameters controlling the execution of the Biogeme program. Some of these parameters include the optimization algorithm, output display levels, missing value specification, etc. A default parameter file is used for each trip purpose and it is shown in **Figure 5-11**.

```
// This file has automatically been generated.
// 10/13/06 16:11:34
// Michel Bierlaire, EPFL (c) 2001-2005

// BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
// Author: Michel Bierlaire, EPFL (2001-2005)

[GEV]
gevAlgo = "BIO"
gevScreenPrintLevel = 1
gevLogFilePrintLevel = 2
gevRandomDistrib = "PSEUDO"
gevPrintVarCovarAsList = 1
gevPrintVarCovarAsMatrix = 0
gevTtestThreshold = 1.28

[BasicTrustRegion]
BTRMaxIter = 1000

[cfsqp]
cfsqpMaxIter = 1000

[solvopt]
solvoptMaxIter = 1000
```

Figure 5-11: Biogeme Default Parameter File

MNL Model Estimation (using a text editor and the Biogeme software)

16. The data file, model file, and parameter file are exported from MS Excel as space delimitated or tab delimitated file (.prn) and they are opened in TextPad. Then, the files are saved as UNIX format with a .dat, .mod, and .par file extension for the data file, model file, and parameter file, respectively. **Figure 5-12** on the following page shows the conversion of the NHB trip purpose model file from MS Excel to TextPad to Biogeme format.

17. Once the files are converted to Biogeme format, each file is reviewed closely in TextPad to ensure that all data are correctly converted from excel format to text format and that no data were lost or truncated in the process. Additionally, the files must be verified that a space or tab separates all words or numbers in each row and that each row in the data file (.dat) contains the same number of values.

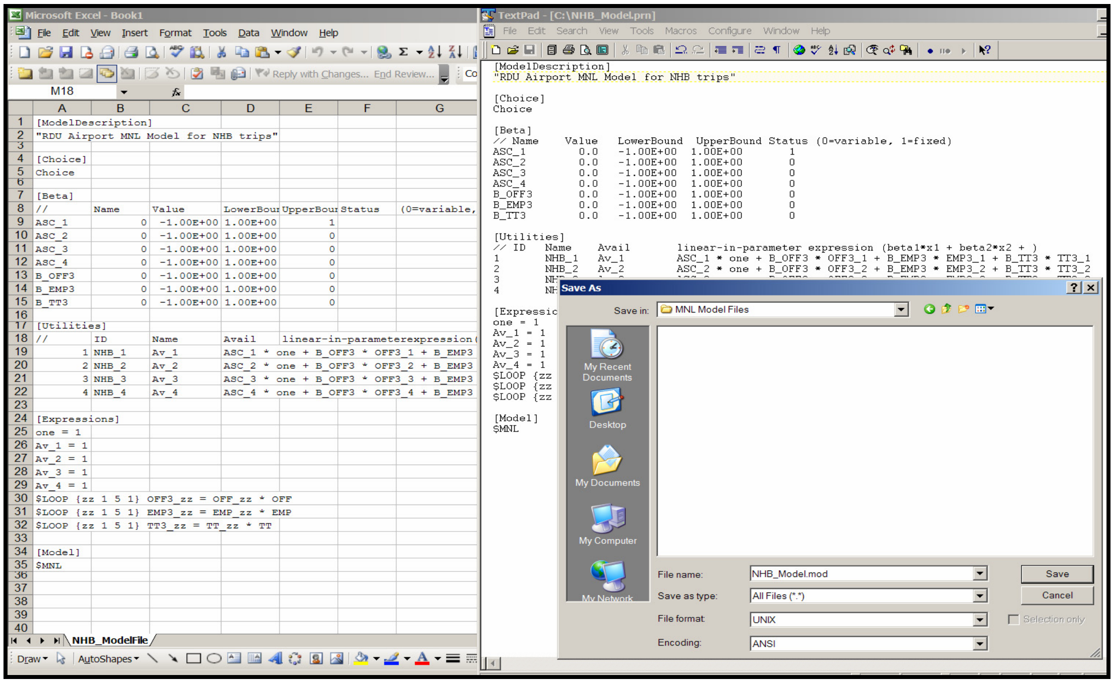


Figure 5-12: File Conversion from MS Excel to TextPad to Biogeme Specifications

18. The Biogeme executable downloaded from the website roso.epfl.ch/Biogeme is executed using a MS Windows DOS terminal. In the DOS window, the data file (.dat), MNL model file (.mod), and parameter file (.par) are specified (**Figure 5-13**) and the outputs are reported in the DOS window (**Figure 5-14**) as well as in separate text files.

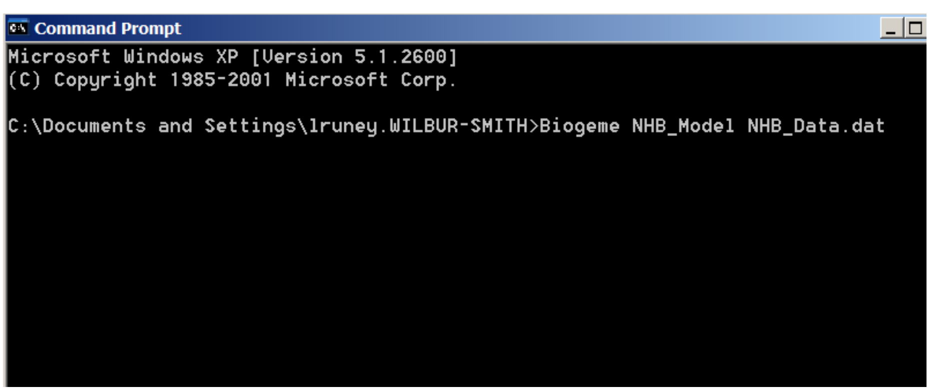
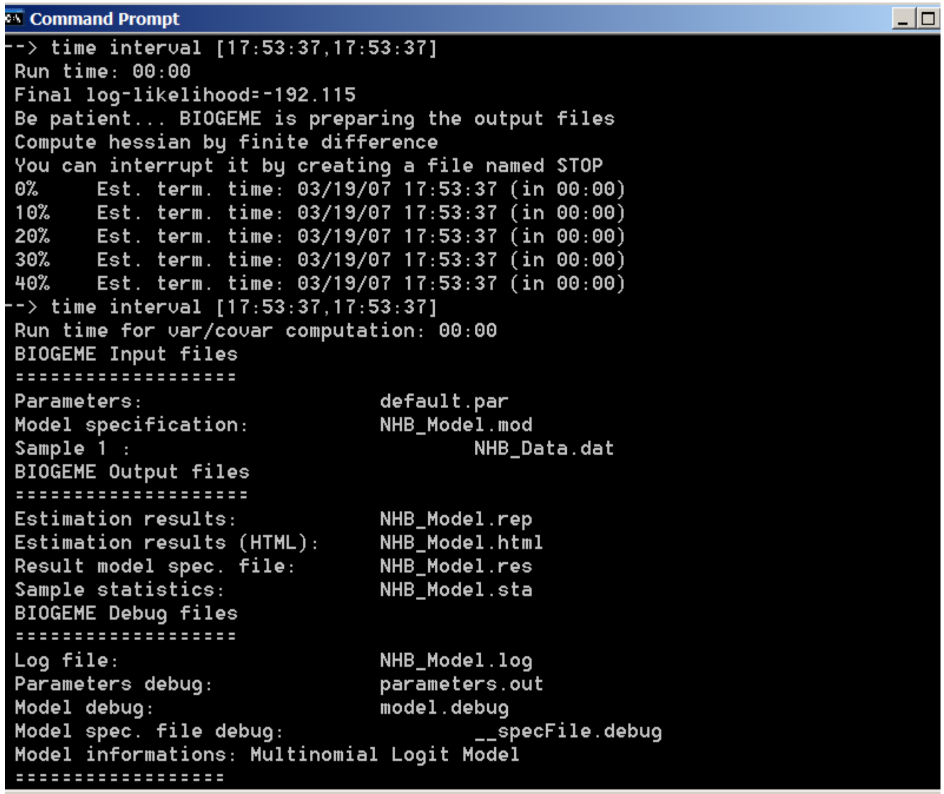


Figure 5-13: Execution of Biogeme for the NHB Trip Purpose MNL Model



```
Command Prompt
--> time interval [17:53:37,17:53:37]
Run time: 00:00
Final log-likelihood=-192.115
Be patient... BIOGEME is preparing the output files
Compute hessian by finite difference
You can interrupt it by creating a file named STOP
0%     Est. term. time: 03/19/07 17:53:37 (in 00:00)
10%    Est. term. time: 03/19/07 17:53:37 (in 00:00)
20%    Est. term. time: 03/19/07 17:53:37 (in 00:00)
30%    Est. term. time: 03/19/07 17:53:37 (in 00:00)
40%    Est. term. time: 03/19/07 17:53:37 (in 00:00)
--> time interval [17:53:37,17:53:37]
Run time for var/covar computation: 00:00
BIOGEME Input files
===================
Parameters:                    default.par
Model specification:           NHB_Model.mod
Sample 1 :                             NHB_Data.dat
BIOGEME Output files
====================
Estimation results:            NHB_Model.rep
Estimation results (HTML):     NHB_Model.html
Result model spec. file:       NHB_Model.res
Sample statistics:             NHB_Model.sta
BIOGEME Debug files
===================
Log file:                      NHB_Model.log
Parameters debug:              parameters.out
Model debug:                   model.debug
Model spec. file debug:                __specFile.debug
Model informations: Multinomial Logit Model
==================
```

Figure 5-14: Results of Biogeme Execution for the NHB MNL Model

19. The output files from the MNL model runs are reviewed for odd values and statistical validity. The output file with the .sta file extension presents the statistical review of the data file. The output file with the .rep file extension presents the statistical review of the model file. The Biogeme output files of the final MNL models can be referenced in **Appendix H**. Details of the final MNL model statistics are discussed at the end of this step.

Figure 5-15 shows the NHB_Model.sta file, which is the statistics of the NHB_Data.dat file. The MNL model data statistical files show the mean, minimum, and maximum values of each variable used in the MNL model estimation. Also, the files present the number of observations used in the MNL model estimation and the number of observations per choice destination.

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Data Statistics for NHB trips

Sample   size=168
Excluded Obs.:           0
Total    obs.     in      files:        167
Number   of       cases:        504
Statisticof       attributes
++++++++++++++++++++++++
Name     Mean     Min      Max
Choice    2.28402        1        4
EMP3_1     817117     5706 3.63E+06
EMP3_2     922801     6444 4.10E+06
EMP3_3     712722     4977 3.17E+06
EMP3_4     832583     5814 3.70E+06
OFF3_1    28656.1     94.5   194985
OFF3_2      48306    159.3   328689
OFF3_3    49124.8      162   334260
OFF3_4    20195.7     66.6   137418
TT3_1     574.196  257.123  911.074
TT3_2     377.305  168.956  598.667
TT3_3     625.954    280.3  993.198
TT3_4     597.857  267.718  948.616
one             1        1        1
Nbr of chosen alternatives
Alt      #
       1       38
       2       57
       3       59
       4       14
Group    membership
Group    #
       1      168
```

Figure 5-15: Data File Statistical Results for the NHB MNL Model Data

Figure 5-16 shows the first section of the NHB_Model.rep file. This section is the overall MNL model statistics of the NHB_Model.mod file. This file is checked for model goodness-to-fit measures including the log-likelihood ratio test and the adjusted Rho-square. The log-likelihood ratio test is a statistical test that is used to make inferences about the model fit compared to the base model, also known as the null model or unrestricted model. When the log-likelihood ratio is greater than the critical Chi-square statistic for a certain degrees of freedom and significance level, the null model is rejected and the model being tested (restricted model) is the better model fit for the observed data. The adjusted Rho-square statistic provides the portion of the log-likelihood that is explained by the model considering the number of variables used in the model estimation. A value of 0.2 to 0.3 is acceptable and values greater than 0.3 are recommended. The log-likelihood ratio test, Chi-square statistic, and adjusted Rho-square statistic are described further in **Appendix B**. The final MNL model statistics are discussed at the end of this step.

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Statistics for NHB trips

Model: Multinomial Logit
Number of estimated parameters: 6
Number of observations: 168
Number of individuals: 168
Null log-likelihood:        -232.897
Init log-likelihood:        -232.897
Final log-likelihood:       -192.118
Likelihood ratio test:       81.5588
Rho-square:                 0.175096
Adjusted rho-square:        0.149334
Final gradient norm:         12.3526
Variance-covariance:   from finite difference hessian
```

Figure 5-16: Model File Statistical Results for the NHB MNL Model

Figure 5-17 shows the second part of the NHB_Model.rep file. This file presents the utility function parameter statistics of the MNL model. The ASC estimates and the generic explanatory variable estimates are checked for reasonable signs, values, and t-values. The estimates are not interpreted as stand-alone values, but they are addressed relative to the fixed ASC value of one. The t-values are used to help indicate the significance of the variables and the variables are flagged with an asterisk (*) as insignificant if the absolute value of the t-values is less than or equal to the critical t-statistic of 1.96 at 95% confidence, 1.65 at 90% confidence, or 1.28 at 80% confidence for a two tailed test.

Utility parameters
****

Name	Value	Std err	t-test	
ASC_1	0.00E+00	fixed		
ASC_2	1.00E+00	3.91E-05	2.56E+04	
ASC_3	-1.35E-01	2.42E-01	-5.60E-01	*
ASC_4	-1.00E+00	6.71E-06	-1.49E+05	
B_EMP3	3.08E-06	1.13E-06	2.73E+00	
B_OFF3	1.61E-05	6.16E-06	2.62E+00	
B_TT3	8.59E-03	1.33E-03	6.47E+00	

Figure 5-17: Utility Function Statistical Results for the NHB MNL Model

Even though a variable parameter is flagged as insignificant according to the critical t-statistic, researchers imply that it is not good practice to eliminate a variable simply because the parameter is not significantly different from zero at the 5%, 10%, or 20% alpha level; the inability to reject the hypothesis that some parameter is zero at a particular significance level does not imply that the hypothesis must be accepted (Ben-Akiva, 2006). Additionally, research has used a confidence level as low as 70% to indicate significant parameters (McFadden and Train, 2000). This study uses a confidence level of 80% because the observed sample size per choice destination is low and the t-values are asymptotically t-distributed (i.e. as the sample size approaches infinity, the estimated model parameters are t-distributed). Some of the

MNL model characteristics are flagged as insignificant to the choice of destination at 80% confidence. However, there is a risk of rejecting these parameters as being insignificant when in fact they are significant in influencing trip maker's choice of destination (type II error). This research feels that these characteristics are sensitive to the RDU airport trip maker's choice of destination since the MNL models goodness-to-fit statistics are best using these variables. Therefore, the characteristics are kept in the MNL models as explanatory variables of destination choice. The final MNL model characteristics and statistics are discussed in the preceding paragraphs of this step.

Based on the model goodness-to-fit statistics and the utility parameter outputs (magnitude, size, and t-values) the utility form of the MNL model and the characteristics used in the MNL model are revised in a stepwise approach until the best model results are obtained. Good model results include (1) a high log-likelihood ratio greater than the critical Chi-square statistic, (2) an adjusted Rho-square statistic closer to one, and (3) parameters values and t-values that are reasonable and that significantly affect the relationship between the trip maker and the choice of destination at 80% confidence.

The stepwise approach used for each model in this research is a backwards elimination method. First, a base model of all relevant variables is tested and the resulting goodness-to-fit statistics are used as a basis to evaluate all other model steps. Then, one parameter at a time is eliminated from the model. If the model goodness-to-fit statistics improve compared to the base model, then this characteristic is removed permanently from the model. If the model goodness-to-fit statistics get worse, then this characteristic is added back to the model and a different characteristic is removed for the next model test. This process is performed for each trip purpose and for linear and non-linear utility forms. **Table 5-19** shows a section of the stepwise procedure for the NHB trip purpose. All the tables of the stepwise procedures by trip purpose are shown in **Appendix G**.

Table 5-19: Sample of the Stepwise Process for the NHB MNL Model

NHB Utility Model Variable Selection:
Base = (|OFF * SER * HWY|) + (|OFF| * {OFF}) + (|SER| * {SER}) + (|HWY| * {HWY}) + (|Other| * {Other}) + (|EMP| * {EMP}) + (|TT| * {TT}) + ({OFF * SER * HWY}) (|OSH| * {OSH}) **

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base			11	40.885	Yes	0.0405	Yes
29	{OSH}		10	41.328	Yes	0.0458	No
30	{OFF * SER * HWY}		9	82.831	Yes	0.1392	Yes
31	|HWY| * {HWY}		8	82.831	Yes	0.1435	No
32	|Other| * {Other}		7	29.075	Yes	0.0324	Yes
33	|SER| * {SER}	|Other| * {Other}	7	82.624	Yes	0.1473	No
34	|OFF| * {OFF}		6	72.170	Yes	0.1292	Yes
35	|EMP| * {EMP}	|OFF| * {OFF}	6	75.129	Yes	0.1355	Yes
36	|TT| * {TT}	|EMP| * {EMP}	6	42.963	Yes	0.0665	Yes

** |SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

The statistics of the final MNL models are discussed in the remainder of this section. The final log-likelihood and adjusted Rho-square values of the models are presented in **Table 5-20.** The final utility functions for each trip purpose are shown in **Table 5-21** with a description of each variable listed below**.** The corresponding ASC estimates and explanatory parameter estimates of the calibrated MNL models are shown in **Table 5-22** for each trip purpose. The Biogeme output files of the calibrated MNL models by trip purpose can be referenced in **Appendix H**.

Table 5-20 shows the final log-likelihood, log-likelihood ratio test, adjusted Rho-square, and number of parameters estimated in the MNL models by trip purpose. The log-likelihood ratio test values are greater than the Chi-square statistic at 95%

confidence for each trip purpose and this is one indicator of the model fit of the observed data. However, the Rho-square statistics are low for all three trip purposes. It is recommended to have values of 0.3 or greater to explain the portion of the model fit of the observed data. Reasons for the low adjusted Rho-square values could be due to the low sample size per destination, corrupted data, or incorrect market groups used for the SE group segment destinations. Additional tests of these three issues are recommended for future work on the MNL destination choice models for trip distribution of the RDU airport trips.

Table 5-20: MNL Model Summary Statistics by Trip Purpose

Trip Purpose	Final Log-Likelihood	Log-Likelihood Ratio Test	Adjusted Rho square	Number of Parameters
HB	-454.91	184.55	0.16	7
NHB	-192.12	81.56	0.15	6
J-to-W	-491.12	279.16	0.21	9

Table 5-21 shows the final utility functions of the MNL models by trip purpose. The utility functions are vital in the MNL model choice probability estimation (equation 5-1 shown in the next section of this chapter) because they describe the attractiveness of the SE group segment destinations for the RDU airport trip makers. The final utility forms for each trip purpose are linear in parameters with interaction between either the SE group segment destination characteristic and the TAZ destination characteristic, or the SE group segment destination characteristic and the trip maker characteristic.

Table 5-21: Final Utility Functions of the MNL Models

Trip Purpose	Utility Function
HB	$ASC + \beta_{HH}(HH_{SE} * HH_{TAZ}) + \beta_{HS}(HHS_{SE} * HS) + \beta_{INC}(mINC_{SE} * INC)$
NHB	$ASC + \beta_{OFF}(OFF_{SE} * OFF_{TAZ}) + \beta_{EMP}(EMP_{SE} * EMP_{TAZ}) + \beta_{TT}(TT_{SE} * TT_{TAZ})$
J-to-W	$ASC + \beta_{TT}(TT_{SE} * TT_{TAZ}) + \beta_{HH}(HH_{SE} * HH_{TAZ}) + \beta_{HS}(HHS_{SE} * HS) + \beta_{INC}(mINC_{SE} * INC)$

Parameter Descriptions

ASC - Alternative Specific Constant
β_{HH} - Number of household
β_{HS} - Household Size
β_{INC} - Household Income

β_{OFF} - Office Employment
β_{EMP} - Total Employment
β_{TT} - Travel Time to the RDU Airport

Variable Descriptions

SE Group Segment Destinations
HH_{SE} - Number of Households
HHS_{SE} - Household Size
$mINC_{SE}$ -Median Household Income
OFF_{SE} - Number of Households
EMP_{SE} - Household Size
TT_{SE} - Travel Time to the RDU Airport

Trip Maker
HS - Household Size
INC -Median Household Income

TAZ Destinations
HH_{TAZ} - Number of Households
OFF_{TAZ} - Number of Households
EMP_{TAZ} - Household Size
TT_{TAZ} - Travel Time to the RDU Airport

Below discusses the sensitivity of the generic variables (i.e. MNL model variables that reflect the effects of all destinations) for each MNL model by trip purpose:

- The HB utility function shows that three characteristics affect the choice of destination for RDU air passenger HB trip makers; (1) average number of households of the SE group segment and TAZ destination, (2) average household size of the SE group segment and the trip maker, and (3) average household income of the SE group segment and the trip maker. This seems logical that a trip maker's income and household size effect trip making to the RDU airport. Additionally, since the non-airport trip end is the home, the number of households is a reasonable measure for the destination characteristic. Travel time to the RDU airport is not a major factor of choice destination for HB air passengers since the RDU airport is the only major commercial airport in the TRM study area.

- The NHB utility function shows that characteristics of the SE group segment destination and characteristics of the TAZ destinations, but not characteristics of the trip maker affect the choice of destination for RDU air passenger non-home based trip makers. The NHB utility function characteristics are (1) average office employment of the SE group segment and TAZ destination, (2) average total employment of the SE group segment and TAZ destination, and (3) average travel time to RDU airport of the SE group segment and TAZ destination. This is sensible for travel time to influence non-home based airport trips and for employment, such as the workplace to affect the non-airport trip ends for airport air passengers.
- The J-to-W utility function for RDU airport employees is similar to the utility function for HB air passengers, except that travel time to the RDU airport is an additional measure of attractiveness for the RDU airport employees. The J-to-W parameters are reasonable because these trips have a home non-airport trip end and the travel time does have an affect on employee's choice of employment location. However, the effect of travel time to the RDU airport is relatively low in magnitude compared to other parameters such as household size.

The variables' effects on the choice of destination are discussed next. **Table 5-22** shows the signs and magnitudes of the parameters estimated for each trip purpose.

Table 5-22: Calibrated Characteristics of the MNL Model by Trip Purpose

Trip Purpose	Characteristic	Abbreviation	Description	Estimated Parameter
HB	INC_1 Constant	ASC 1	SE Group Segment 1 Constant	fixed*
	INC_2 Constant	ASC 2	SE Group Segment 2 Constant	0.2560
	INC_3 Constant	ASC 3	SE Group Segment 3 Constant	0.5540
	INC_4 Constant	ASC 4	SE Group Segment 4 Constant	0.9727
	INC_5 Constant	ASC 5	SE Group Segment 5 Constant	-0.8618
	Households	HH	Average Number of Households	1.939E-06
	Household Size	HS	Average Household Size	0.1983
	Household Income	INC	Average Household Income	6.932E-06
NHB	NHB_1 Constant	ASC 1	SE Group Segment 1 Constant	fixed*
	NHB_2 Constant	ASC 2	SE Group Segment 2 Constant	1.0000
	NHB_3 Constant	ASC 3	SE Group Segment 3 Constant	-0.1355
	NHB_4 Constant	ASC 4	SE Group Segment 4 Constant	-1.0000
	Office Employment	OFF	Average Office Employment	1.6149E-05
	Total Employment	EMP	Average Employment	3.080E-06
	Travel Time	TT	Average Travel Time to RDU	0.008594
J-to-W	INC_1 Constant	ASC 1	SE Group Segment 1 Constant	fixed*
	INC_2 Constant	ASC 2	SE Group Segment 2 Constant	0.3836
	INC_3 Constant	ASC 3	SE Group Segment 3 Constant	-0.9994
	INC_4 Constant	ASC 4	SE Group Segment 4 Constant	0.8789
	INC_5 Constant	ASC 5	SE Group Segment 5 Constant	-1.0000
	INC_6 Constant	ASC 6	SE Group Segment 6 Constant	-0.1441
	Travel Time	TT	Average Travel Time to RDU	0.009337
	Households	HH	Average Number of Households	2.584E-05
	Household Size	HS	Average Household Size	-0.82385
	Household Income	INC	Average Household Income	9.470E-06

* Fixed Value at 1.0

The fixed alternative specific constant (ASC 1) for each trip purpose is the reference value that all other parameters are evaluated against. The positive estimated parameters indicate that the characteristic contributes more to the attractiveness of a destination in comparison to ASC 1 and the negative estimated parameters indicate that the characteristic contributes to less attractiveness of the destination in comparison to ASC 1. The following bullets discuss the MNL model ASC values of the choice destinations and the generic explanatory variables by trip purpose:

- The ASC values of the HB MNL model show that the destination of median household income between $50,000 and $80,000 (SE group segment 4) has the highest ASC value and the destination of median household income greater than $80,000 (SE group segment 5) has the lowest ASC value compared to the destination of a median household income less than $25,000 (SE group segment 1), which is the reference ASC. It is reasonable that the mid-level income categories (SE group segments 3 and 4) have higher ASC values than the low level income categories (SE group segments 1 and 2) as reflected by the RDU air passenger survey. However, it does not seem very reasonable that the high level income ASC value is negative, considering that the RDU air passenger survey finds two-fifths of the respondents to have a household income greater than $80,000 (SE group segment 5).

  The generic explanatory variable parameters of the HB MNL model show that the number of households, household size, and household income contribute to the attractiveness of a destination. The trip maker's household size has the most influence on the choice of destination and the trip maker's household income has the least influence on the choice of destination. It is sensible that the trip maker's household income is least sensitive to the choice of destination because the choice destinations are already segmented by household income level.

- The ASC values of the NHB MNL model show that the destination with high office employment relatively close (low travel time) to the RDU airport (SE group segment 2) has the highest ASC value and the destination with high highway and university employment (SE group segment 4) has the lowest ASC value compared to the destination of high service employment (SE group segment 1), which is the reference ASC. It is reasonable that the office employment land use category has the highest ASC value given that a majority of the airport air passenger non-home trip ends are at the workplace.

  The generic explanatory variable parameters of the NHB MNL model show that office employment, total employment, and travel time to the RDU airport contribute to the attractiveness of destinations. Travel time to the RDU airport has a greater effect than the destination employment. This is logical because the choice destinations are already segmented by employment type and RTP is nearby. Additionally, the travel time parameter is a positive value, which indicates that more NHB trips are made to destinations farther away from the RDU airport in travel time. Even though the ASC values show that the office employment is preferred closer to the RDU airport (shown by the positive ASC of SE group segment 2 and the negative ASC of SE group segment 3), the travel time parameter is generic and it reflects the effect of travel time considering all destinations for NHB trip makers.

- The ASC values of the J-to-W MNL model show that the destination of median household income between \$50,000 and \$80,000 closer to the RDU airport (SE group segment 4) has the highest ASC value and the destinations of median household income between $50,000 and $80,000 farther away from the RDU airport (SE group segment 5) has the lowest ASC value compared to the destination with a median household income less than $35,000 (SE group segment 1), which is the reference ASC. It is reasonable that the ASC values of destinations closer to the RDU airport in travel time are higher than the ASC values of the destinations farther away from the RDU airport in travel time because most employees prefer to have low travel time between their home and place of employment.

The generic explanatory variable parameters of the J-to-W MNL model show the travel time to the RDU airport, number of households, and household income contribute to the attractiveness of a destination for airport employees. However, unlike HB air passengers, household size negatively affects the attraction of destinations for the airport employees. The negative household size parameter implies that employees of the RDU airport are less likely to have a high household size. The positive parameter of number of households is logical because the non-airport J-to-W trip end comes from the home. The positive parameter of travel time implies that more airport employees have longer travel time than shorter travel time between their home and the RDU airport. The positive sign of travel time seems counter intuitive considering that the two destinations with higher travel time to the RDU airport (SE group segments 3 and 5) have the lowest ASC values (lowest attraction) compared to the reference destination. However, the travel time parameter is generic and it reflects the effect of travel time considering all destinations for the J-to-W airport employees. In other words, the travel time parameter is a function of all observed travel times to the RDU airport for each SE group segment of the J-to-W trip purpose.

The implications of the choice destination ASC estimates suggest that the RDU airport trip makers with a home trip end and a median household income between $50,000 and $80,000 are more likely to make a trip to the RDU airport. The RDU airport trip makers with a non-home trip end at high office employment, such as the Research Triangle Park are more likely to make a trip to the RDU airport. However, the ASC estimates are not a direct reflection of the overall choice probability of the destinations. The parameter signs and magnitudes of the explanatory variables such as travel time to the RDU airport and household size are also influential in the choice probability estimation for all available destinations. (The choice probabilities are discussed in the following section).

The implications of the explanatory variable parameters suggest that household size and travel time are the most sensitive, respectively, to the choice of destination for the RDU airport trip makers. Unlike the gravity model, which assumes that destinations are less likely at locations with larger travel time to the RDU airport, the MNL destination choice model predicts that destinations are more likely at locations farther in travel time to the RDU airport for the NHB and J-to-W trip purpose. This reflects that most air passengers with non-home trip ends and airport employees have longer travel times to RDU airport.

MNL Choice Probability Estimation for SE Group Segments (using the Biosim application)

20. Once the parameters of the calibrated utility function are estimated in Biogeme, the probability of the chosen SE group segment by each trip maker is estimated using the Biosim application of the Biogeme software. The Biogeme output file with a .res extension is renamed to _res.mod. This file is used as the model input file in Biosim. For example, the HB output file (HB_Model.res) is renamed to HB_Model_res.mod. The same data file and parameter file used in the MNL model parameter estimation (Biogeme) are used in the MNL choice probability estimation (Biosim).

21. The Biosim application is executed in a DOS terminal and the model file (_res.mod), data file (.dat), and parameter file (.par) are specified. **Figure 5-18** shows the HB trip purpose files specified in the Biosim application and **Figure 5-19** shows the output files of Biosim for the HB trip purpose.

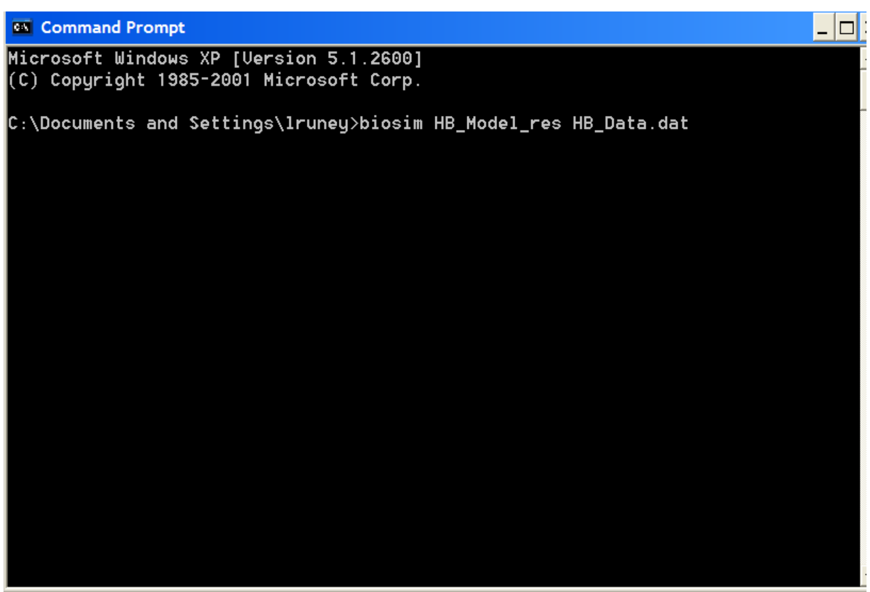


Figure 5-18: Execution of Biosim for the HB Trip Purpose MNL Model

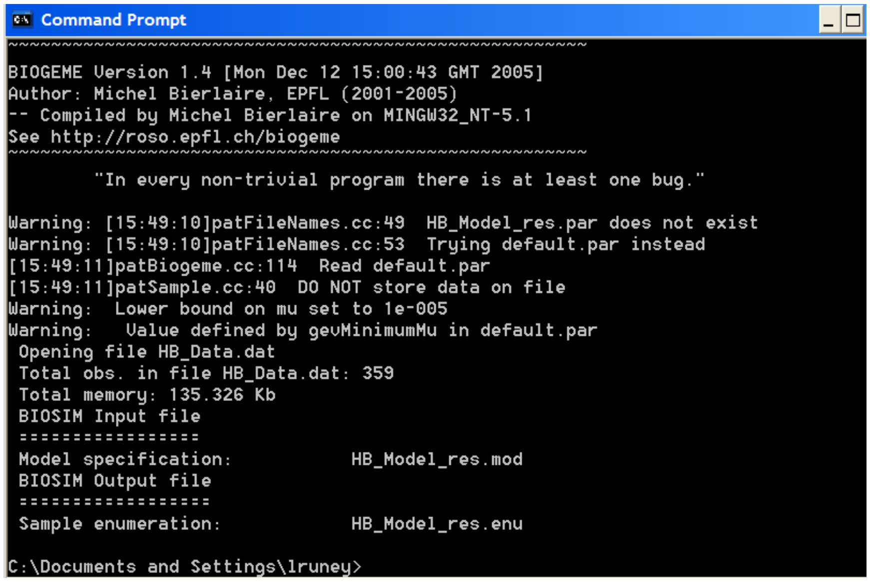


Figure 5-19: Results of Biosim Executable for the HB Trip Purpose MNL Model

22. The Biosim enumeration output file (.enu) contains the probabilities of each trip maker choosing their actual chosen SE group segment destination (**Appendix H**). The choice probabilities are based on the utility of the choice destination versus the aggregate utility of all available destinations for the trip maker. In this research, all choice destinations of a trip purpose are available for each trip maker of the trip purpose. The choice probability calculation of the MNL models is:

$$P_{ni}(i \mid J_p) = \frac{e^{U_{ni}}}{\sum_{j \in J_p} e^{U_j}} \tag{5-1}$$

where,

$P_{ni}(i \mid J_p)$ - Conditional probability of trip maker n choosing destination i from destination choice set J_p

U_{ni} - Utility of the choice destination i for trip maker n

U_j - Utility of destination j for trip maker n

J_p - Set of available destinations j for trip maker n

To get the overall SE group segment probabilities based on all the observations, the trip maker probabilities are averaged by SE group segment. The overall choice probabilities of trip interchanges between the RDU airport and the SE group segments is shown in **Table 5-23** by trip purpose.

Table 5-23: SE Group Segment Choice Probabilities by Trip Purpose

SE Group	SE Group Segment	Segment Specification (mINC is Median Income)	Estimated Probability
Income Level (HB)	1	mINC < $25,000	5%
	2	$25,000 ≤ mINC < $35,000	9%
	3	$35,000 ≤ mINC < $50,000	17%
	4	$50,000 ≤ mINC < $80,000	42%
	5	mINC ≥ $80,000	28%
Land Use Type & Travel Time to RDU (NHB)	1	Land use is SER	23%
	2	Land use is OFF & TT ≤ 21 min from RDU	32%
	3	Land use is OFF & TT >21 min from RDU	35%
	4	Land use is HWY & Ubeds	10%
Income Level & Travel Time to RDU (J-to-W)	1	mINC < $35,000	8%
	2	$35,000 ≤ mINC < $50,000 & TT < 25 min	18%
	3	$35,000 ≤ mINC < $50,000 & TT ≥ 25 min	15%
	4	$50,000 ≤ mINC < $80,000 & TT < 25 min	19%
	5	$50,000 ≤ mINC < $80,000 & TT ≥ 25 min	26%
	6	mINC ≥ $80,000	14%

Implications of the choice probabilities are that the RDU airport trip makers with a home trip end (HB and J-to-W) have a high probability of choosing a destination with a median household income between $50,000 and $80,000 and they are least likely to choose a destination with low median household income less than $35,000. The RDU airport trip makers with a non-home trip end (NHB) are least likely to choose a destination with high highway or university employment and most likely to choose a destination with high office employment. Furthermore, the destination probabilities are approximately the same for office employment locations that are greater than 21 minutes away from the RDU airport and that are less than 21 minutes from the RDU airport. Thus, the destination choice probability results reflect travel time to the RDU airport is not a major deterrent for airport trip makers.

23. To justify the IID assumption of the MNL model and that the MNL models are a good model fit of the observed data, the estimated MNL model destination choice probabilities are compared to the observed survey choice probabilities. The observed survey choice probabilities are the percent of total observations for each SE group segment obtained from the RDU airport survey data. **Table 5-24** shows the observed and predicted choice probabilities as well as the residuals (difference). A residual plot of the models (**Figure 5-20**) indicates that the predicted choice probabilities are independent and identically distributed.

Table 5-24: Observed and Predicted Choice Probabilities by Trip Purpose

SE Group	SE Group Segment	Observed Survey Probability	Predicted MNL Model Probability	Residual
Income Level (HB)	1	5%	5%	-0.43%
	2	8%	9%	-0.70%
	3	17%	17%	0.25%
	4	44%	42%	2.08%
	5	26%	28%	-1.20%
Land Use Type & Travel Time to RDU (NHB)	1	23%	23%	0.04%
	2	34%	32%	2.32%
	3	35%	35%	-0.20%
	4	8%	10%	-2.16%
Income Level & Travel Time to RDU (J-to-W)	1	10%	8%	1.75%
	2	17%	18%	-0.72%
	3	18%	15%	3.09%
	4	20%	19%	0.79%
	5	21%	26%	-4.49%
	6	14%	14%	-0.42%

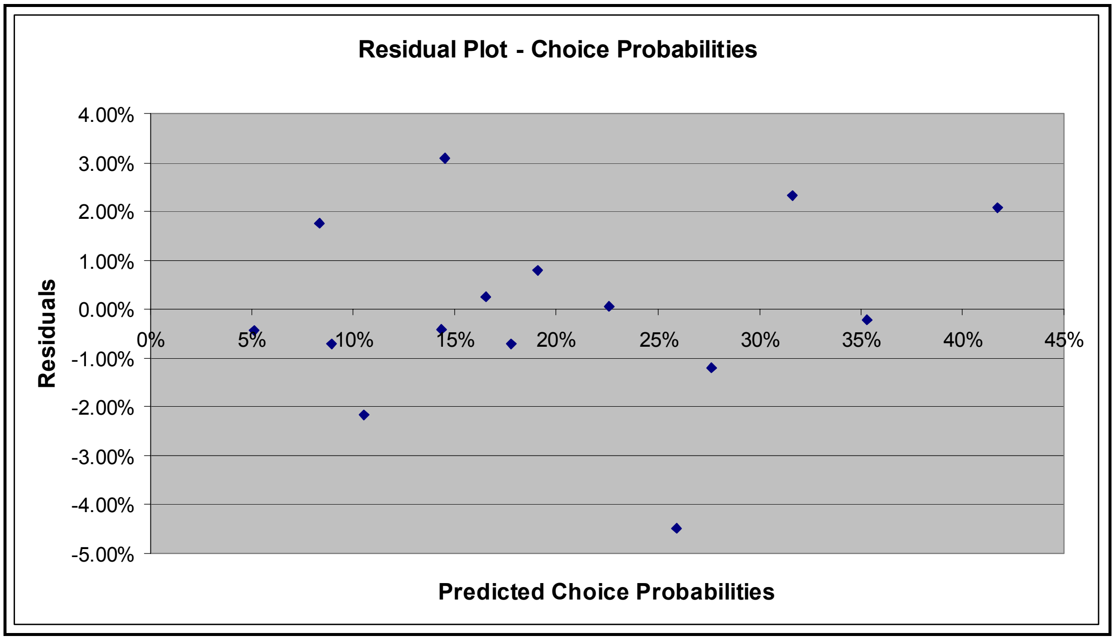


Figure 5-20: Residual Plot of the Predicted MNL Model Choice Probabilities

The plot shows that there is no obvious trend to the data points and that the residuals are contained in a horizontal band, meaning that the residuals have approximately the same variance. This shows that the data used for the model development complies with the assumption of the MNL model that the error components are independently and identically distributed.

Additionally, the IIA property of the MNL models is tested to verify the assumption that the relative probability of choosing between two destinations is unaffected by the inclusion or exclusion of additional choice destinations. The Hausman test proposed by Hausman and McFadden (1984) is used in this study to check for IIA. This test involves the comparison of the final MNL model parameter estimates using all choice destinations to the model estimates using one less choice destination. This study eliminates SE group segment destination 2 from each MNL model to verify that the parameters of these models are proportionally the same as those of the full MNL destination choice set models. The results from this test show that the IIA assumption is not significantly violated for the MNL models of homogeneous SE group segments. The household size parameter for the HB trip purpose and the SE group segment 6 for the J-to-W trip purpose have the most discrepancies between the parameter estimates, but in general the parameters of the models without SE group segment 2 choice destination (restricted models) are approximately the same as the parameters of the models with all destination choices (unrestricted models). **Table 5-25** shows the comparison of the two model parameters from the IIA test.

Table 5-25: IIA Test of the MNL Models

Trip Purpose	Characteristic	Abbreviation	Unrestricted Parameter Estimates	Restricted Parameter Estimates
HB	INC_1 Constant	ASC 1	fixed*	fixed*
	INC_3 Constant	ASC 3	0.5540	0.5803
	INC_4 Constant	ASC 4	0.9727	1.0000
	INC_5 Constant	ASC 5	-0.8618	-0.7912
	Households	HH	1.94E-06	1.77E-06
	Household Size	HS	0.1983	0.5148
	Household Income	INC	6.93E-06	5.71E-06
NHB	NHB_1 Constant	ASC 1	fixed*	fixed*
	NHB_3 Constant	ASC 3	-0.1355	-1.0000
	NHB_4 Constant	ASC 4	-1.0000	-1.0000
	Office Employment	OFF	1.61E-05	1.09E-05
	Total Employment	EMP	3.08E-06	4.81E-07
	Travel Time	TT	0.00859	0.00283
J-to-W	INC_1 Constant	ASC 1	fixed*	fixed*
	INC_3 Constant	ASC 3	-0.9994	-0.9417
	INC_4 Constant	ASC 4	0.8789	1.0000
	INC_5 Constant	ASC 5	-1.0000	-1.0000
	INC_6 Constant	ASC 6	-0.1441	0.2152
	Travel Time	TT	0.009337	0.0099715
	Households	HH	2.58E-05	2.91E-05
	Household Size	HS	-0.82385	-0.8616
	Household Income	INC	9.47E-06	7.79E-06

* Fixed Value at 1.0

Since the observed data satisfies the IID and IIA assumptions of the MNL models, the choice probabilities of the SE group segment destinations can be applied to the study area TAZs.

Application to the Study Area TAZs (using MS Excel)

24. Zonal relative attraction factors are applied to the SE group segment choice probabilities to estimate the probability of each TAZ in the TRM study area to be chosen by the RDU airport trip makers. A MS Excel worksheet is created for each trip purpose and the SE group segment probabilities are applied only to the TAZs corresponding to that SE group segment (**Appendix I**). These TAZs were specified in Step 7 of *MNL Model Data Setup*. The relative factor calculations by trip purpose are shown below.

$$\text{HB:}\quad Factor_{TAZ} = \frac{(Households + DwellingUnits)}{\sum(Households + DwellingUnits)} \tag{5-2}$$

$$\text{NHB:}\quad Factor_{TAZ} = \frac{(TotalEmployment)}{\sum(TotalEmployment)} \tag{5-3}$$

$$\text{J-to-W:}\quad Factor_{TAZ} = \frac{(Households + DwellingUnits)}{\sum(Households + DwellingUnits)} \tag{5-4}$$

Table 5-26 shows the average relative factor, average choice probability, and maximum choice probability of the TAZs available for each trip purpose. The TAZ choice probabilities sum equal the SE group segment choice probabilities, which the overall sum equals 100% by trip purpose. The factors and choice probabilities are small, but they are reasonable considering that there are 2,317 TAZs in the 2002XP TRM study area.

Table 5-26: Average TAZ Relative Factors and Choice Probabilities by Trip Purpose

Trip Type	Average TAZ Relative Factor	Average TAZ Choice Probability	Maximum TAZ Choice Probability
HB	0.00243	0.049%	0.71%
NHB	0.00226	0.056%	1.59%
J-to-W	0.00292	0.049%	0.81%

25. In the same MS Excel worksheet used in the previous step, the TAZ probabilities are applied to the corresponding person trips generated in the trip generation step of the RDU airport sub-model to determine the number of person trips per TAZ (**Appendix I**). The following columns are included in the MS Excel worksheets for each trip purpose. **Table 5-27** schematically shows the resulting person trips by trip purpose.

[TAZ] – The TAZ identification number

[HH + DU] – The number of households plus the number of dwelling units (for the HB and J-to-W trip purposes)

[EMP] – The number of total employment (for the NHB trip purpose)

[Level] – The SE group segment identification number

[Relative Factor] – The TAZ relative factor calculated as shown in Step 24

[SE Probability] – The estimated overall choice probability of the SE group segment (as shown in **Table 5-24**)

[TAZ Probability] – The relative TAZ choice probability (calculated by multiplying the SE group segment probability by the relative factor)

[TAZ Trips] – The number of RDU airport person trips by TAZ

$$T_{jp} = \overline{T}_p * \hat{\Pr}_{jp} \quad (5\text{-}5)$$

where,

T_{jp} - Number of person trips from zone j to RDU for trip purpose p

$\overline{T}_p$ - Generated trips of trip purpose p determined in trip generation of the RDU airport sub-model shown in **Table 5-6**

$\hat{\Pr}_{jp}$ - Relative TAZ probability of zone j being chosen by trip makers of trip purpose p

Table 5-27: RDU Airport Person Trips by Trip Purpose

TAZ	HB Total Person Trips	NHB Total Person Trips	J-to-W Total Person Trips	Total RDU Person Trips
1	0.00	18.90	0.00	18.90
2	0.00	7.17	0.00	7.17
3	0.00	7.56	0.00	7.56
4	0.00	11.89	0.00	11.89
5	0.00	5.28	0.00	5.28
6	0.00	0.00	0.00	0.00
7	6.36	0.21	1.07	7.64
8	0.09	0.88	0.01	0.98
9	0.78	0.00	0.12	0.90
10	0.00	0.62	0.00	0.62
11	0.34	0.07	0.13	0.53
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
2304	1.40	0.00	0.53	1.93
2305	1.54	0.00	0.58	2.12
2306	4.38	0.00	1.16	5.54
2307	4.09	0.30	1.56	5.95
2308	0.90	0.00	0.34	1.25
2309	1.75	0.00	0.46	2.21
2310	1.49	0.00	0.39	1.88
2311	10.67	3.26	2.83	16.76
2312	1.94	0.00	0.74	2.68
2313	1.78	0.31	0.68	2.76
2314	3.26	0.00	1.24	4.51
2315	0.78	0.00	0.30	1.07
2316	1.27	0.00	0.48	1.76
2317	1.96	0.00	0.75	2.71
TOTAL	10,057	7,283	2,866	20,206

The RDU airport person trips are compared to the 2002XP TRM estimates and to the ITE trip generation manual estimates of average weekday person trips. **Table 5-28** shows that the RDU airport sub-model estimates approximately 2,000 person trips higher than the 2002XP TRM and approximately 1,000 person trips higher than the ITE trip generation manual. This is logical because the RDU airport sub-model considers air passenger trips as well as airport employee trips and not just airport employees.

Table 5-28: Comparison of Total Person Trips

	2002XP TRM	RDU Sub-Model
Employment	3,800	1,433
Model Person Trips	18,250	20,200
ITE Person Trips*	50,900	19,200

*Based on a rate of 13.4 person trips per employee on an average weekday

26. Given that vehicle trips are modeled in the TRM, the TAZ person trips by trip purpose are converted to vehicle trips using vehicle occupancy factors (persons per vehicle). The occupancy factors are obtained from the observed survey data using the "Travel Method" and "Number of Companions" survey information. **Table 5-29** shows the occupancy factors by trip purpose. These factors seem reasonable because they are similar to those reported by and used in TRM surveys and models. The occupancy factors by trip purpose are then applied to the person trips by dividing the person trips by the corresponding occupancy factor. This results in vehicle trip interchanges between the RDU airport and the 2002XP TRM study area (**Appendix I**).

Table 5-29: Vehicle Occupancy Factors by Trip Purpose

Trip Purpose	Occupancy Factor (Persons per Vehicle)
HB	1.04
NHB	1.40
J-to-W	1.02

27. The RDU airport origin-destination (O-D) trips are obtained by assuming that the vehicle trip productions equal the vehicle trip attractions for each trip purpose. Therefore, the vehicle trip origins are assumed to equal half of the total vehicle trip interchanges and the vehicle trip destinations are assumed to equal half of the total vehicle trip interchanges. The O-D trip table represents a balanced table of daily vehicle trip interchanges between the RDU airport zone and all other TRM zones for each trip purpose (**Table 5-30**). The total O-D trip interchanges of the study area are calculated by summing the RDU daily vehicle trips for each trip purpose by TAZ (**Appendix I**).

Table 5-30: Daily RDU Airport Origin-Destination Vehicle Trip Table

TAZ	HB Vehicle Origins	HB Vehicle Destinations	NHB Vehicle Origins	NHB Vehicle Destinations	J-to-W Vehicle Origins	J-to-W Vehicle Destinations	Total Vehicle Origins	Total Vehicle Destinations
1	0.00	0.00	6.75	6.75	0.00	0.00	6.75	6.75
2	0.00	0.00	2.56	2.56	0.00	0.00	2.56	2.56
3	0.00	0.00	2.70	2.70	0.00	0.00	2.70	2.70
4	0.00	0.00	4.25	4.25	0.00	0.00	4.25	4.25
5	0.00	0.00	1.89	1.89	0.00	0.00	1.89	1.89
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	3.06	3.06	0.08	0.08	0.52	0.52	3.66	3.66
8	0.04	0.04	0.32	0.32	0.01	0.01	0.36	0.36
9	0.38	0.38	0.00	0.00	0.06	0.06	0.43	0.43
10	0.00	0.00	0.22	0.22	0.00	0.00	0.22	0.22
11	0.16	0.16	0.02	0.02	0.06	0.06	0.25	0.25
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
2304	0.67	0.67	0.00	0.00	0.26	0.26	0.93	0.93
2305	0.74	0.74	0.00	0.00	0.29	0.29	1.03	1.03
2306	2.10	2.10	0.00	0.00	0.57	0.57	2.67	2.67
2307	1.97	1.97	0.11	0.11	0.76	0.76	2.84	2.84
2308	0.43	0.43	0.00	0.00	0.17	0.17	0.60	0.60
2309	0.84	0.84	0.00	0.00	0.23	0.23	1.07	1.07
2310	0.72	0.72	0.00	0.00	0.19	0.19	0.91	0.91
2311	5.13	5.13	1.17	1.17	1.39	1.39	7.68	7.68
2312	0.93	0.93	0.00	0.00	0.36	0.36	1.30	1.30
2313	0.85	0.85	0.11	0.11	0.33	0.33	1.29	1.29
2314	1.57	1.57	0.00	0.00	0.61	0.61	2.18	2.18
2315	0.37	0.37	0.00	0.00	0.14	0.14	0.52	0.52
2316	0.61	0.61	0.00	0.00	0.24	0.24	0.85	0.85
2317	0.94	0.94	0.00	0.00	0.37	0.37	1.31	1.31
TOTAL	4,835	4,835	2,601	2,601	1,405	1,405	8,841	8,841

Trip Distribution Validation

Validation of the RDU airport sub-model trip distribution shows how reliable the MNL destination choice method is compared to the gravity method for trip distribution of the RDU airport trips and how well it replicates real-world travel conditions. Validation checks of the daily person trips and O-D vehicle trips are compared to the corresponding 2002XP TRM trips. Additionally, the 2002XP TRM is re-run with the RDU airport sub-model trip distribution results and the traffic assignments on the roadways in the vicinity of the RDU airport are compared to the year 2002 AADT counts and to the 2002XP TRM assignment estimates. The TRM Service Bureau provided all data files, expertise, and documentation associated with the Triangle Region study area. This data comes from the 2002XP TRM dated May 15, 2006 and it requires the TransCAD software to view and modify the files. The highway network geography includes road condition information as well as travel times and travel distances for each highway link. The five main comparison checks for validation between the RDU airport sub-model and the 2002XP TRM model include:

1. Daily Person Trips by Trip Purpose
2. Total O-D Vehicle Trip Interchanges
3. Desire Lines
4. Average Trip Length
5. Assignment Results versus AADT Counts

Daily Person Trips by Trip Purpose

The first validation check of the destination choice method for trip distribution of the RDU airport trips is to compare the daily person trip interchanges by trip purpose with those of the 2002XP TRM using the gravity method for trip distribution. **Table 5-31** shows the RDU airport sub-model and the 2002XP TRM person trips by trip purpose.

Table 5-31: RDU Airport Sub-Model and 2002XP TRM Person Trip Interchanges

RDU Sub-Model Trip Purpose	RDU Sub-Model Person Trips	2002XP TRM Trip Purpose	2002XP TRM Person Trips
HB	10,057	HBO	5,386
NHB	7,283	NHB	7,546
J-to-W	2,866	HBW	5,320
Total	**20,206**	**Total**	**18,252**

This table shows that the RDU airport sub-model estimates approximately 2,000 more person trips on an average weekday than the 2002XP TRM. The RDU airport sub-model air passenger trips with a non-home trip end are similar to the 2002XP TRM NHB trips for the RDU airport zone, but the RDU airport sub-model estimates lower airport employee trips and higher air passenger trips with a home trip end than the 2002XP TRM trip estimates of HBW and HBO, respectively. It is logical that the RDU airport sub-model shows higher air passenger trips than airport employee trips because more air passengers travel to the RDU airport on an average week day than airport employees.

Total O-D Vehicle Trip Interchanges

The total O-D vehicle trip interchanges of the RDU airport sub-model and the 2002XP TRM are compared. The total O-D trip table represents the sum of the daily vehicle trips by trip purpose between the RDU airport and the 2002XP TRM study area. **Table 5-32** displays a section of the total 2002XP TRM and RDU airport sub-model O-D trip interchanges compared by TAZ. This comparison shows that the 2002XP TRM has approximately 15,800 O-D trip interchanges and the RDU airport sub-model has approximately 17,700 O-D trip interchanges.

Table 5-32: 2002XP TRM and RDU Airport Sub-Model Vehicle Trip Interchanges

TAZ	2002XP TRM Total Vehicle O-D Trips	RDU Sub-Model Total Vehicle O-D Trips
1	9.00	13.50
2	3.00	5.12
3	3.00	5.40
4	7.00	8.49
5	2.00	3.77
6	0.00	0.00
7	0.00	7.31
8	3.00	0.73
9	1.00	0.87
10	2.00	0.44
11	0.00	0.50
12	0.00	1.30
13	0.00	0.52
14	0.00	0.12
15	0.00	0.25
16	6.00	2.16
17	3.00	2.98
.	.	.
.	.	.
.	.	.
.	.	.
.	.	.
.	.	.
2301	8.00	12.35
2302	1.00	1.40
2303	7.00	7.29
2304	4.00	1.87
2305	4.00	2.05
2306	7.00	5.35
2307	7.00	5.68
2308	4.00	1.20
2309	1.00	2.13
2310	2.00	1.82
2311	11.01	15.37
2312	3.00	2.59
2313	2.00	2.59
2314	8.01	4.36
2315	2.00	1.04
2316	2.00	1.70
2317	5.00	2.62
TOTAL	15,794	17,681

Additionally, the difference between the 2002XP TRM and RDU airport sub-model O-D trip interchanges is computed by TAZ. The maximum difference between the trip interchanges is the RDU zone (TAZ 1054). The 2002XP TRM estimates 2,144 intrazonal trips (trips that do not leave the RDU zone for another zone in the study area and do not drive on the highway network), whereas the RDU airport sub-model estimates 49 intrazonal trips for the RDU zone. The 49 intrazonal trips per day seem reasonable considering that there are no households in the RDU zone and there is no employment besides the RDU airport employment in the RDU zone. Without considering the RDU zone, the average difference of the TAZ trips in the study area is 1.72 trips higher for the RDU airport sub-model O-D trip interchanges than the 2002XP TRM O-D trip interchanges. **Table 5-33** lists the TAZs that have the largest difference of O-D trip interchanges. The locations of these TAZs are shown in **Figure 5-21**.

Table 5-33: Highest O-D Trip Interchange Difference

TAZ	2002XP TRM - RDU Sub-Model O-D Trips	TAZ	2002XP TRM - RDU Sub-Model O-D Trips
932	-56.44	410	214.74
302	-48.72	1061	129.61
1487	-47.84	1522	103.51
2270	-46.57	1069	103.29
1448	-44.02	409	99.01
388	-40.09	1524	93.70
1806	-36.94	1513	83.39
523	-33.73	1065	78.93
1613	-33.28	1062	77.72
1672	-33.18	1771	74.13

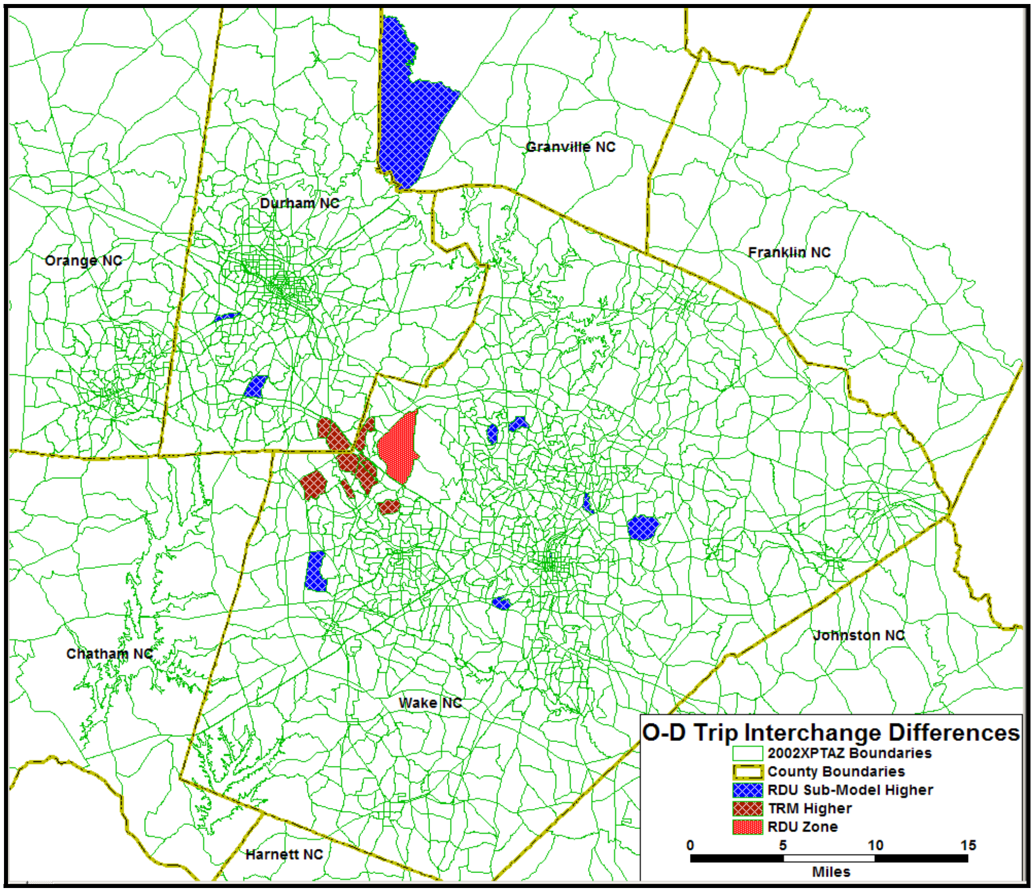


Figure 5-21: TAZ Locations of the Highest O-D Trip Interchange Differences

This figure shows that the TRM model estimates more O-D trip interchanges with locations closer to the RDU airport zone, whereas the RDU airport sub-model estimates more O-D trip interchanges scattered across the study area. One reason that the 2002XP TRM estimates more trips closer to the airport is due to the gravity model attracting more trips to locations closer to the RDU zone and to locations with high employment. The area where the TRM is much higher than the RDU airport sub-model is just southeast of RTP. The zones where the RDU airport sub-model trips are higher than the 2002XP TRM have either high total housing units or total employment.

Desire Lines

The RDU airport O-D trip table is converted from MS Excel table format to TransCAD matrix format so that further comparisons can be made using the TransCAD software. Desire lines of major trip interchanges between the RDU airport zone and other zones in the study area are compared for the RDU airport sub-model and the 2002XP TRM trip estimates. **Figure 5-22** and **Figure 5-23** compare the two models using desire lines that have greater than 10 trips per day and greater than 30 trips per day. Thicker desire lines reflect a larger number of trip interchanges between that zone and the RDU airport zone. This comparison shows that the RDU airport sub-model estimates more zones that have greater than 10 trip interchanges with the RDU airport zone per day and less zones that have greater than 30 trip interchanges with the RDU airport zone per day. This seems practical since few zones generate a large number of airport trips on an average weekday. Additionally, the desire line figures show that the RDU airport sub-model trips are scattered throughout the study area whereas the 2002XP TRM desire lines are closer to the RDU airport zone (shorter travel time and travel distances) and more clustered (high attraction areas).

Furthermore, the figures show that the TRM does a better job in predicting trips to and from RTP, which is close to the RDU airport and has a large amount of employment. The RDU airport sub-model predicts greater than 30 trip interchanges per day from the RTP area as well as from Granville County in the area of Butner, NC and Stem, NC. One reason for the large number of trips to Granville County is that this TAZ is very large and completely covers both the cities of Butner, NC and Stem, NC. Therefore, the TAZ has a large number of households, dwelling units, and employment in the zone including the

Butner-Stem Central School and the John Umstead Hospital. The hospital serves 16 counties in North Carolina and it may be the high attractor of airport trips to this zone.

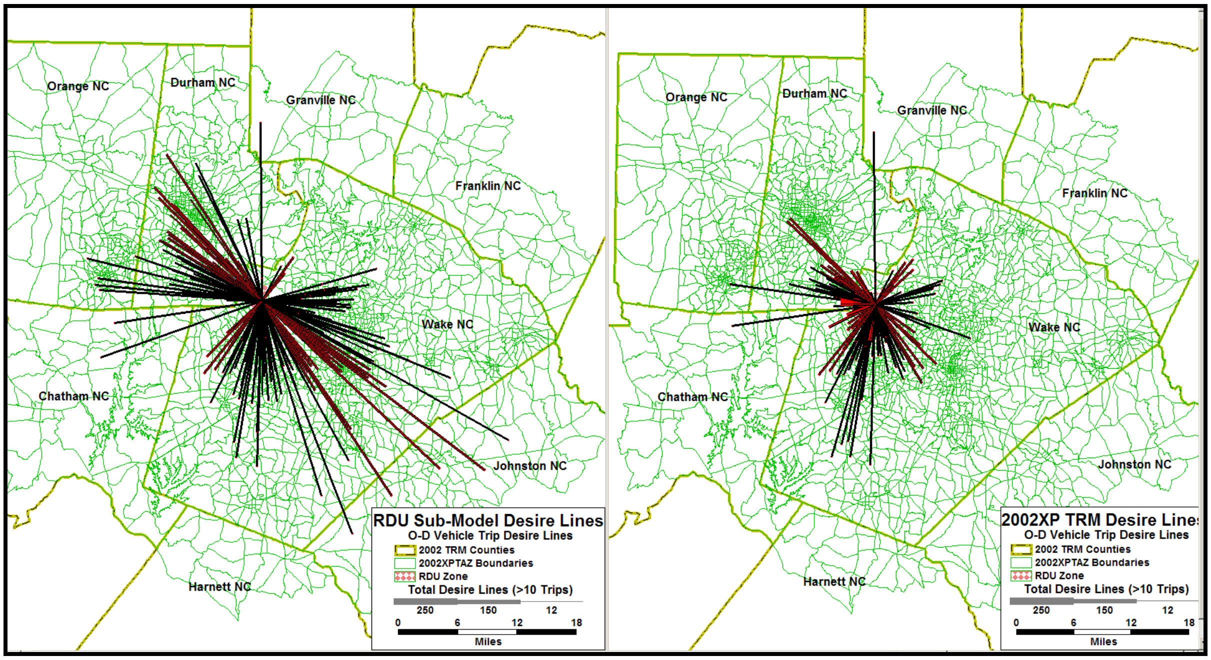


Figure 5-22: RDU Airport Desire Lines with Greater Than 10 Trips per Day

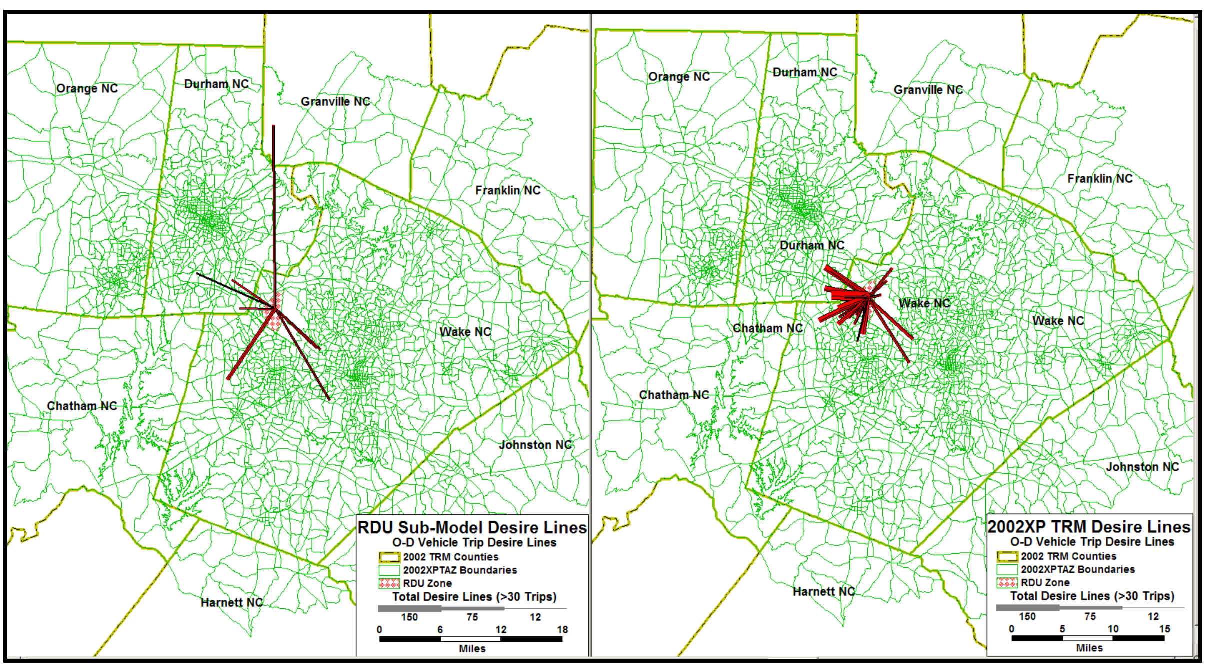


Figure 5-23: RDU Airport Desire Lines with Greater Than 30 Trips per Day

Average Trip Length

The RDU airport sub-model average trip lengths in minutes and in miles are compared to those of the 2002XP TRM (**Table 5-34**). The average trip length is an average of the travel time or travel distance between the RDU zone and all other zones in the study area. Both time and distance are based on an impedance matrix of free flow travel time and travel distance. The same travel impedance matrix is used for both the RDU airport sub-model and the 2002XP TRM.

Table 5-34: RDU Airport Sub-Model and 2002XP TRM Average Trip Lengths

	RDU Sub-Model Travel Time	2002XP TRM Travel Time	RDU Sub-Model Travel Distance	2002XP TRM Travel Distance
Min Trip Length	8.69	8.69	1.42	1.42
Max Trip Length	59.74	59.94	50.93	50.93
Average Trip Length	29.92	23.98	20.04	13.35

The trip length distributions show that the RDU airport sub-model estimates a higher average travel time (+ 5.94 minutes) and average travel distance (+ 6.69 miles) to the RDU airport than the 2002XP TRM. This is logical because the RDU airport is the only major commercial airport in the Triangle Region and trip makers tend to travel farther for airport trips than non-airport trips such as shopping trips.

Assignment Results versus AADT Counts

The final validation check performed in this study compares the RDU airport sub-model traffic assignment results with the 2002 AADT counts. This comparison shows how well the sub-model assignment results fit the observed traffic conditions in the vicinity of the

RDU airport as well as the Triangle Region. These results are also compared to the 2002XP TRM traffic assignment results. However, this is an initial assignment check of the RDU airport sub-model trips. The 2002XP TRM (version May 15th 2006) has been calibrated for the gravity method trip distribution trip estimates, but no calibration has been performed with the updated RDU airport sub-model trip distribution trip estimates for traffic assignment.

The RDU airport sub-model assignment is estimated using the 2002XP TRM assignment procedure. The same input files are used for the RDU airport sub-model assignment except that the RDU zone O-D vehicle trip interchanges are replaced with the RDU airport sub-model O-D vehicle trip interchanges. The 2002XP TRM estimates trips by low occupancy vehicles (≤ 2 persons per vehicle) and high occupancy vehicles (≥ 3 persons per vehicle) as well as by time of day (AM, PM, and off peak) and direction ("to home" and "from home"). Because the RDU airport trips have vehicle occupancy factors less than two, all the RDU O-D trip interchanges are assumed to be low occupancy vehicle trips. The three time of day periods in the 2002XP TRM are (1) the AM peak from 7:00AM to 9:00AM, (2) the PM peak from 3:00PM to 7:00PM and (3) the off peak representing all other hours of the day. The time of day and directional split factors used in the 2002XP TRM for HBO and NHB trips are assumed to be the same for the HB and NHB trips of the RDU airport sub-model, respectively. This assumption is made because of lack of data to indicate other time of day factors for air passengers. However, the TRM HBW time of day and directional split factors are modified for the J-to-W trip purpose of the RDU airport sub-model. Modifications are made for the J-to-W trip purpose because the RDU Airport Authority reports that airport employees have different work schedules than most workplaces. Approximately one-third of the RDU airport employees work normal work hours between 8:00AM and 5:00PM and approximately two-thirds of the RDU airport employees work in shifts that have a mid-day shift change varying between 12:30PM and 2:30PM on an average weekday. **Table 5-35** shows the RDU airport sub-model time of day and directional split factors.

Table 5-35: RDU Airport Sub-Model Time of Day and Directional Split Factors

Type	Direction	AM Peak	PM Peak	Off Peak	*Total Daily*	*Total*
HB	From Home	0.135	0.148	0.226	*0.510*	
	To Home	0.014	0.207	0.269	*0.490*	*1*
NHB	N/A	0.100	0.299	0.601	*1*	*1*
J-to-W	From Home	0.151	0.015	0.337	*0.503*	
	To Home	0.015	0.153	0.329	*0.497*	*1*

After the RDU airport sub-model O-D vehicle trips are split by time of day and direction for each trip purpose (resulting in nine O-D trip matrices), the O-D trips are summed together by time of day (resulting in three O-D trip matrices). These three matrices of the RDU airport O-D trips by time of day replace the O-D vehicle trips in the 2002XP TRM for the RDU airport zone. The total trips by time of day are shown in **Table 5-36** for the RDU airport sub-model and for the 2002XP TRM. The RDU airport sub-model estimates most of the trips to be made in the off peak hours and less than 15% of the trips to be made in the AM peak hours. On the other hand, the 2002XP TRM estimates less than 20% of the trips to be made in the off peak and the majority of the trips to be made in the PM and AM peak hours. The high number of trips in the off peak is reasonable for the following reasons: (1) the RDU airport is a major airport with flights arriving and departing constantly throughout the day, (2) most of the airport employee trips are made in the off peak hours at shift change between 12:30PM and 2:30PM, and (3) the ITE trip manual confirms that the weekday peak hours are from 11:00AM to 12:00PM and from 5:00PM to 7:00PM for a commercial airport (ITE, 2003), which are time periods in the off peak and PM peak of the TRM.

Table 5-36: Total O-D Vehicle Trips by Time of Day

Time of Day	RDU Sub-Model O-D Trips	2002XP TRM O-D Trips
AM	2,437	5,374
PM	5,460	7,720
OP	9,784	2,706
Daily Trips	17,681	15,800

The resulting traffic assignment volumes using the RDU airport sub-model O-D trips are shown in **Figure 5-24.** The figure shows the RDU airport sub-model daily vehicle trips compared to the 2002 AADT counts and to the 2002XP TRM assignment results. Additionally, this information is provided in tabular format in **Table 5-37**. For each TRM network link with 2002 AADT count, the following three volumes are displayed:

1. 2002 AADT Count
2. RDU Airport Sub-Model Assignment
3. TRM Assignment

This assignment comparison helps to determine how well the MNL model destination choice method used in trip distribution matches the observed traffic conditions in the year 2002. The AADT counts are obtained from the 2002XP TRM calibration files and from the NC Department of Transportation.

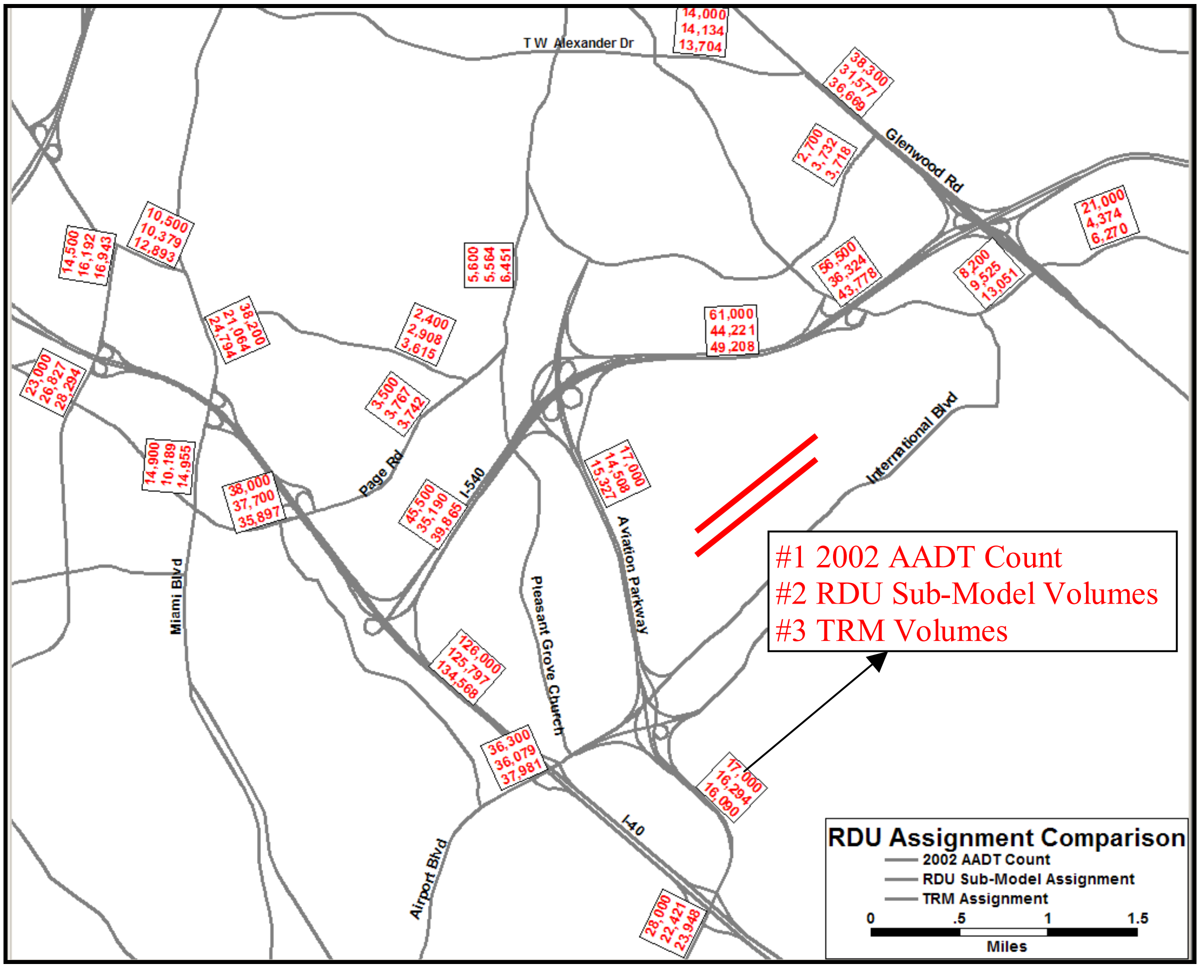


Figure 5-24: Assignment Results of the RDU Airport Sub-Model

The assigned volumes show that in general the RDU airport sub-model assignments are low compared to the observed counts and they are low compared to the 2002XP TRM, especially on the interstate roadways. Additionally, the root mean square error of the RDU airport sub-model traffic assignments and the 2002XP TRM traffic assignments compared to the observed traffic counts in year 2002 are shown in **Table 5-38**. The RDU airport sub-model underestimates daily traffic and has a higher percent error than the 2002XP TRM both in the vicinity of the RDU airport and in the entire Triangle Region.

Table 5-37: Assignment Results Compared to 2002 AADT

Road Name	Functional Classification	2-way 2002 AADT	RDU Sub-Model 2-way Volume	TRM 2-Way Volume
Airport Blvd: Bw I-40 & Pleasant Grove Ch	13	21,000	13,820	14,856
Airport Blvd: Bw I-40 & Slater Rd	16	36,300	36,079	37,981
Aviation Pkway: W of Glenwood Rd	14	8,200	9,525	13,051
Aviation Pkwy: Bw I-40 & Airport Blvd	14	17,000	16,294	16,090
Aviation Pkwy: Bw I-540 & Nelson Rd	11	17,000	14,508	15,327
Aviation Pkwy: W of I-40	14	28,000	22,421	23,948
Brier Creek Pkwy: Bw US 70 & Lumley Rd	16	2,700	3,732	3,718
Chin Page Rd: Bw Page Rd & Miami Blvd	16	2,400	2,908	3,615
Cornwallis Rd: Bw David Rd & Miami	14	10,500	10,379	12,893
Davis Dr: Bw Cornwallis & I-40	15	14,500	16,192	16,943
Davis Dr: Bw I-40 & Hwy 54	15	23,000	26,827	28,294
I-40: Bw Airport Blvd & I-540	11	126,000	125,797	134,568
I-40: S of Aviation Pkwy	11	131,000	125,147	135,409
I-540: Bw Aviation Pkwy & Lumley Rd	11	61,000	44,221	49,208
I-540: Bw I-40 & Aviation Pkwy	11	45,500	35,190	39,865
I-540: Bw Lumley Rd and Glenwood Rd	11	56,500	36,324	43,778
Miami Blvd: Bw I-40 & Chin Page Rd	14	38,200	21,064	24,794
Miami Blvd: Bw I-40 & Page Rd	14	14,900	10,189	14,955
Page Rd: Bw Airport Rd & Brier Creek Pkw	15	5,600	5,564	6,451
Page Rd: Bw Chin Page & I-40	15	3,500	3,767	3,742
Page Rd: Bw I-40 & Miami Blvd	16	38,000	37,700	35,897
Southern Pkwy: Bw US 70 & Lumley Rd	15	14,000	14,134	13,704
US 70: Bw BrierCreek & Southern Pkwy	13	38,300	31,577	36,669
Westgate Rd: E of Glenwood Rd	13	21,000	4,374	6,270

Table 5-38: Root Mean Square Error Comparison

	RDU Study Area		2002XP TRM Study Area	
	RDU Sub-Model	2002XP TRM	RDU Sub-Model	2002XP TRM
Number of Counts	24	24	1275	1275
RMSE	26%	20%	85%	81%
Sum of Counts	774,100	774,100	20,657,215	20,657,215
Sum of Flows	667,733	732,026	14,845,809	15,350,474
% Flow / Count	-12.70%	-5.44%	-28.13%	-25.69%

One reason for the lower volumes is that the time of day factors and directional split for the RDU airport sub-model trips may be incorrect. Additional data is required to confirm these assumptions. Another reason for the lower volumes is that the external trips of the RDU airport may not be reflected properly in the trip distribution and traffic assignment of this study. The RDU airport external trip estimation is not in the scope of this study. The external stations do not have zonal data to link the airport trip makers to the destinations using a MNL destination choice model. Furthermore, it is assumed that the 2002XP TRM external-internal trip rates developed from the *1997 Triangle Origin-Destination Survey Report* represented the RDU airport trip interchanges between the RDU airport zone and the TRM external stations (72 external stations). Further review of the TRM external-internal trip matrix generated for the RDU airport zone show that the TRM estimates approximately 40 external-internal trips per day to the RDU airport. This number is low when compared to the RDU Airport Authority and the observed RDU air passenger survey estimates of external-internal trips. These data sources approximate 20 percent (4,000 trips per day) of the RDU air passenger trips to be external-internal trips. Thus, it is practical for the ground counts to be higher than the RDU airport sub-model assignments since the airport external-internal trips are not included in the RDU airport sub-model assignment. Further analysis is recommended for the external-internal trips of the RDU airport.

Summary

Chapter 5 develops, calibrates, and validates a destination choice model for trip distribution of the Raleigh-Durham International Airport. The resulting DCM model summary highlights that observed data constraints can cause difficulty in estimating a DCM when the sample size per destination is less than 30 observations. The resulting MNL models developed for the RDU airport trip distribution do not have high adjusted Rho-square values (not greater than 0.3) and not all of the estimated MNL utility parameters are statistically significant from zero at 80% confidence. However, the resulting choice probabilities are reasonable that the HB and J-to-W RDU airport trip makers are most likely to have a non-airport trip end at destinations of mid-level income and the NHB RDU airport air passengers are most likely to have a non-airport trip end at destinations of high office employment.

The DCM was applied to the RDU airport case and compared to the TRM gravity model for trip distribution. The RDU airport trips were generated by trip purpose and the MNL models were developed and calibrated to best fit the relationship between RDU trip makers and the SE group destinations by trip purpose. Next, the destination choice probabilities were estimated by SE group segment and applied to the corresponding TAZs of the 2002XP TRM study area. Then, the TAZ person trips and vehicle trip interchanges were determined and compared to the 2002XP TRM person and vehicle trips. Finally, the trip interchanges were incorporated into the TRM, the TRM was re-run with the RDU airport sub-model O-D trips, and the assignment results were compared with year 2002 AADT counts.

The resulting DCM and gravity method comparison of trips highlights that the RDU airport sub-model distributes trips farther away in travel time and travel distance from the RDU airport zone and more scattered throughout the study area than the TRM trip distribution. Additionally, the resulting initial assignment of the RDU airport sub-model trips show that the volumes are low compared to the year 2002 AADT counts. However, additional adjustments and calibration of the time of day and directional split factors for the airport O-D trip matrix as well as consideration of external-internal RDU airport trips is required to calibrate the RDU sub-model traffic assignment. Once the model assignment is calibrated and validated, the model results can be used for decision-making purposes with confidence. Chapter 6 provides conclusions and recommendations for future work.

CHAPTER 6 – CONCLUSION AND RECOMMENDATIONS

Until recently, most urban areas in the U.S. used gravity models for distributing trips in the four-step travel demand model. However, destination choice models are now being to be accepted as a state of the art alternative to gravity models due to their ability to simultaneously model the effects of personal and socio-economic characteristics on travel behavior. The MMNL destination choice model was determined not to be a good model for this study due to the available data not conforming to the complexity of the MMNL model. The MNL destination choice model was chosen for trip distribution of the RDU airport trips in this study. The MNL model is less cumbersome to apply and relatively simple, while at the same time equivalent to the MMNL model in both goodness-to-fit and predictive accuracy (Gopinath et al., 2005). The following sections of this chapter summarize the findings of this research and discuss recommendations for future work.

Summary of Findings

The development of the RDU airport sub-model using a MNL destination choice model for trip distribution has been presented and compared to the 2002XP TRM gravity model method for trip distribution. The data needed to develop the RDU airport sub-model were: (1) RDU airport survey data, RDU airport activity data, and TRM zonal data for development of the MNL models for the HB, NHB, and J-to-W trip purposes, (2) the Biogeme software to estimate the MNL model parameters and choice probabilities for each SE group segment destination of each trip purpose, and (3) MS Excel and TransCAD software to determine the RDU airport person and vehicle trip interchanges by TAZ and to compare them to the corresponding 2002XP TRM trips. The main findings from the MNL destination choice method are discussed below.

Generated Trips

The trips generated for the RDU airport sub-model were developed using easily accessible information from the RDU Airport Authority. Historic data of the RDU airport were evaluated to determine the impact of the 9-11 terrorist attack on the RDU airport activity. The year 2002 RDU airport activity data did not have a noticeable effect of the attack. The RDU airport sub-model generated approximately 20,200 person trips per day in year 2002, which are 2,000 trips more than the 2002XP TRM estimates. The RDU airport sub-model trips seem reasonable since they include airport employee and air passenger trips, whereas the 2002XP only considers airport employees as the explanatory model variable. Additionally, the generated trips of the RDU airport sub-model are close to the ITE Trip Generation Manual estimates of 19,200 person trips based on the model variable of 1,433 airport employees in year 2002.

Survey Data

The survey data of the RDU airport was the most challenging component of the RDU airport sub-model. Most likely, this was because the RDU airport surveys were intended for rail forecasts to the RDU airport and not for destination choice trip distribution of RDU airport trips. The survey data cleaning and formatting were meticulous and very time consuming. The observed dataset had to be checked thoroughly and all observations with incomplete data such as missing explanatory variables or unidentifiable destination locations and with destinations external to the study area were removed from the dataset. Additionally, all of the observed destinations had to be geocoded to the 2002XP TRM zones in TransCAD. The TransCAD software provides a geocoding tool to facilitate the geocoding process using zip code and street address data but several of the observed records were not located by the TransCAD software. Consequently, these observed destinations had to be manually geocoded using local knowledge, TRM geographic street layer files, and the Google Earth software.

The resulting sample size of the survey data, after data cleaning and removal of outlying observations, was 860 observations; a small number in comparison to the 2,317 possible study area TAZ destinations (**Table 6-1**). Given that there are 2,317 possible 2002XP TRM destinations; this sample size by trip purpose does not reflect ample data to statistically estimate the MNL models at the TAZ destination level. The recommended survey sample size (50,000 for TAZ destination level and 1,800 for the SE group segment destination level) for the RDU airport trip distribution is discussed in the "Recommendations for Future Work" section of this chapter.

Table 6-1: Survey Sample Size for MNL Model Estimation

Number of Observations	**Air Passengers**		**Airport Employees**	**Total Airport Observations**
	HB	**NHB**	**J-to-W**	
Original	1,525		523	2,048
Data Complete	460	244	411	1,115
Complete Internal	359	202	374	935
Without Outliers	**340**	**168**	**352**	**860**

This research found that aggregating the zonal destinations to the SE group segment destination level provided a means to estimate the MNL models with more statistical significance. The SE group segment specifications of deciding which market group, how many segments, and what segment bounds to use were determined using guidelines and definitions from the TRM. The observed survey data and study area TAZs were linked to the corresponding SE group segments and the MNL model data files were formatted to reflect SE group segment destination data. Results from the SE group segment aggregation provided a sample size of thirty or more for all SE group segments except the HB SE group segments 1 and 2 and the NHB SE group segment 4. Therefore, the observed data characteristics of these destinations were tested for normal distribution using “Q-Q” plots. If the normal distributions were not met, then interaction or log transformations of the data characteristics were tested. Results from the “Q-Q” plots show that the HB characteristics follow a normal distribution and the transformations of the NHB characteristics of service and office employment data follow a normal distribution. However, the NHB other (industry and retail) employment characteristic does not follow a normal distribution and can not to be used in the MNL model estimation.

Utility Model Function

Estimating the MNL utility model form (linear or non-linear) and parameters was the second most difficult task of the RDU airport sub-model. This was a continuous process of developing the MNL model and data files according to the Biogeme specifications, executing the Biogeme program, evaluating the goodness-to-fit and statistical results, and revising the MNL models. The model and data files were converted from MS Excel format to Biogeme format and closely reviewed in TextPad to ensure that all data were correctly converted and that no data were lost or truncated in the process. The Biogeme program was easily executed, but the backwards elimination stepwise process of calibrating the utility function was very redundant. The calibrated MNL models from this process show that the goodness-to-fit tests (the log-likelihood ratio test compared to the critical Chi-square test statistic) were satisfied at 95% confidence, but the adjusted Rho-square values were low and some of the parameter t-values were not significant at 80% confidence (**Table 6-2**). Reasons for the low statistics could be due to the low sample size per destination, corrupted data, or incorrect market groups used for the SE group segment destinations. The MNL model utility functions are shown in **Table 6-3**.

Table 6-2: Statistics of the MNL Models

Trip Purpose	Final Log-Likelihood	Log-Likelihood Ratio Test	Adjusted Rho square	Number of Parameters
HB	-454.91	184.55	0.16	7
NHB	-192.12	81.56	0.15	6
J-to-W	-491.12	279.16	0.21	9

Table 6-3: MNL Model Utility Functions

Trip Purpose	Utility Function
HB	$ASC + \beta_{HH}(HH_{SE} * HH_{TAZ}) + \beta_{HS}(HHS_{SE} * HS) + \beta_{INC}(mINC_{SE} * INC)$
NHB	$ASC + \beta_{OFF}(OFF_{SE} * OFF_{TAZ}) + \beta_{EMP}(EMP_{SE} * EMP_{TAZ}) + \beta_{TT}(TT_{SE} * TT_{TAZ})$
J-to-W	$ASC + \beta_{TT}(TT_{SE} * TT_{TAZ}) + \beta_{HH}(HH_{SE} * HH_{TAZ}) + \beta_{HS}(HHS_{SE} * HS) + \beta_{INC}(mINC_{SE} * INC)$

Even though some of the models are not statistically satisfactory, the explanatory destination and trip maker variables and the corresponding estimated parameters of the MNL models seem logical. The HB model shows that household size (HHS) influences home based air passenger trips to the RDU airport and that those air passengers with a median household income (mINC) between \$50,000 and \$80,000 are most likely to travel to the airport on an average weekday. The NHB model shows that office employment (OFF) and travel time (TT) to the RDU airport effect the RDU air passenger's traveling from non-home destination and that those destinations with high office employment are most likely to have airport trips. The J-to-W model shows that household size and travel time to the RDU airport influence the home destinations of the RDU airport employees and that those employees with a median household income between \$50,000 and \$80,000 are most likely to work at the airport. A significant finding from the MNL model parameters is that travel time affects the RDU airport trip makers opposite to how the gravity model assumes that travel time affects trip makers. The MNL model destination choice method predicts that more trips are attracted to destinations farther away from the RDU airport in travel time where as the gravity model method predicts more trips attracted to destinations closer to the RDU airport in travel time. The longer travel time trips to the RDU airport are reasonable considering that the RDU airport is the only major airport in the Triangle Region.

MNL Model Choice Probabilities and Model Validation

The MNL model choice probabilities of trip makers choosing their observed destination were easily estimated using the Biosim application of the Biogeme software, and the overall SE group segment choice probabilities were easily determined using MS Excel. The resulting choice probabilities were verified against the observed choice probabilities using a residual plot and they were confirmed to follow the IID assumption of the MNL model. Additionally, the IIA property of the MNL models was tested to verify the assumption that the relative probability of choosing between two destinations is unaffected by the inclusion or exclusion of additional choice destinations. The Hausman test proposed by Hausman and McFadden (1984) was used in this study to check for IIA. The results from this test show that the IIA assumption is not significantly violated for the MNL models of homogeneous SE group segments. The overall SE group segment choice probabilities are shown in **Table 6-4**.

Table 6-4: Overall SE Group Segment Choice Probabilities

SE Group	**SE Group Segment**	**Segment Specification** (mINC is Median Income)	**Estimated Probability**
Income Level (HB)	1	mINC < \$25,000	5%
	2	\$25,000 ≤ mINC < \$35,000	9%
	3	\$35,000 ≤ mINC < \$50,000	17%
	4	\$50,000 ≤ mINC < \$80,000	42%
	5	mINC ≥ \$80,000	28%
Land Use Type & Travel Time to RDU (NHB)	1	Land use is SER	23%
	2	Land use is OFF & TT ≤ 21 min from RDU	32%
	3	Land use is OFF & TT >21 min from RDU	35%
	4	Land use is HWY & Ubeds	10%
Income Level & Travel Time to RDU (J-to-W)	1	mINC < \$35,000	8%
	2	\$35,000 ≤ mINC < \$50,000 & TT < 25 min	18%
	3	\$35,000 ≤ mINC < \$50,000 & TT ≥ 25 min	15%
	4	\$50,000 ≤ mINC < \$80,000 & TT < 25 min	19%
	5	\$50,000 ≤ mINC < \$80,000 & TT ≥ 25 min	26%
	6	mINC ≥ \$80,000	14%

The HB destination choice probabilities show that HB air passengers are most likely to choose a destination with a median household income between \$50,000 and \$80,000 and least likely to choose a destination with a median household income of less than \$25,000. The NHB destination choice probabilities show that NHB air passengers are most likely to choose a destination with high office employment and least likely to choose a destination with high highway or university employment. The J-to-W destination choice probabilities show that the airport employees are most likely to choose a destination with a median household income between $50,000 and $80,000 and least likely to choose a destination with a median household income of less than $35,000.

Person Trips

The overall destination choice probabilities were easily applied to the 2002XP TRM TAZs using a relative attraction factor of the number of households and dwelling units for the HB and J-to-W trip purposes and the amount of total employment for the NHB trip purpose. The resulting average and maximum TAZ destination choice probabilities by trip purpose are shown in **Table 6-5**. The TAZ destination choice probabilities seem reasonable considering the large number of TAZs in the 2002XP TRM study area.

Table 6-5: TAZ Destination Choice Probabilities

Trip Type	Average TAZ Choice Probability	Maximum TAZ Choice Probability
HB	0.049%	0.71%
NHB	0.056%	1.59%
J-to-W	0.049%	0.81%

The TAZ destination choice probabilities were applied to the trips generated for the RDU airport sub-model and the person trips by trip purpose were compared to the corresponding 2002XP TRM person trips (**Table 6-6**). This table shows that the RDU airport sub-model estimates approximately 2,000 more person trips on an average weekday than the 2002XP TRM. The RDU airport sub-model and the 2002XP TRM have similar air passenger trips with a non-home trip end, but the RDU airport sub-model estimates lower airport employee trips and higher air passenger trips with a home trip end than the 2002XP TRM. It is logical that the RDU airport sub-model predicts higher air passenger trips than airport employee trips because more air passengers travel to the RDU airport on an average weekday than airport employees.

Table 6-6: Total Person Trips

RDU Sub-Model Trip Purpose	RDU Sub-Model Person Trips	2002XP TRM Trip Purpose	2002XP TRM Person Trips
HB	10,057	HBO	5,386
NHB	7,283	NHB	7,546
J-to-W	2,866	HBW	5,320
Total	**20,206**	**Total**	**18,252**

Vehicle Trips

The person trips by TAZ were converted to vehicle trips by TAZ using vehicle occupancy factors developed from the observed data and compared to the 2002XP TRM vehicle trips. The TAZ with the largest difference in vehicle trips was the RDU airport zone. The 2002XP TRM predicts 2,144 intrazonal trips (trips that do not leave the RDU airport zone for another zone in the study area and do not drive on the highway network) whereas the RDU airport sub-model estimates 49 intrazonal trips for the RDU airport zone. The 49 intrazonal trips per day seem reasonable considering that there are no households in the RDU airport zone and there is no other employment besides the RDU airport employment in the RDU airport zone.

Another significant difference in the predicted vehicle trips is that the RDU airport sub-model distributes more trips to destinations that are further away from the RDU airport in travel time and travel distance and more scattered throughout the study area than the 2002XP TRM gravity model distribution. The distribution comparison between the two models can be seen in **Figure 6-1** of desire lines between the RDU airport zone and other zones in the study area for trips greater than 10 per day as well as in **Table 6-7** of the average trip length distributions for the RDU airport trips.

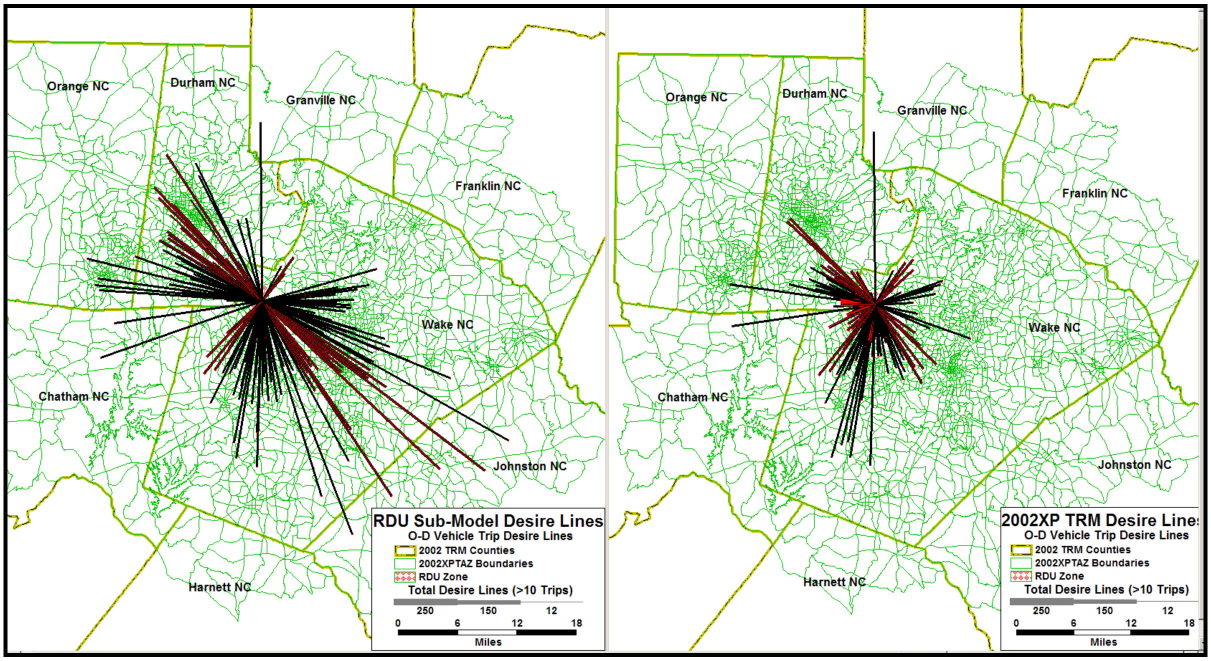


Figure 6-1: Desire Lines of the RDU Airport Trips Greater than 10 per Day

Table 6-7: Average Trip Length Distribution of RDU Airport Trips

	RDU Sub-Model Travel Time	2002XP TRM Travel Time	RDU Sub-Model Travel Distance	2002XP TRM Travel Distance
Min Trip Length	8.69	8.69	1.42	1.42
Max Trip Length	59.74	59.94	50.93	50.93
Average Trip Length	29.92	23.98	20.04	13.35

The trip length distributions show that the RDU airport sub-model distributes trips with a higher average travel time (+ 5.94 minutes) and average travel distance (+ 6.69 miles) to the RDU airport than the 2002XP TRM trip distribution. This is reasonable since the RDU airport is the only major commercial airport in the Triangle Region and trip makers tend to travel farther for airport trips than non-airport trips such as shopping trips.

Traffic Assignment

The RDU airport sub-model O-D vehicle trip interchanges were incorporated into the 2002XP TRM by adjusting the trip table for high and low occupancy vehicles, time of day, directional splits. Because traffic assignment was not the focus of this research, the task of determining the split factors was challenging, subjective, and lacked concrete data. Overall, the assigned volumes show that the RDU airport sub-model assignments are low compared to the observed counts; and they are low compared to the 2002XP TRM, especially on the interstate roadways. **Table 6-8** presents the difference between the estimated traffic volumes and the observed traffic counts for the RDU airport vicinity and for the entire 2002XP TRM study area.

Table 6-8: Root Mean Square Error of the RDU Airport Traffic Assignment

	RDU Study Area		2002XP TRM Study Area	
	RDU Sub-Model	2002XP TRM	RDU Sub-Model	2002XP TRM
Number of Counts	24	24	1275	1275
RMSE	26%	20%	85%	81%
Sum of Counts	774,100	774,100	20,657,215	20,657,215
Sum of Flows	667,733	732,026	14,845,809	15,350,474
% Flow / Count	-12.70%	-5.44%	-28.13%	-25.69%

One reason for the lower volumes is that the factor splits for the RDU airport sub-model trips may be incorrect. Another reason for the lower volumes is that the external-internal trips of the RDU airport were not in the scope of this study and they may not be reflected properly in the trip distribution and traffic assignment. The TRM estimates approximately 40 external-internal RDU airport trips per day, but the RDU Airport Authority and the observed RDU air passenger survey estimate 20 percent (4,000 trips per day) of the RDU air passenger trips to have an external trip end. The RDU airport sub-model has not been calibrated for the O-D vehicle trip split factors, the external-internal airport trips, or traffic assignment of the RDU airport sub-model trips. The assignment presented in this study is an initial assignment.

Findings Conclusion

In conclusion, these findings reflect that the MNL destination choice method is logical and intuitive in its estimation process for the RDU airport and it reflects that the airport trip makers travel longer in travel time and farther in travel distance than predicted by the gravity model. The destination choice method can enhance trip distribution of special land uses, but there remains the continuous challenge of developing a destination choice model from less than ample data. Destination choice models demand better quality data than the gravity model since it offers an extended framework that captures a greater amount of behavioral variability in destination choice making. The SE group segment method used in this research to overcome data deficiency is one approach for the MNL destination choice model trip distribution. However, other methods should be examined in future work on MNL destination choice modeling for trip distribution of special land uses such as an airport.

Recommendations for Future Work

Modeling destination choice, especially for airports, is a relatively undeveloped area in transportation modeling. Thus, it is necessary to make progress in this area because airport travel is unique to other travel types and it is important in a region with only one major airport. The MNL models developed in this study were used knowing that not all details of the destination choice can be captured and that further developments are desirable. Some future work recommendations for the RDU airport sub-model using the MNL destination choice model follow.

Observed Survey Data

It is recommended to develop guidelines and set performance standards of observed survey datasets used for model development. The guidelines should include methods to evaluate the condition of available datasets when time and money do not allow for new surveys to be conducted and methods to deal with these datasets. The evaluated conditions could include the purpose of the survey and the number of complete survey observations available for the study. The performance standards should include specifications of questions and results required for each survey. Such standards could require the survey to capture a set number of airport trip makers with complete information that is specific to personal characteristics of the airport trip makers and specific to the trip maker's location prior to the airport. These guidelines should be developed based on what has worked well in the past, what has not worked well in the past, and how the difficulties of the survey methods attempted were overcome.

It is recommended for the observed dataset of the RDU airport survey to capture approximately 50,000 trip makers for zonal destination choice trip distribution of the RDU airport. This number is based on other surveys such as the Metropolitan Washington regional air passenger survey and this number allows for survey and coding errors such as missing data or incomplete information. Additionally, the 50,000 observed airport trips allows for the sample size of each choice destination to be large enough (ideally, greater than 30 observations) to estimate the RDU trips by zone. If the choice destination trip distribution level is to be aggregated to the SE group segment, then it is recommended for the airport surveys to capture at least 1,800 airport trip makers who have internal destinations to the 2002XP TRM study area. This number is approximated based on the assumption of capturing four times the sample size in the observed survey to account for survey and measurement error recommended by Horowitz et al. (1986).

MNL Models

It is recommended to evaluate air passenger trips using the MNL model and to evaluate airport employee trips using the standard gravity model. Employee trips are not as heavily based on socio-economic factors compared to the air passenger trips and the gravity model is sufficient to distribute journey-to-work trips.

It is recommended to eliminate highly correlated variables that are in the MNL model utility functions and in the SE group segment definitions (such as number of households, income level, travel time, and total employment). Additionally, it is recommended to simplify the explanatory variables in the utility function to facilitate the data collection, analysis, and forecasting efforts. The SAS software is recommended to calibrate the MNL utility functions to determine the significant utility function variables and forms instead of doing this process manually. The SAS software automates the stepwise model calibration process.

SE Group Segment Destinations

It is recommended to look at different SE markets to segment each trip purpose for the MNL model estimation and to use a MS Excel program to statistically determine the clustering of the SE group segments. One reason that the model adjusted Rho-square values and parameter t-values are low may be due to the SE group segments not differentiating between the study area TAZs. Other SE groups that may better differentiate the study area zones are household size, auto ownership, or airport travel type (air passenger business or leisure travel and airport employees work shift). Additionally, it is recommended to aggregate the SE group segments split by travel time and remove travel time from the SE group segment definitions so that the travel time explanatory variable can be used in the MNL model without being highly correlated.

Split Factors for O-D Vehicle Trips

It is recommended to evaluate and research different time of day and directional split factors for the RDU air passenger and airport employee trips to more precisely determine the origin-destination trip interchanges and better predict the traffic volumes on the TRM study area roadways. Additionally, the low and high occupancy vehicle split of the RDU airport trips should be revisited in assignment calibration. Thus, additional data sources are recommended to calibrate these factors so that they do not reflect the splits of the average TRM study area trips, but more precisely reflect the splits of the RDU airport trips. For example, the RDU air passenger trips are made continuously throughout the day with most of the trips in the PM peak and off peak hours according to the ITE Trip Generation Manual. The RDU airport employees work in shifts at time periods different from the average work day time period and most of the trips occur in the off peak hours according to the RDU Airport Authority.

RDU Airport External-Internal Trips

It is recommended to evaluate and distribute the external-internal airport trips separate from the TRM. The 2002XP TRM external-internal trips are distributed using trip rates developed from an external station survey performed in 1997 on the TRM study area. These trip rates may not reflect the actual number of external trips that are attracted to the RDU airport. Thus, the traffic volumes on the roadways may be low, especially in the vicinity of the RDU airport and on interstate roadways, which are most commonly utilized by travel external to the study area.

Conclusion

This research concludes that the MNL destination choice model for trip distribution of the RDU airport trips is a good state of the art method to distribute trips between the RDU airport zone and all other zones in the 2002XP TRM study area. However, the model is only superior to other distribution methods such as the gravity method when quality data is available. The MNL destination choice model framework and application can be used as a guide to develop RDU airport sub-models for future years of the TRM. Additionally, the methodology and application may be a useful for airport sub-models of other regional demand models. However, geographical, spatial, environmental, and temporal characteristics of the study area must be considered.

The conclusions of this research are useful for the TRM because they reflect that RDU airport trip makers may have a different travel behavior than predicted by the gravity model. The steps of the destination choice trip distribution method and application to the 2002XP TRM study area are a useful guide for the TRM Service Bureau and for other modelers who are distributing trips of a special land use, especially when data is lacking. The results of traffic assignment (distant destinations rather than closer) imply that the RDU airport sub-model may provide a better prediction of traffic assignment by reflecting the longer travel time and travel distance of the RDU airport trips. This information would allow planners to better prepare for travel conditions on the roadways surrounding the airport and to better predict the air quality conditions in the Triangle Region.

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Appendix

Appendix A : TAZ Data of the 2002XP TRM

The table below shows a section of the SE data for TAZs of the 2002XP TRM. The [T_TIME] and [T_DIST] fields reflect travel time and travel distance from the TAZ to and from the RDU airport TAZ.

Table A-1: SE Data of the 2002XP TRM TAZs

TAZ	T_TIME	T_DIST	ATYPE	HH	POP	INC	AVGHH	INCRATIO	IND	RET	HWY	OFF	SER	DWELLUNIT	UBEDS
1	24.92	14.41	1	0	0	0	0.0000	1.0000	0	25	0	700	775	0	0
2	24.79	14.38	1	1	1	60000	1.0000	1.2000	3	3	0	250	313	1	0
3	24.78	14.38	1	0	0	0	0.0000	1.0000	2	0	2	362	234	0	0
4	25.37	14.74	1	3	5	75000	1.6667	1.5000	6	15	3	450	470	3	0
5	22.84	14.22	1	0	0	0	0.0000	1.0000	0	2	2	175	240	0	0
6	22.38	14.01	3	0	0	0	0.0000	1.0000	0	0	0	0	0	0	0
7	23.98	15.14	1	453	1047	30000	2.3113	0.6000	0	0	16	3	22	486	0
8	23.40	14.70	1	7	34	13750	4.8571	0.2750	95	12	32	0	184	6	0
9	21.65	13.52	2	20	90	90065	4.5000	1.8013	0	2	0	0	0	23	0
10	23.04	14.53	1	0	0	0	0.0000	1.0000	0	0	0	12	214	0	0
11	22.47	13.88	2	15	62	56355	4.1333	1.1271	0	0	0	0	24	18	0
12	22.05	13.74	1	28	85	90495	3.0357	1.8099	0	0	0	8	2	33	0
13	22.85	14.18	1	33	85	20555	2.5758	0.4111	63	8	3	0	1	35	0
14	22.86	14.23	2	5	14	36250	2.8000	0.7250	0	0	0	0	0	6	0
15	22.99	14.29	1	8	29	2500	3.6250	0.0500	0	22	0	0	38	10	0
16	26.06	15.17	1	8	16	35000	2.0000	0.7000	0	59	99	5	378	14	0
17	24.09	15.20	1	77	154	47210	2.0000	0.9442	0	15	170	4	153	80	0
18	23.55	14.60	1	167	273	18215	1.6347	0.3643	0	0	2	0	14	114	0
19	23.73	14.60	1	123	343	16475	2.7886	0.3295	0	0	0	0	52	137	0
20	24.16	13.45	1	218	442	33180	2.0275	0.6636	0	30	2	0	28	202	0
21	24.60	15.41	1	103	219	34710	2.1262	0.6942	0	0	0	0	17	105	0
22	24.26	15.26	1	70	134	31980	1.9143	0.6396	0	0	0	0	16	68	0
23	24.68	15.43	1	132	249	34000	1.8864	0.6800	0	0	0	0	54	115	0
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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2294	52.94	36.56	3	95	349	43526	3.6737	0.8705	0	0	0	0	0	125	0
2295	48.40	32.92	3	218	640	39050	2.9358	0.7810	0	0	0	0	0	248	0
2296	46.23	33.40	3	176	516	55912	2.9318	1.1182	0	0	0	0	0	200	0
2297	46.97	33.07	2	241	578	47571	2.3983	0.9514	26	20	13	5	52	234	0
2298	44.14	31.25	3	259	759	46011	2.9305	0.9202	0	0	0	0	0	278	0
2299	45.58	31.28	3	243	702	64962	2.8889	1.2992	0	0	0	0	0	273	0
2300	45.32	31.74	3	138	506	51878	3.6667	1.0376	51	39	25	9	102	153	0
2301	49.61	34.25	3	431	1283	59302	2.9768	1.1860	32	87	48	13	79	484	0
2302	47.29	34.65	3	71	214	47824	3.0141	0.9565	11	1	12	1	36	76	0
2303	49.85	34.50	3	415	1317	44195	3.1735	0.8839	24	19	12	4	49	472	0
2304	51.79	37.84	3	115	293	46171	2.5478	0.9234	0	0	0	0	2	119	0
2305	52.33	38.34	3	125	339	46171	2.7120	0.9234	3	3	2	1	7	132	0
2306	45.06	31.85	3	209	565	55912	2.7033	1.1182	0	0	0	0	0	220	0
2307	48.00	34.53	2	330	969	47571	2.9364	0.9514	25	19	12	4	49	355	0
2308	42.39	30.57	3	71	206	46011	2.9014	0.9202	0	0	0	0	0	80	0
2309	45.73	31.32	3	81	298	64962	3.6790	1.2992	0	0	0	0	0	90	0
2310	43.85	30.60	3	69	204	51878	2.9565	1.0376	0	0	0	0	0	77	0
2311	49.55	33.00	3	507	1520	59302	2.9980	1.1860	15	54	12	44	134	539	0
2312	48.40	34.18	2	152	483	47824	3.1776	0.9565	1	1	0	0	1	173	0
2313	52.37	35.91	3	146	371	44195	2.5411	0.8839	73	7	0	0	32	151	0
2314	52.11	37.73	3	266	720	46171	2.7068	0.9234	0	0	0	0	0	280	0
2315	48.21	35.43	3	61	193	47824	3.1639	0.9565	4	3	2	1	8	69	0
2316	51.14	36.87	3	105	266	44195	2.5333	0.8839	5	4	2	1	9	108	0
2317	51.53	37.72	3	160	432	46171	2.7000	0.9234	0	0	0	0	0	168	0

Appendix B : Goodness-to-Fit Statistics for MNL Models

The following goodness-to-fit statistics can be used to determine if a particular MNL model is a better matched of the observed data. This research uses the log-likelihood ratio, the Chi-square statistic, the adjusted Rho-square statistic, and the parameter t-statistic to evaluate the performance of the MNL models. There are several other statistics that can be used to evaluate model goodness-to-fit, however they are not as common in discrete choice modeling and are not used in this study.

Log-Likelihood

The log-likelihood (LL) is the likelihood of the MNL model fit to the observed survey data. It is the sum of the logarithm of the choice probabilities for each observed trip maker and it can be used to check the model estimates. In this study, the LL is calculated using the BIO optimization algorithm in Biogeme.

$$LL = \sum_{j=1}^{J_p} (\gamma) \log P_{ni} \qquad \text{(B-1)}$$

where,

LL - Likelihood of model fit to the observed data
J_p - Available set of observed destination choices of trip purpose p
γ - Dummy variable indicating if the destination is the actual chosen alternative (1) or if the destination is not chosen (0).
P_{ni} - Conditional probability of trip maker n choosing destination i from choice set J_p

Log-Likelihood Ratio

The likelihood ratio is used to compare models with different levels of complexity and to test if two different models explain the same choice process. The test is directly related to the difference in the model maximum likelihood estimates as shown in equation B-2 and it is asymptotically distributed as Chi-square distribution. This implies that as the number of observations approaches infinity, the log-likelihood ratio approaches Chi-square distribution.

$$-2*(LL_R - LL_U) \qquad \text{(B-2)}$$

where,

LL_R - Value of the log-likelihood at its maximum for the restricted model.
LL_U - Value of the log-likelihood at its maximum for the unrestricted model.

The restricted model is the model that reflects the null hypothesis (H_o). The null hypothesis states that the MNL model parameters equal zero and that there are no unobserved variations of variables between the destination choices. The unrestricted model is the model that is being tested and that represents the alternative hypothesis (H_A). The alternative hypothesis states that the MNL model parameters do not equal zero and that there is unobserved variation between the destination choice variables.

Chi-Square Statistic

The Chi-square statistic (X^2) is used to assess evidence that two distributions (choice processes) are dissimilar between MNL models. The Chi-square statistic equation is shown in equation B-3, where N_{ij} is the observed value of trip maker i and choice destination j and $\widehat{T}_{ij}$ is the estimated value of trip maker i and choice destination j .

$$X^2 = \sum \frac{(Observed - Estimated)^2}{Estimated} = \sum_{ij} \frac{(N_{ij} - \widehat{T}_{ij})^2}{\widehat{T}_{ij}} \qquad \text{(B-3)}$$

Log-Likelihood Ratio Test

The log-likelihood ratio test compares the log-likelihood ratio of the restricted and the unrestricted model against the Chi-square statistic, and it is especially useful to test between different utility function forms. This test checks to see if the unrestricted MNL model follows Chi-square distribution more than the restricted MNL model. The models are tested at 0.05 and 0.1 significance level with a degree of freedom reflected by the difference in the number of variables between the two models. **Figure B-1** shows the log-likelihood ratio test of two MNL models using the Chi-square test statistic.

If the log-likelihood ratio is larger than the Chi-square test statistic, then the unrestricted model (the model that is being tested) is a better fit of the observed data and the null hypothesis (the restricted model) should be rejected. Otherwise, the null hypothesis cannot be rejected and the restricted model is preferred. Thus, the larger the value of the log-likelihood ratio than the Chi-square value, the better the model fit for the restricted model with non-zero parameters.

Chi-Square Test Statistic Distribution

df	90%	95%
1	2.71	3.84
2	4.61	5.99
3	6.25	7.81
4	7.78	9.49
5	9.24	11.07
6	10.64	12.59
7	12.02	14.07
8	13.36	15.51
9	14.68	16.92
10	15.99	18.31
11	17.28	19.68
12	18.55	21.03
13	19.81	22.36
14	21.06	23.68
15	22.31	25.00
16	23.54	26.30
17	24.77	27.59
18	25.99	28.87
19	27.20	30.14
20	28.41	31.41
21	29.62	32.67
22	30.81	33.92
23	32.01	35.17
24	33.20	36.42
25	34.38	37.65
26	35.56	38.89

To perform a likelihood ratio test between two models, type the final-loglikelihood and the number of estimated parameters for each model

	Loglikelihood	# parameters	Ratio Test	Critical Chi-Square	Confidence
Restricted Model	-463.154	8	16.486	5.99	(95%)
Unrestricted Model	-454.911	10		4.61	(90%)

OK at 95%

OK at 90%

Figure B-1: Log-Likelihood Ratio Test using the Chi-Square Test Statistic

Rho-Square Statistic

The Rho-square test statistic, also known as the pseudo coefficient of determination, is a test statistic of the MNL model that is especially useful to test models of different variables. The Rho-square statistic provides the portion of the log-likelihood that is explained by the model. A value of 0.2 to 0.3 is acceptable and values greater than 0.3 are recommended. The adjusted Rho-square statistic is a form of the Rho-square statistic that takes into consideration the number of variables used in the MNL models. This statistic is best used when comparing two models that have a different number of estimated parameters ($\dot{K}$). Usually, a higher number of estimated parameters mean a lower adjusted Rho-square value. The Rho-square statistic and the adjusted Rho-square statistic are shown in the following two equations.

Rho-square statistic: $\rho^2 = 1 - \left[\frac{LL_U}{LL_R}\right]$ (B-4)

Adjusted Rho-square statistic: $\rho_a{}^2 = 1 - \left[\frac{LL_U - \dot{K}}{LL_R}\right]$ (B-5)

T-statistic

A t-statistic is similar to the log-likelihood ratio test, except the t-statistic tests a single variable in the model for t-distribution. T-distribution is a distribution of values with particular degrees of freedom of difference between the sample and the population mean divided by the standard error of the mean (Equation B-6).

$$t = \frac{\bar{x} - \mu}{\frac{S}{\sqrt{n}}} \approx t_\alpha(df = n - 1) \qquad \text{(B-6)}$$

This test is used to determine the probability that the true variable parameters are equal to zero. However, t-tests are not exact results for discrete choice models such as the MNL model. Instead, the t-statistics are asymptotically t-distributed. This means that as the sample size approaches infinity, the estimated model coefficients are t-distributed.

Other Test Statistics

The following test statistics can be used to check the validity of the MNL model but they are used in this study. The other statistics are presented below in equations B-7 through B-11, where N_{ij} is the observed value of trip maker i and choice destination j and $\widehat{T}_{ij}$ is the estimated value of trip maker i and choice destination j.

Neyman's Modified Chi-Square Statistic

$$X^2 = \sum \frac{(Observed - Estimated)^2}{Observed} = \sum_{ij} \frac{(N_{ij} - \widehat{T}_{ij})^2}{N_{ij}} \tag{B-7}$$

Simplified Freeman-Turkey Statistic

$$\sum_{ij} 4\left[\sqrt{N_{ij}} - \sqrt{\widehat{T}_{ij}}\right]^2 \tag{B-8}$$

Scale Deviance Statistics

$$2\sum_{ij}\left[N_{ij} \log\left(\frac{N_{ij}}{\widehat{T}_{ij}}\right)\right] \tag{B-9}$$

Sum of Errors Squared

$$\sum_{ij}\left(N_{ij} - \widehat{T}_{ij}\right)^2 \tag{B-10}$$

Mean Error Squared

$$\frac{\sum_{ij}\left(N_{ij} - \widehat{T}_{ij}\right)^2}{n} \tag{B-11}$$

Appendix C：RDU Airport Passenger and Employee Survey Variables

Air Passenger Survey Variables

Table C-1 shows the questions asked to the RDU airport air passengers in the *Airport Rail Link Study Passenger Survey* (PBS&J and NuStats Partners, 2002). The questions and variables in red italics font are the relevant trip maker characteristics used in this study.

Airport Employee Survey Variables

Table C-2 shows the questions asked to the RDU airport employees in the *Airport Rail Link Study Employee Survey* (PBS&J and NuStats Partners, 2002). The questions and variables in red italics font are the relevant trip maker characteristics used in this study.

Table C-1: RDU Airport Air Passenger Survey Variables

Item	Variable Name	Variable Description	Type	Width	Codeset (or Format)	Question
1	ST_DATE	Date on which survey began	N	6	yymmdd	Confirm date
2	ST_TIME	Time at which survey began	N	4	hhmm	Confirm time
3	EN_DATE	Date on which survey was completed	N	6	yymmdd	Confirm date
4	EN_TIME	Time at which survey was completed	N	4	hhmm	Confirm time
5	DURATION	Amount of time spent on survey	N	4	(total seconds)	
6	USERID	Surveyor ID	C	5		
7	USERNAME	Surveyor Name	C	20		
8	RECTYPE	No Data				
9	AIRLINE	Airline	C	30	AIRLINE	Record airline from gate information.
10	AIRLN_O	Airline (other)	C	15		Record airline from gate information
11	FLIGHT_N	Flight Number	C	5		Record flight number from gate information
12	***GENDER***	***Gender***	***N***	***1***	***1=Male; 2=Female***	***Gender [VISUAL DO NOT ASK]***
13	***CONNECT***	***Connecting Flight?***	***N***	***1***	***1=Yes; 2=No***	***Did you just get off one flight and ready to connect to another flight?***
14	***LIVE***	***Live in R-D?***	***N***	***1***	***1=Yes; 2=No***	***Do you live in the Raleigh-Durham area?***
15	***LIVE_OTH***	***Where do you live?***	***C***	***30***		***What city and state do you live in? If you live outside the US, what country are you from?***
16	***TRAV_MET***	***Travel Method***	***N***	***2***	***TRAV_MET***	***Which statement best describes how you got to the airport today?***
17	PAY2PARK	Paid to Park	N	1	1=Yes; 2=No	Will you have to pay to park?
18	PARK_AMT	Amount paid to park daily	N	2		How much a day will you pay to park at the airport?
19	Q1_ANS	No Data				
20	***PURP_FUT***	***Trip Purpose***	***N***	***1***	***PURPOSE***	***Is this trip for business, pleasure or a combination of both purposes?***
21	***PURP_PAS***	***Trip Purpose***	***N***	***1***	***PURPOSE***	***Was this trip for businiess, pleasure or a combination of both purposes?***
22	DAY_FUT	Length of trip (in days)	N	2		How many days will you be gone on this trip?
23	DAY_PAS	Length of trip (in days)	N	2		How many days have you been gone on this trip?
24	COMP_ADU	Number of adult companions	N	2		How many adults are travelling with you?
25	COMP_CHI	Number of child companions	N	2		How many children are travelling with you?
26	WHERE_TR	Travel Destination	N	2	WHERE_TR	Where are you travelling to?
27	WHERE_CI	Destination (City)	C	30		What city are you travelling to?
28	WHERE_ST	Destination (State)	N	2	STATES	What state are you travelling to?
29	WHERE_CO	Destination (Country)	C	20		What country are you travelling to?
30	***PRIO_AIR***	***Location prior to airport***	***N***	***2***	***PRIO_AIR***	***Prior to arriving at the airport, where did you come from?***
31	***HOTEL***	***Hotel***	***N***	***2***	***HOTEL***	***What hotel did you stay at?***
32	***WORK_PLA***	***Work Place***	***N***	***2***	***WORK_PLA***	***What work place were you at?***
33	***SCHOOL***	***School***	***N***	***2***	***SCHOOL***	***What school where you at?***
34	***PLA_NAME***	***Place Name***	***C***	***30***		***What is the name of this place?***
35	***EXAC_ADD***	***Exact Address***	***C***	***20***		***What is the exact address of this place?***
36	***CROS_ST***	***Cross Streets***	***C***	***20***		***What are the cross streets of this place?***
37	***CIT_ST_Z***	***City, State and Zip***	***C***	***35***		***What is the city, state and zip of this place?***
38	Q1_ANS	No Data				
39	RAL_BUS	Used Raleigh bus in past 3 months?	N	1	1=Yes; 2=No	Have you used bus service in the Raleigh area during the past 3 months?
40	RAL_TRIP	Number of Raleigh bus trips	N	3		Estimate how many one-way trips you have taken in the past 3 months
41	BUS_USED	Used bus in the past 3 months?	N	1	1=Yes; 2=No	Have you used bus service during the past 3 months?
42	BUS_TRIP	Number of bus trips	N	3		Estimate how many one-way bus trips you have taken in the past 3 months
43	SUB_USED	Used rail/subway in past 3 months?	N	1	1=Yes; 2=No	Have you used rail/subway service during the past 3 months?
44	SUB_TRIP	Number of rail/subway trips	N	3		Estimate how many one-way rail/subway trips you have taken in the past 3 months
45	HR_USED	Used heavy rail in past 3 months?	N	1	1=Yes; 2=No	Have you used heavy rail service during the past 3 months?
46	HR_TRIP	Number of heavy rail trips	N	3		Estimate how many one-way heavy rail trips you have taken in the past 3 months
47	HOUS_ADL	Number of adults in household	N	2		Including yourself, how many adults live in your household?
48	HOUS_CHD	Number of children in household	N	2		How many children live in your household?
49	INCOME	Household income	N	1	INCOME	What is your approximate annual household income?
50	VOUCHER	No Data				These last two questions will enter you into a drawing for a $500 airline voucher…
51	ADDRESS	Home Adresss	C	20		What is your home address?
52	PHONE	Home Phone	C	15		What is your home phone number?
53	END	No Data	N	1		End of Survey
11.1	TIME_PER	TIME PERIOD	N	1		

Table C-2: RDU Airport Employee Survey Variables

Item	Variable Name	Variable Description	Codeset (or Format)	Question	Type
1	**SERIAL**	**SERIAL #**	**######**		**N**
2	NAME	Name		What is your first and last name?	C
3	PHONE	Telephone Number		What is your telephone number?	N
4	*ADDNUM*	***Street Address Number***		***What is your street number?***	***C***
5	*ADDNAME*	***Street Address Name***		***What is your street named?***	***C***
6	*CITY*	***City***		***What city?***	***C***
7	*STATE*	***State***		***What state?***	***C***
8	*ZIP*	***ZIP code***		***What is your zip code?***	***N***
9	Q1	How get to work	1 = Drive by myself 2 = Bus 3 = Walk/ bicycle 4 = Dropped off by someone 5 = Taxi 6 = Carpool/vanpool 7 = Other 9 = Refused	How do you usually get to work?	N
10	Q2	How long to get to work	##	How long does it take to get to work (minutes)?	N
11	*Q3*	***How many days worked per week***	***1 = 1 day*** ***2 = 2 days*** ***3 = 3 days*** ***4 = 4 days*** ***5 = 5 days*** ***6 = 6 days*** ***7 = 7 days*** ***9 = Refused***	***On average, how many days a week do you work at the airport?***	***N***
12	Q4A	Shift start time		What is the start time of your shift?	C
13	Q4AX	Start time AM or PM	1 = AM 2 = PM 9 = Refused	Start time AM or PM?	N
14	Q4B	Shift end time		What is the end time of your shift?	C
15	Q4BX	End time AM or PM	1 = AM 2 = PM 9 = Refused	End time AM or PM?	N
16	Q5	Stop on your way to or from work	1 = YES 2 = NO 9 = Refused	Do you usually make a stop on your way to or from work?	N
17	Q6	How often do you stop	1 = Everyday 2 = 3 or 4 times a week 3 = 1 or 2 times a week 4 = Once a month 5 = Never 9 = Refused	In a typical week, how often do you stop on your way to of from work to do an errand?	N
18	Q7	Where do you park at work	1 = Private parking for employees working at my company 2 = Airport employee parking lot and then ride shuttle bus 3 = Airport employee lot and then walk to my work area 4 = I don't drive to work at the airport 9 = Refused	Where do you park at the airport when you come to work?	N
19	Q8	Amount paid to park for work	####.##	How much do you pay to park?	N
20	Q8A	Per day or Per month	1 = Per Day 2 = Per Month 9 = Refused	Is that amount Per Day or Per Month?	N
21	Q8B	Free parking	1 = Nothing my employer provides free parking		N

Table C-2: RDU Airport Employee Survey Variables (Continued)

Item	Variable Name	Variable Description	Codeset (or Format)	Question	Type
22	Q9A	To go to lunch	1 = Yes, to go to lunch	Do you usually use your car to go out to lunch or run business or personal errand while you are at work?	N
23	Q9AX	# of times per week	##	Do you usually use your car to go out to lunch or run business or personal errand while you are at work?	N
24	Q9B	Personal errands	1 = Yes, for personal errands	Do you usually use your car to go out to lunch or run business or personal errand while you are at work?	N
25	Q9BX	# of times per week	##	Do you usually use your car to go out to lunch or run business or personal errand while you are at work?	N
26	Q9C	Company errands/ appointments	1 = Yes, for company errands/ appointments:	Do you usually use your car to go out to lunch or run business or personal errand while you are at work?	N
27	Q9CX	# of times per week	##	Do you usually use your car to go out to lunch or run business or personal errand while you are at work?	N
28	Q9D	Don't use car during workday	1 = No, I don't use my car during the work day	Do you usually use your car to go out to lunch or run business or personal errand while you are at work?	N
29	*Q10A*	***Adults***	***##***	***How many adults live in your household?***	***N***
30	*Q10B*	***Children***	***##***	***How many children live in your household?***	***N***
31	Q10C	ADDS Q10A + Q10B	= Q10A + Q10B		N
32	*Q11*	***Household Income***	***1 = Under $25,000 2 = $25,000 - $34.999 3 = $35,000 - $49.999 4 = $50,000 - $79.999 5 = More than $80,000 9 = Refused***	***What is your estimated household income in 2001 before taxes?***	***N***
33	*Q12*	***Gender***	***1 = Male 2 = Female 9 = Refused***	***Are you Male or Female?***	***N***
34	*Q13*	***Job Description***	***1 = Maintenance/ Repair 2 = Customer service 3 = Materials handling 4 = Food preparation 5 = Administration (management)***	***Which statement best describes your job?***	***N***
			6 = Administration (Technical, clerical support) 7 = Flight crew 8 = Ground crew 9 = Security 10 = Air traffic controller 11 = Other 99 = Refused		

Appendix D：Survey Data Files Linked to SE Group Segment Destinations

The following three tables (**Table D-1**, **Table D-2**, and **Table D-3**) shows the field [Choice] inserted into the observed data table that links the observed data to the SE group segment for each trip purpose. The [Choice] field represents the SE group segment choice destination chosen by the observed trip maker.

Table D-1: HB Survey Data

Obs_ID	INC	HS	GEN	T_Type	Choice_TAZ	**CHOICE**
3	3	2	2	7	397	4
6	5	6	2	1	1020	4
10	3	1	2	1	1651	5
14	2	4	2	3	1275	3
15	4	1	1	3	2215	4
22	5	4	2	7	2311	4
24	3	1	2	7	256	4
25	5	3	2	1	992	4
27	5	1	1	5	91	4
29	5	5	1	1	1076	4
32	3	6	1	1	362	5
37	5	3	1	1	1510	4
39	5	5	2	3	1914	5
40	3	3	1	3	739	4
45	5	2	2	5	1520	4
46	1	5	1	5	1825	2
47	5	1	1	1	2297	3
54	5	4	1	1	702	4
57	5	4	1	1	818	3
58	3	1	2	7	1513	5
67	5	3	2	1	1560	4
81	3	4	2	7	2170	4
97	2	4	1	1	210	2
100	5	2	1	5	1882	3
101	1	1	2	7	1936	5
106	4	2	2	7	1479	4
113	5	2	1	1	1167	4
116	5	2	2	3	1134	4
118	1	1	2	7	1662	5
120	4	2	1	1	445	2
129	2	4	2	7	1520	4
142	1	2	1	7	1507	4
145	5	5	1	1	2081	3
147	5	2	2	1	1676	3
148	5	3	2	7	305	4
150	2	1	2	7	1049	4
156	5	4	2	7	366	5
158	5	1	1	7	1079	5
161	5	4	1	1	1662	5
163	4	3	1	5	1520	4
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Table D-2: NHB Survey Data

Obs_ID	INC	HS	GEN	PRIOR	T_Type	Choice_TAZ	Choice_LU	Choice_TT	**CHOICE**
2	3	3	1	4	2	919	4	20.33	2
9	3	4	1	4	2	273	4	15.34	2
11	4	2	1	4	2	723	4	21.59	3
12	4	4	2	4	8	248	4	20.21	2
30	5	1	2	4	2	542	4	24.48	3
33	5	3	1	4	2	1471	4	22.12	3
35	5	9	1	4	2	1590	4	26.87	3
36	2	4	2	3	8	1062	3	11.77	1
48	5	5	2	4	2	1627	4	26.9	3
53	5	3	1	3	8	1062	3	11.77	1
55	3	3	2	4	2	512	4	28.13	3
59	4	2	2	5	6	547	5	24.79	4
78	2	1	2	4	2	1522	4	11.75	2
96	5	7	1	4	6	628	4	23.29	3
99	5	2	2	4	2	1522	4	11.75	2
102	3	1	2	4	2	434	4	23.66	3
107	5	2	2	4	2	1522	4	11.75	2
111	5	2	2	4	2	1920	4	29.66	3
112	5	4	2	4	2	1513	4	16.18	2
115	5	4	1	4	6	724	4	20.68	2
132	4	2	1	4	2	592	4	21.1	3
135	5	3	1	3	8	2077	3	48.38	1
140	1	2	1	3	8	263	3	15.48	1
149	4	3	2	3	8	1475	3	19.69	1
151	5	3	2	4	2	262	4	16.97	2
160	5	1	1	5	6	919	5	20.33	4
166	5	4	1	3	8	300	3	18.95	1
169	5	5	1	4	2	771	4	27.84	3
205	3	2	2	5	8	585	5	23.86	4
210	4	3	1	5	8	533	5	28.24	4
217	5	3	1	4	2	1065	4	13.2	2
235	5	3	2	4	2	919	4	20.33	2
238	4	7	1	3	8	672	3	21.73	1
241	3	1	1	4	8	514	4	27.91	3
246	3	2	2	3	8	545	3	23.33	1
253	5	2	1	4	2	275	4	17.23	2
258	5	2	1	4	2	919	4	20.33	2
272	4	1	1	4	6	262	4	16.97	2
280	5	2	1	4	2	700	4	20.5	2
281	5	1	1	4	2	1580	4	23.67	3
288	2	2	2	4	2	1931	4	29	3
289	5	2	1	4	6	275	4	17.23	2
290	4	4	1	4	2	681	4	19.92	2
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Table D-3: J-to-W Survey Data

ID	Time	INC	HS	GEN	Choice_TAZ	Choice_INC level	Choice_TT	**CHOICE**
276	25	4	2	1	913	4	28.41	5
277	20	3	1	1	346	3	27.42	3
278	30	2	3	1	811	4	33.28	5
280	25	3	2	2	1591	2	29.49	1
281	28	2	3	1	1644	2	24.32	1
282	25	3	2	2	1631	3	26.58	3
283	10	3	2	1	723	4	21.59	4
285	15	2	1	2	708	5	23.41	6
286	20	3	6	2	350	1	24.69	1
288	15	3	1	1	270	5	14.74	6
291	10	1	1	2	416	4	21.4	4
292	30	1	4	1	664	3	31.59	3
293	15	3	3	2	1753	4	16.64	4
294	20	4	3	1	778	5	26.68	6
298	20	2	3	2	1462	2	18.36	1
299	15	4	1	2	314	3	23.19	2
301	15	5	4	1	1514	5	15.08	6
302	10	3	3	1	253	3	19.17	2
304	18	5	2	1	1753	4	16.64	4
305	30	4	4	1	811	4	33.28	5
306	10	2	2	1	1069	3	12.54	2
310	15	4	2	1	241	4	23.6	4
325	30	3	4	1	1488	4	29.71	5
351	35	4	3	1	1400	4	39.95	5
357	20	5	4	1	1613	4	20.99	4
360	20	5	4	1	794	4	27.68	5
361	15	5	4	1	1023	4	20.27	4
362	45	3	2	1	2180	4	47.2	5
363	10	4	2	1	704	4	20.24	4
364	30	1	3	1	857	3	31.43	3
365	25	5	3	1	787	4	25.76	5
366	20	4	1	1	878	1	34.35	1
452	20	2	1	2	1806	3	20.53	2
454	20	4	1	1	784	4	23.39	4
457	8	2	3	2	268	4	13.2	4
459	15	2	4	1	304	3	22.46	2
460	35	2	3	2	1676	3	37.55	3
461	19	5	3	1	1911	1	31.66	1
462	30	2	2	1	314	3	23.19	2
464	25	3	2	1	1671	4	28.64	5
465	30	3	2	1	1152	5	30	6
466	20	5	5	2	297	3	21.19	2
467	15	1	1	1	560	3	26.65	3
469	35	4	3	1	1225	3	39.26	3
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Appendix E : Scatter and "Q-Q" Plots of SE Group Segment Characteristics

Scatter Plots

Scatter plots are used to check that the observed data records within each SE group segment have similar characteristics. Any trip maker or destination data value that is an outlier to the average characteristic value is removed from the dataset. The following figures (**Figure E-1** through **Figure E-12**) show the scatter plots for each characteristic considered in the development of the MNL destination choice model for each trip purpose.

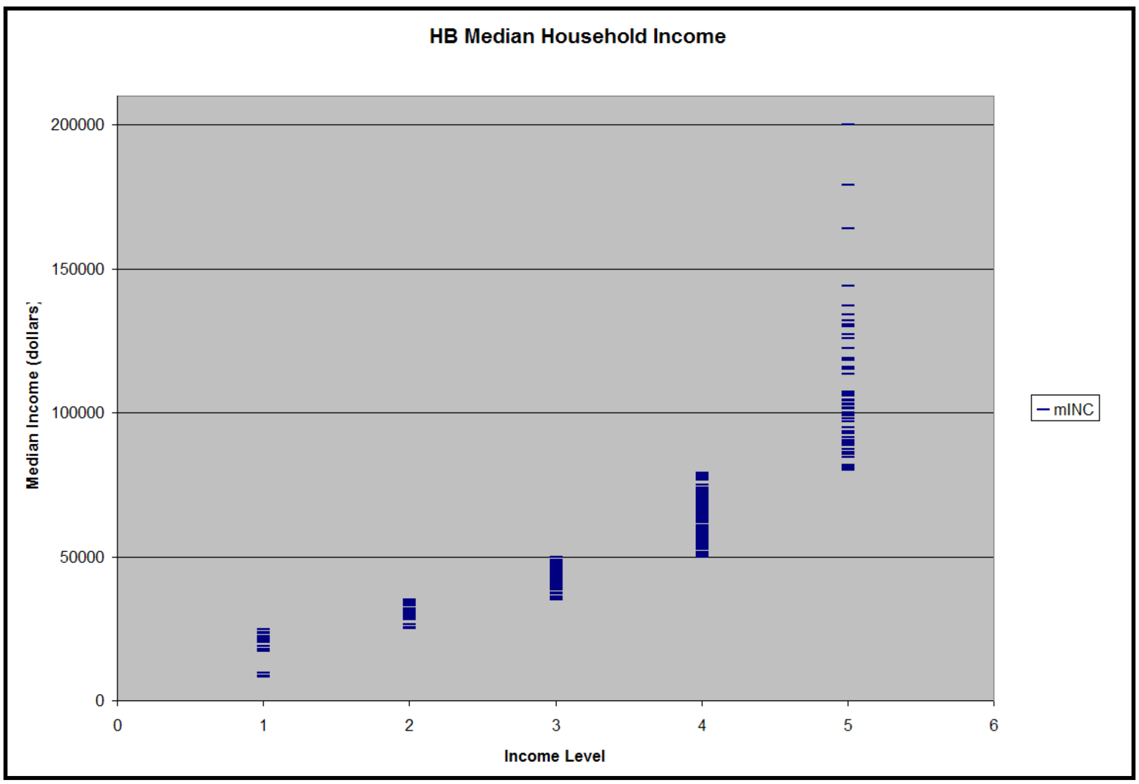

Figure E-1: Household Median Income of the HB Trip Purpose

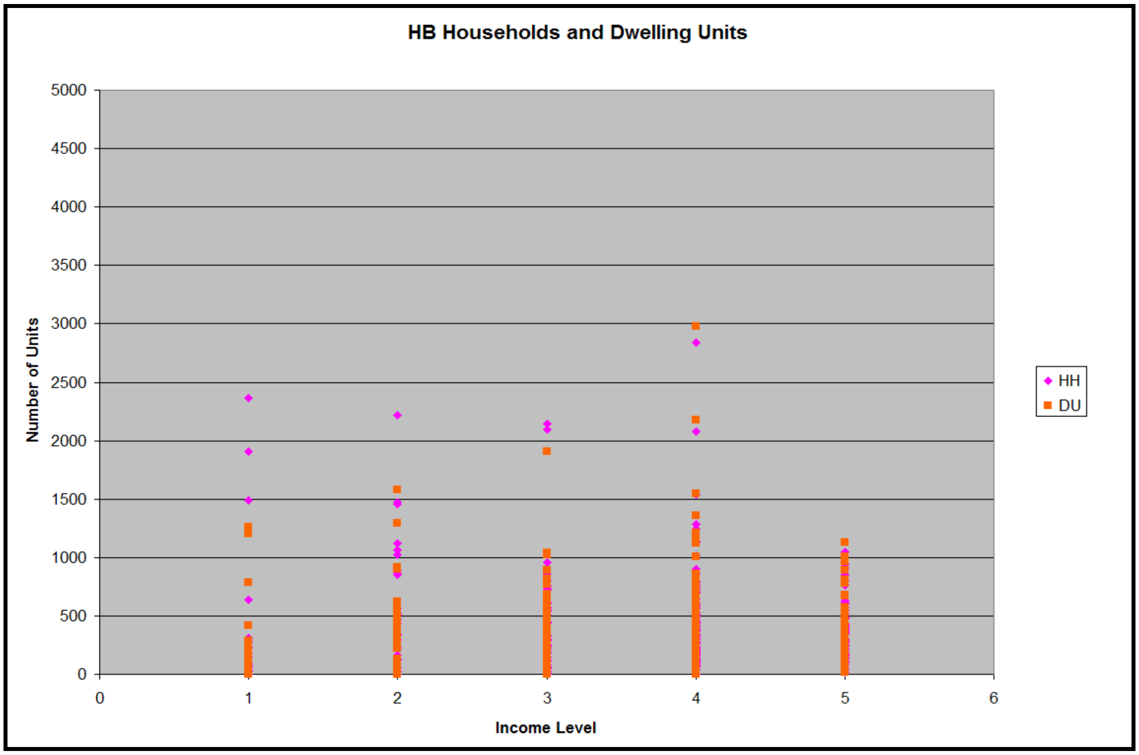

Figure E-2: Number of Households and Dwelling Units of the HB Trip Purpose

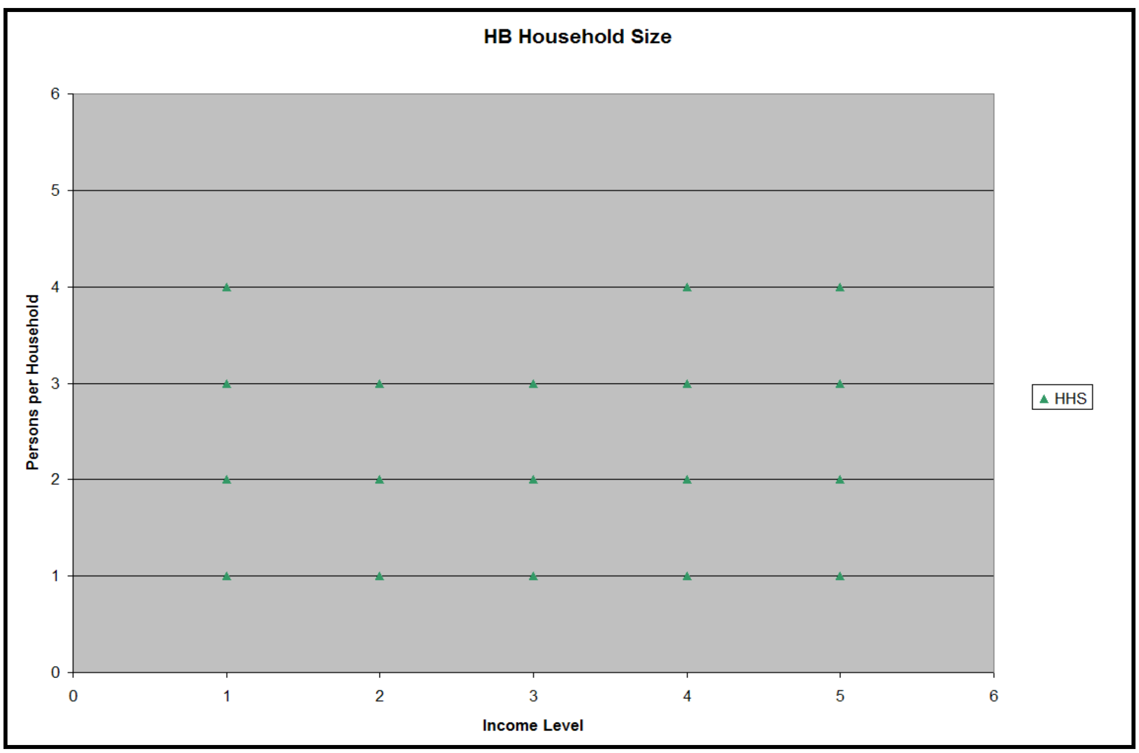

Figure E-3: Average Household Size of the HB Trip Purpose

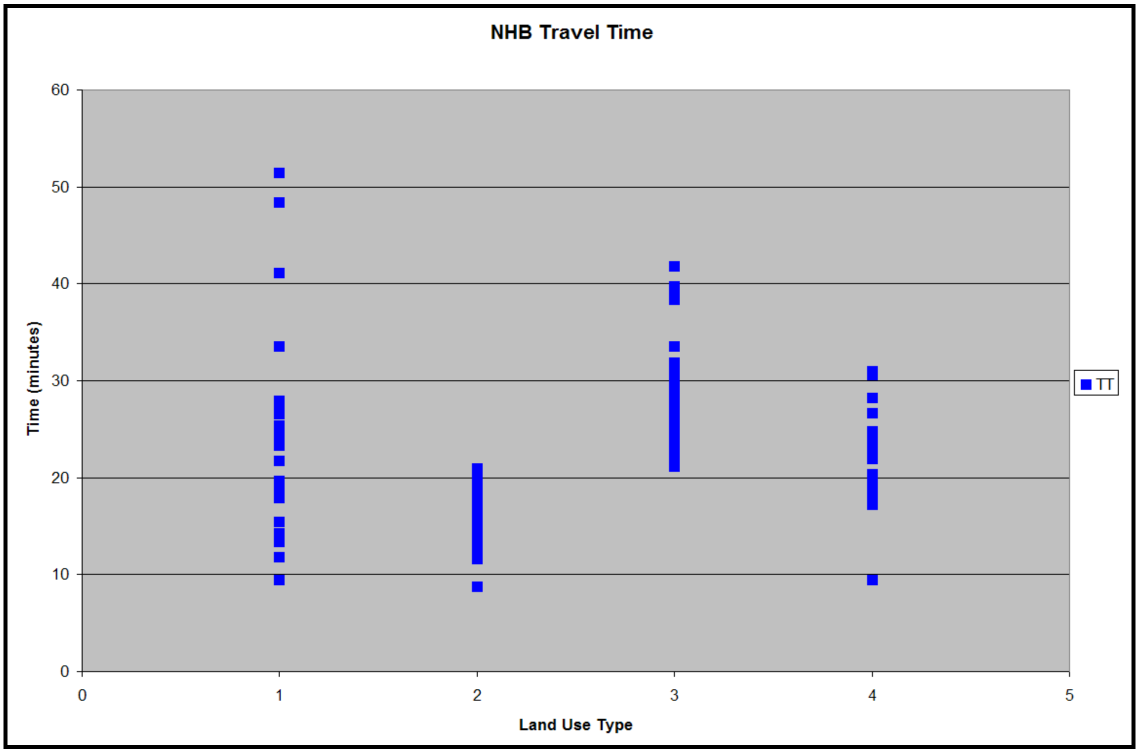

Figure E-4: TAZ Travel Time to the RDU Airport of the NHB Trip Purpose

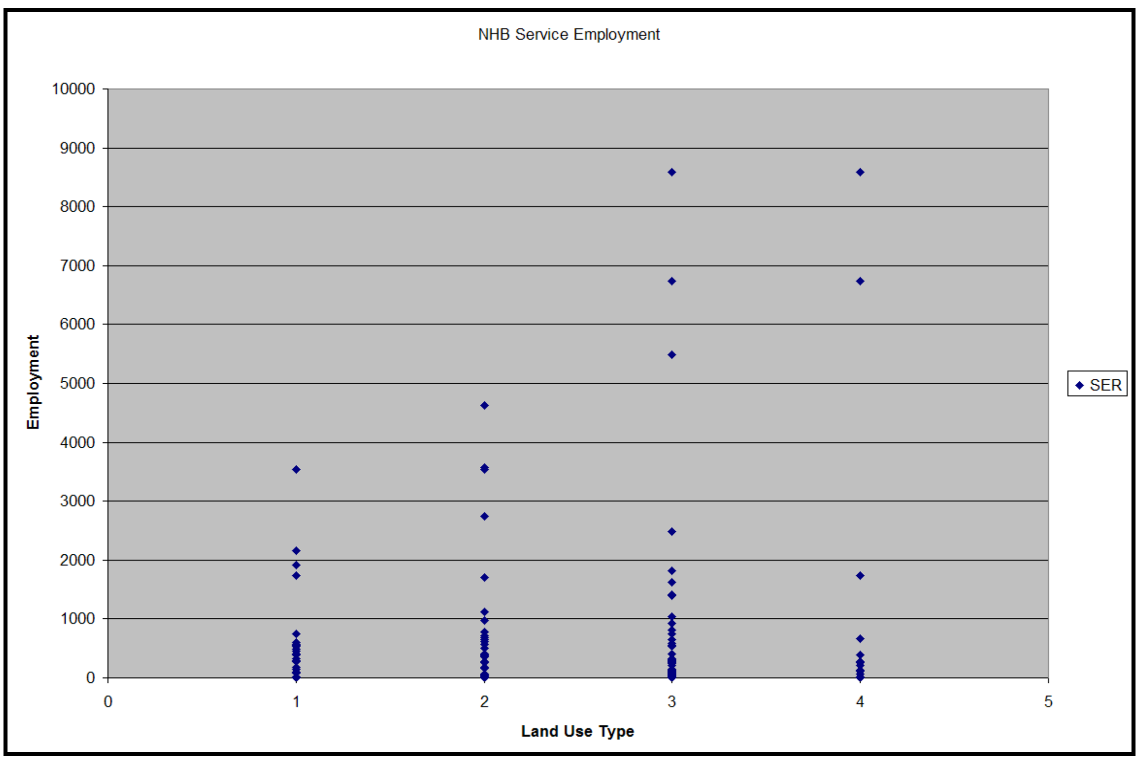

Figure E-5: Service Employment of the NHB Trip Purpose

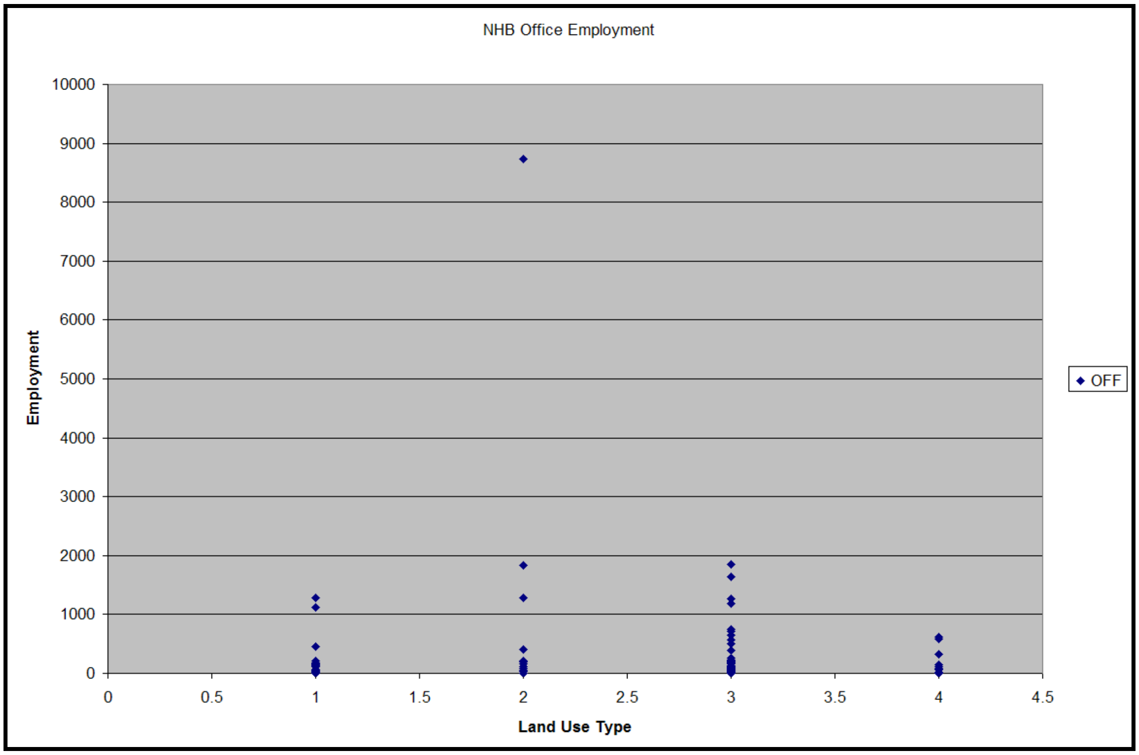

Figure E-6: Office Employment of the NHB Trip Purpose

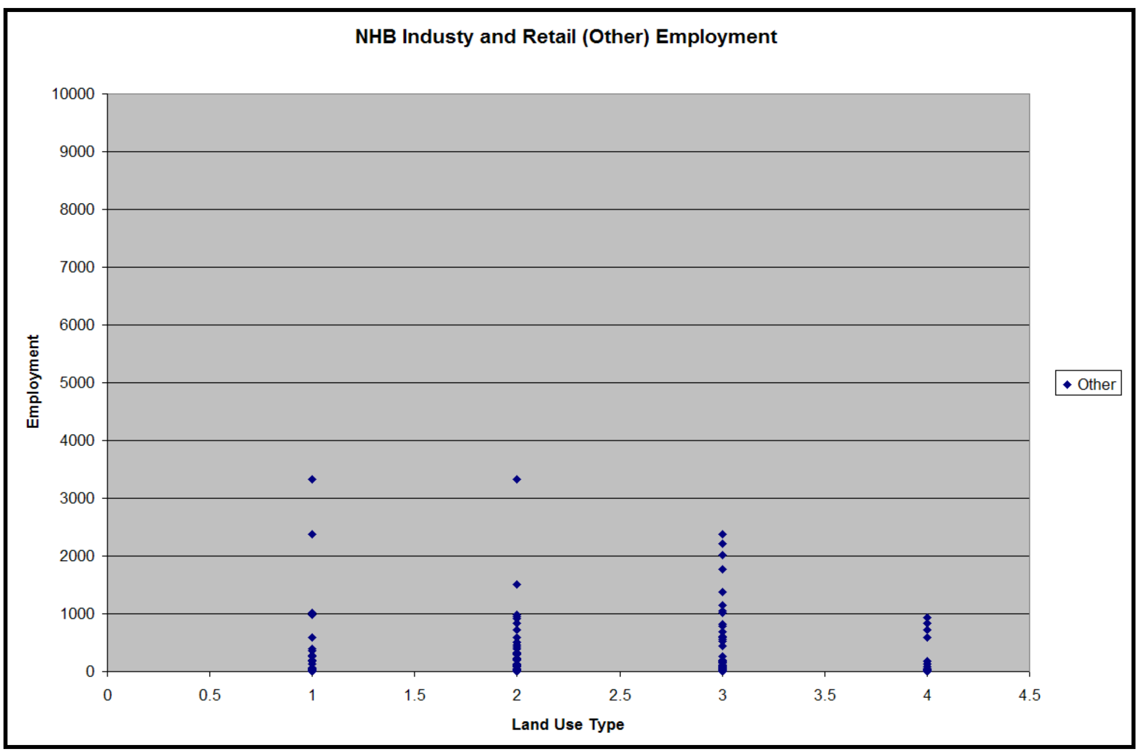

Figure E-7: Industry and Retail (Other) Employment of the NHB Trip Purpose

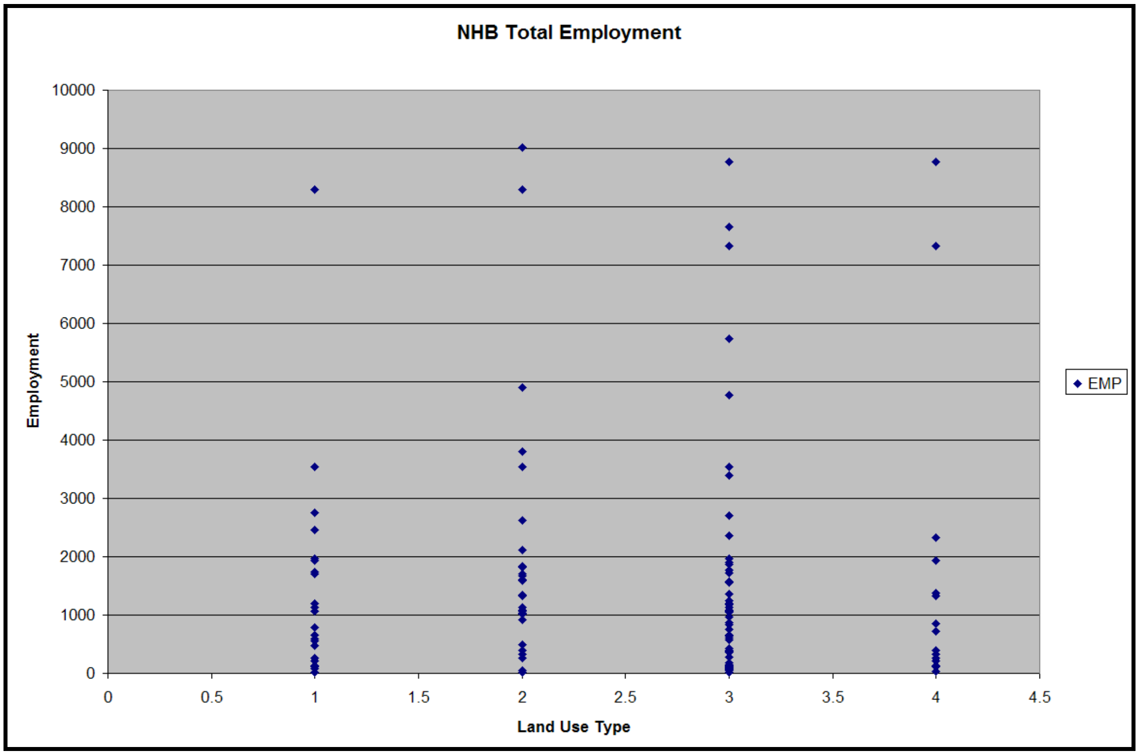

Figure E-8: Total Employment of the NHB Trip Purpose

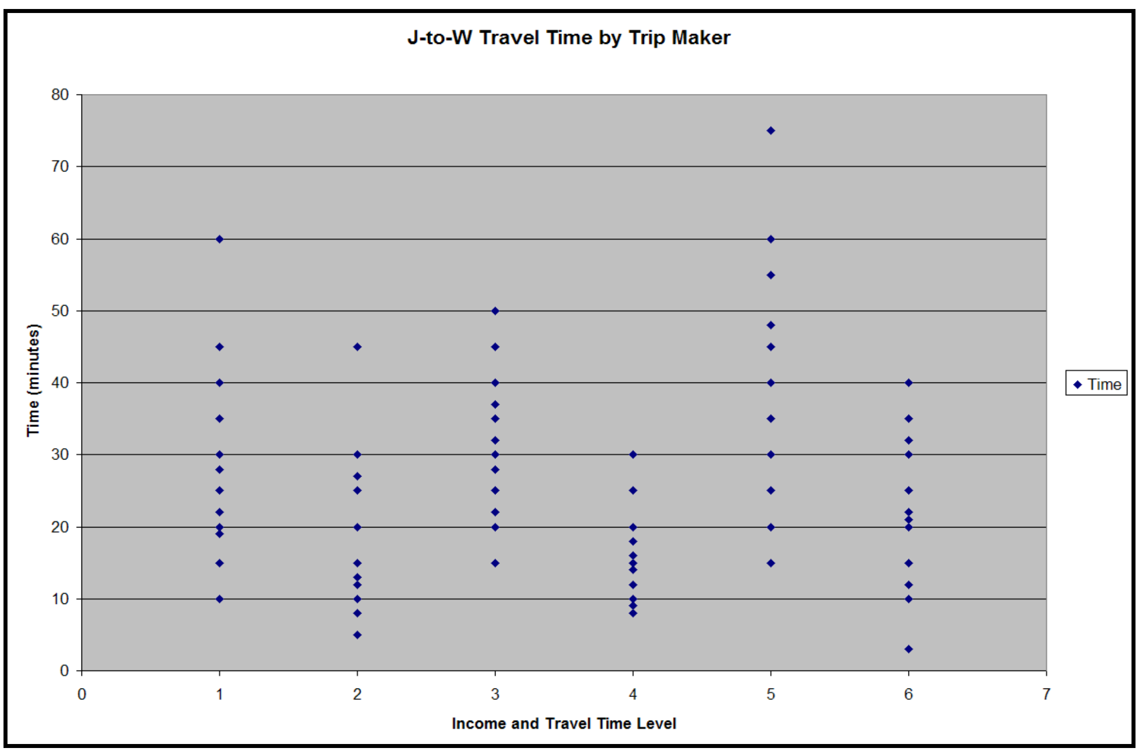

Figure E-9: Trip Maker Travel Time to the RDU Airport of the J-to-W Trip Purpose

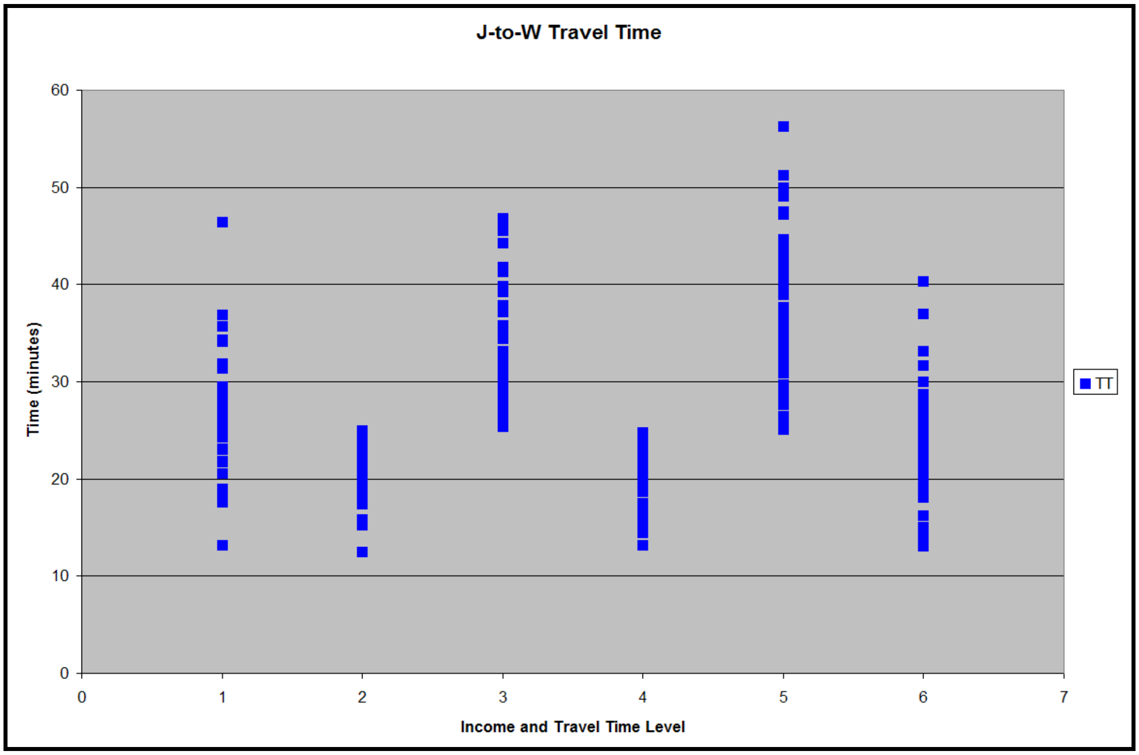

Figure E-10: TAZ Travel Time to the RDU Airport of the J-to-W Trip Purpose

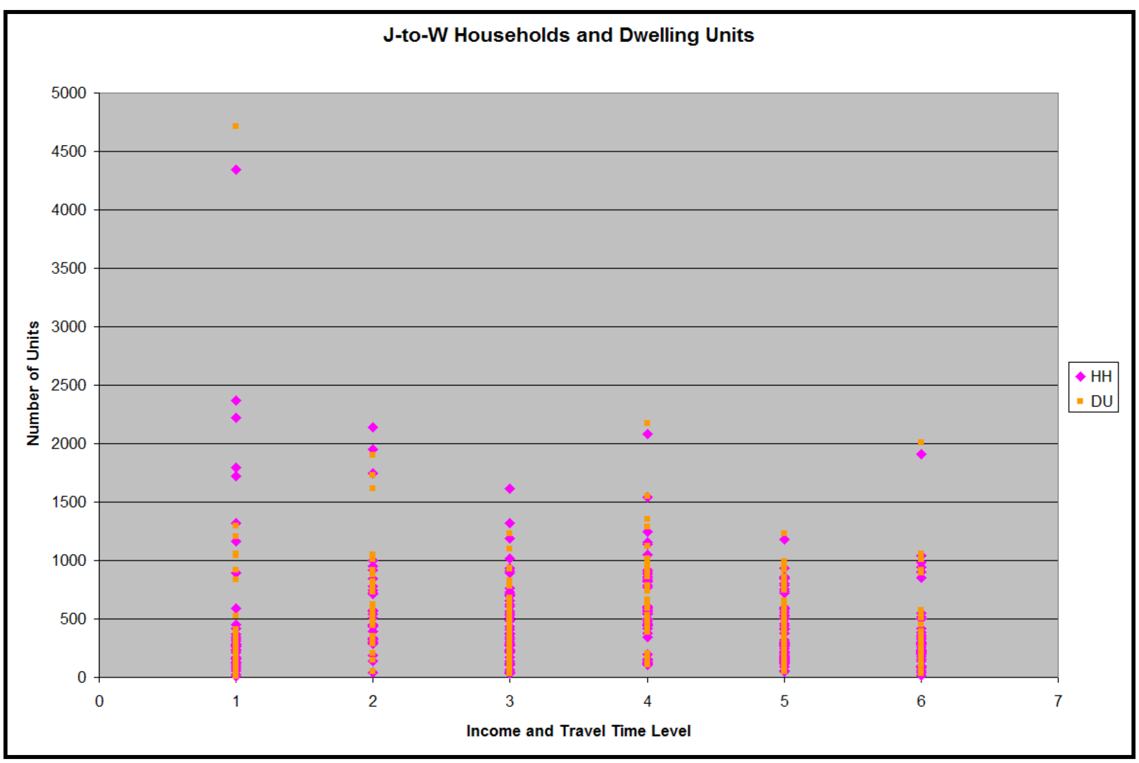

Figure E-11: Number of Households and Dwelling Units of the J-to-W Trip Purpose

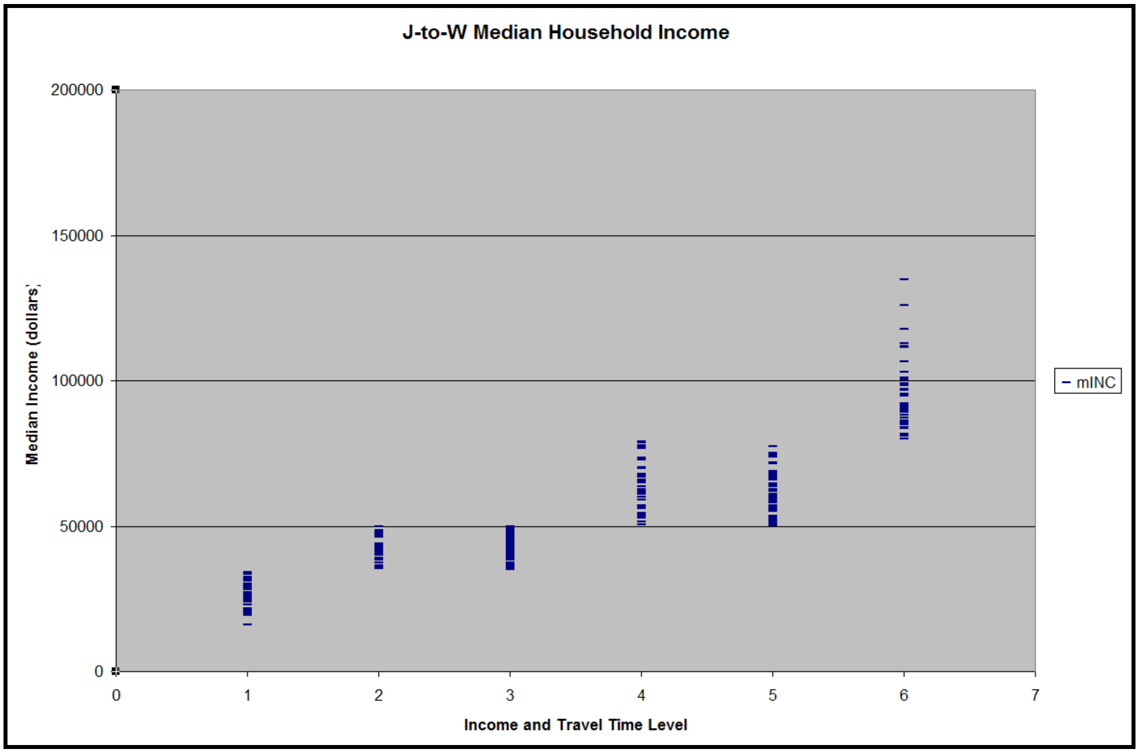

Figure E-12: Median Household Income of the J-to-W Trip Purpose

“Q-Q” Plots

“Q-Q” plots are used to check of normal distribution of the SE group segment characteristics when there are less than 30 observations. The “Q-Q” plots order the observed data characteristics against the corresponding normal quantiles. Normal distribution of the data is indicated if the points generally follow a straight line. The following figures (**Figure E-13** through **Figure E-29**) show the “Q-Q” plots for each the characteristic of the HB SE group segment 1 and 2 and the NHB SE group segment 4.

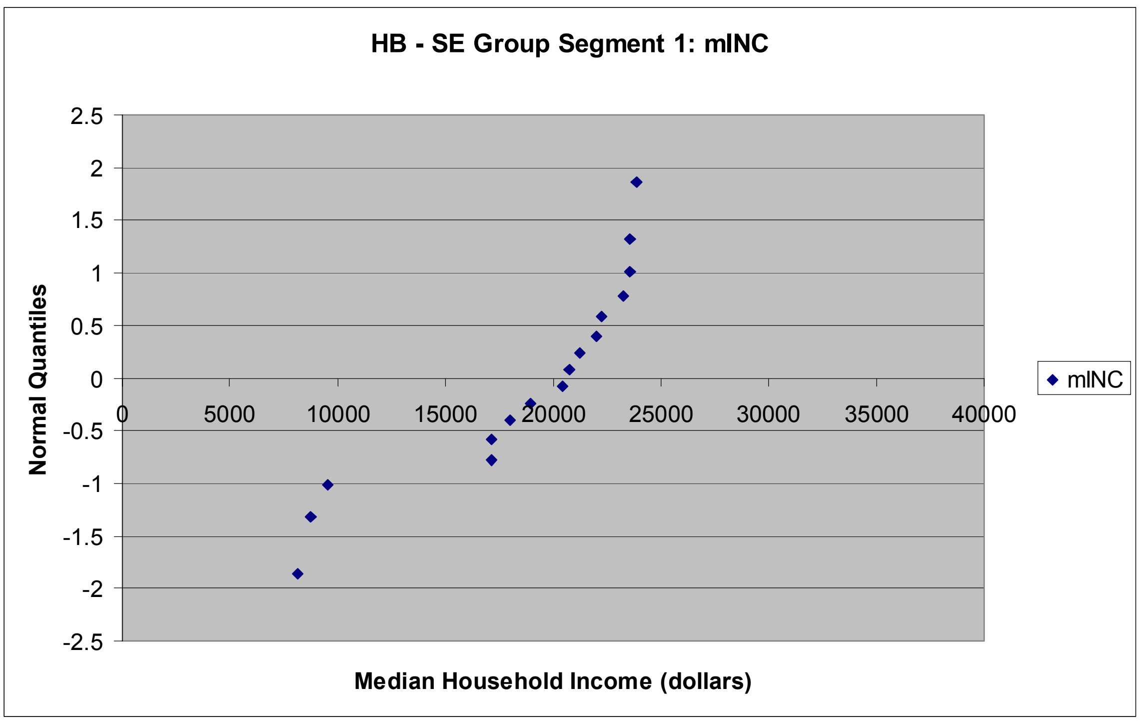

Figure E-13: Median Household Income of the HB SE Group Segment 1

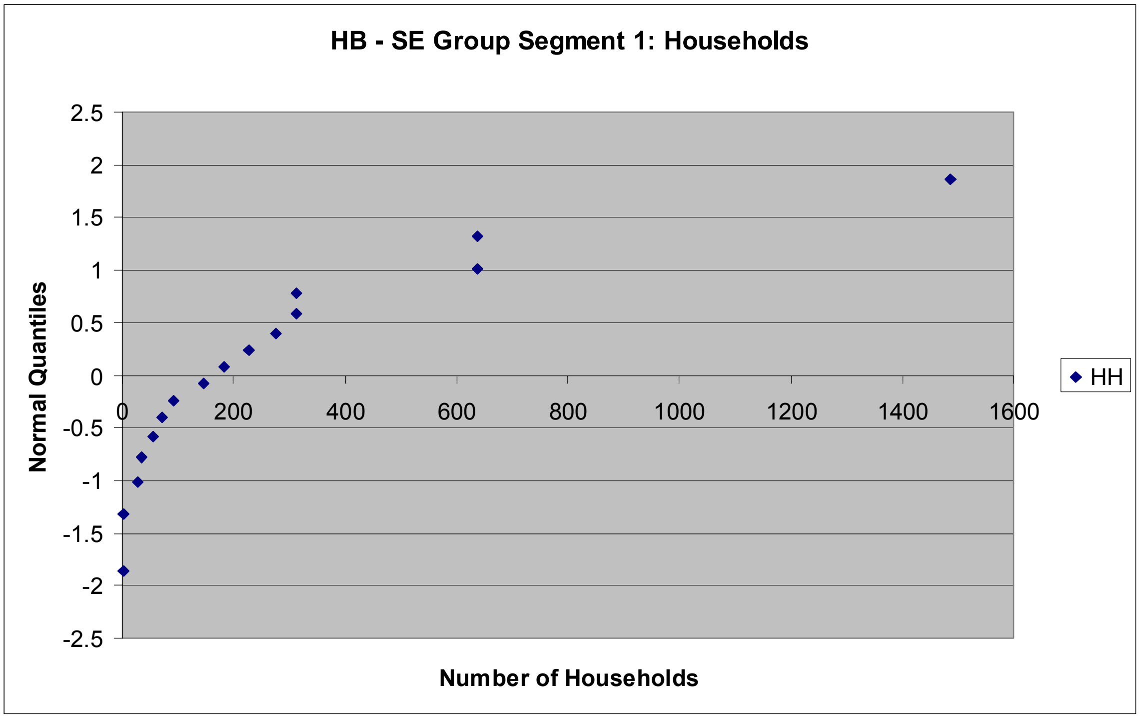

Figure E-14: Number of Households of the HB SE Group Segment 1

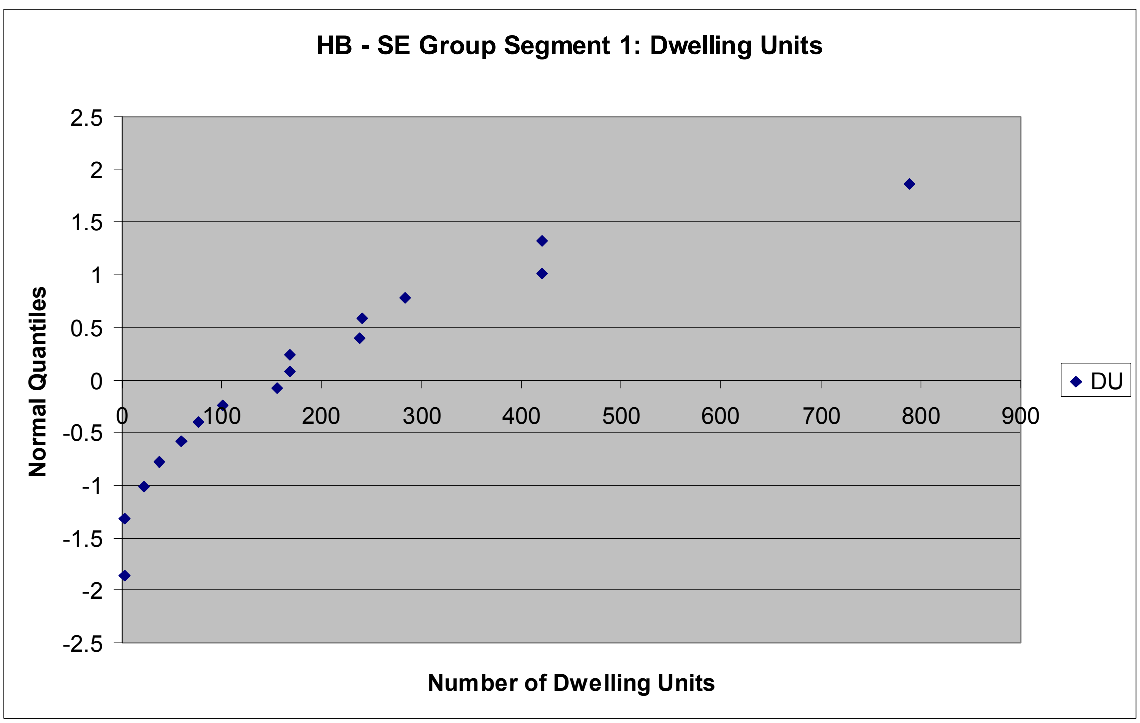

Figure E-15: Number of Dwelling Units of the HB SE Group Segment 1

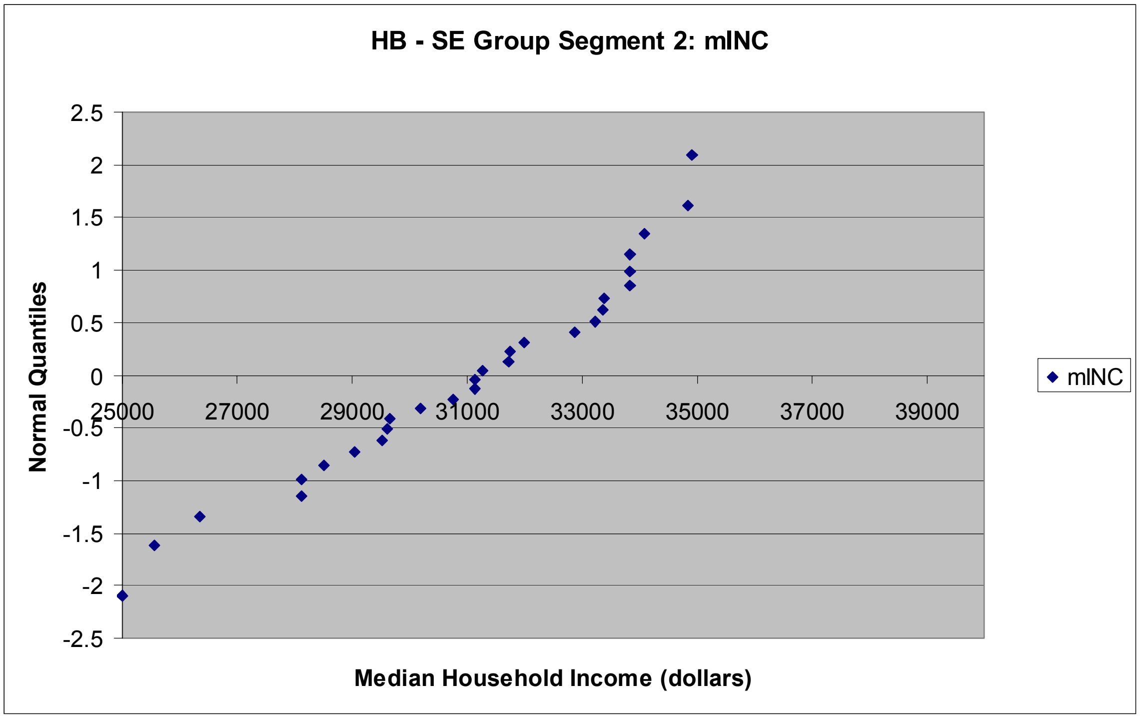

Figure E-16: Median Household Income of the HB SE Group Segment 2

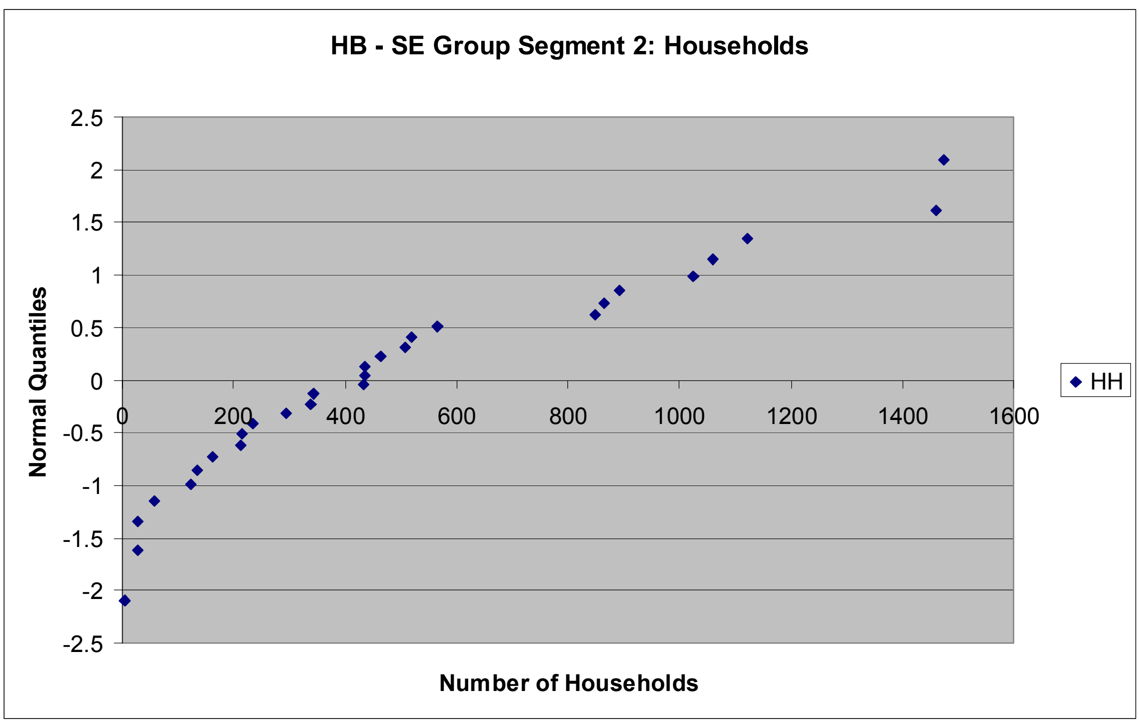

Figure E-17: Number of Households of the HB SE Group Segment 2

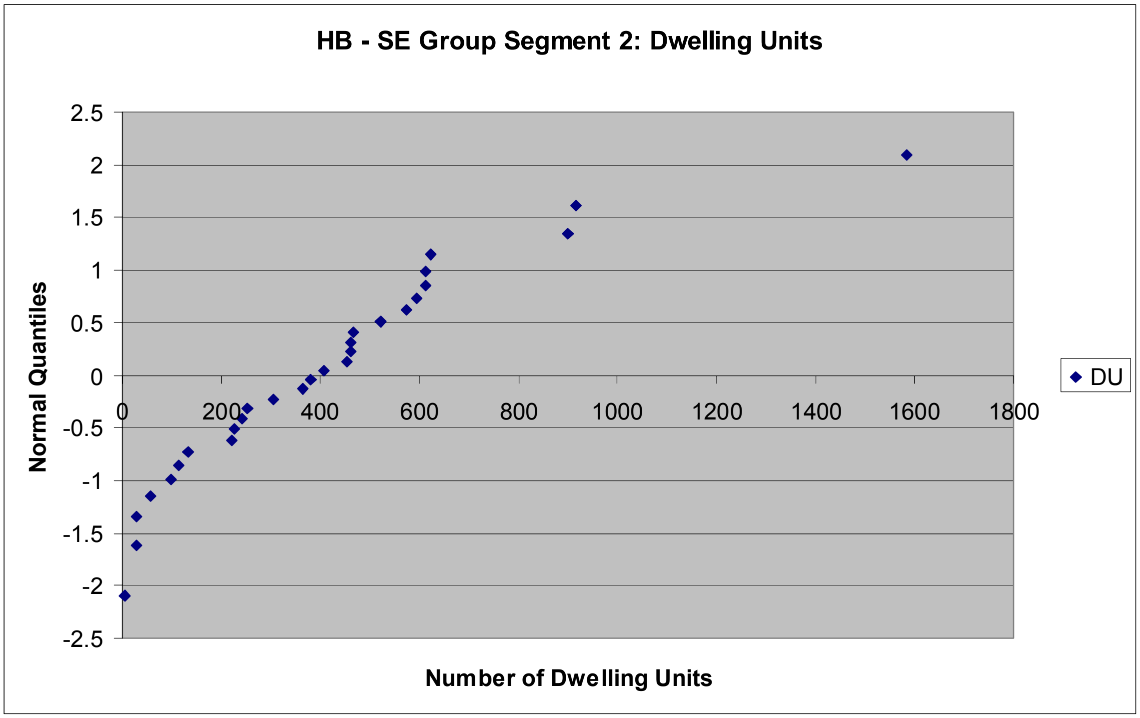

Figure E-18: Number of Dwelling Units of the HB SE Group Segment 2

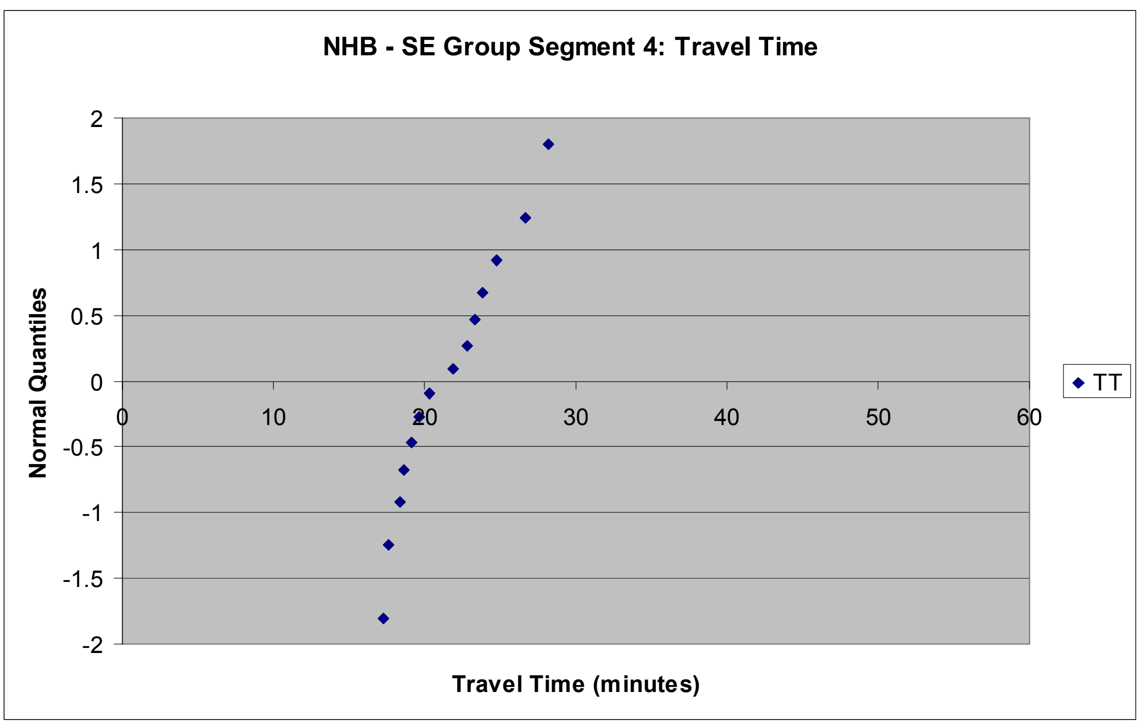

Figure E-19: Travel Time to the RDU Airport of the NHB SE Group Segment 4

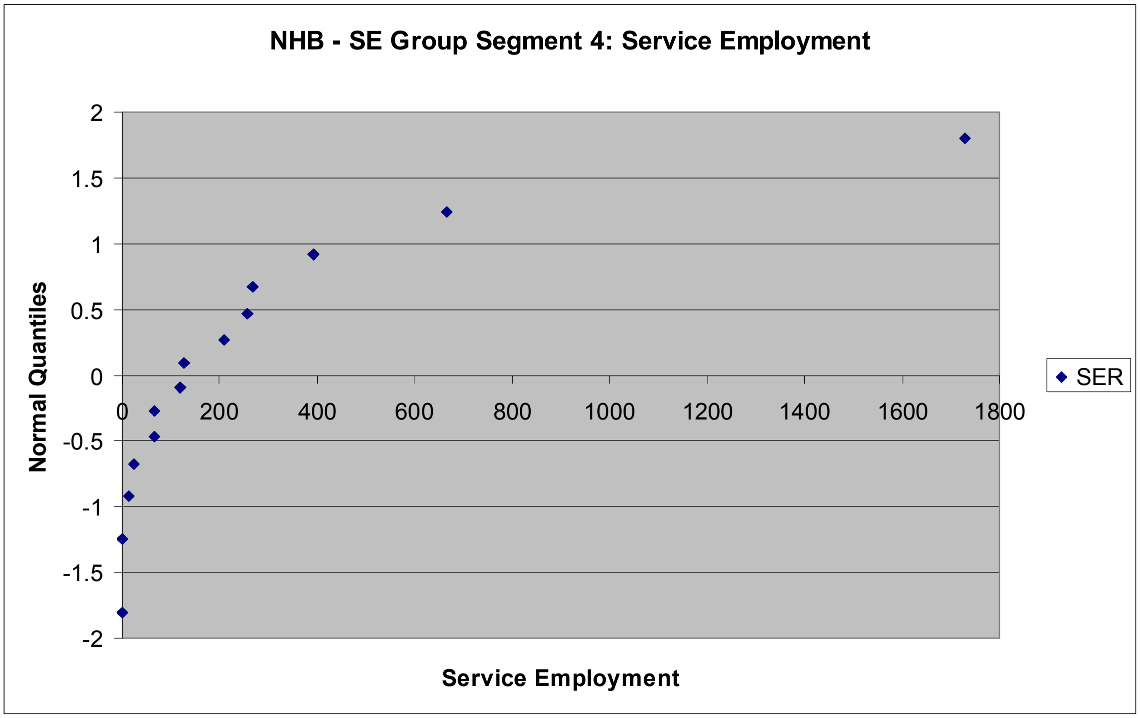

Figure E-20: Service Employment of the NHB SE Group Segment 4

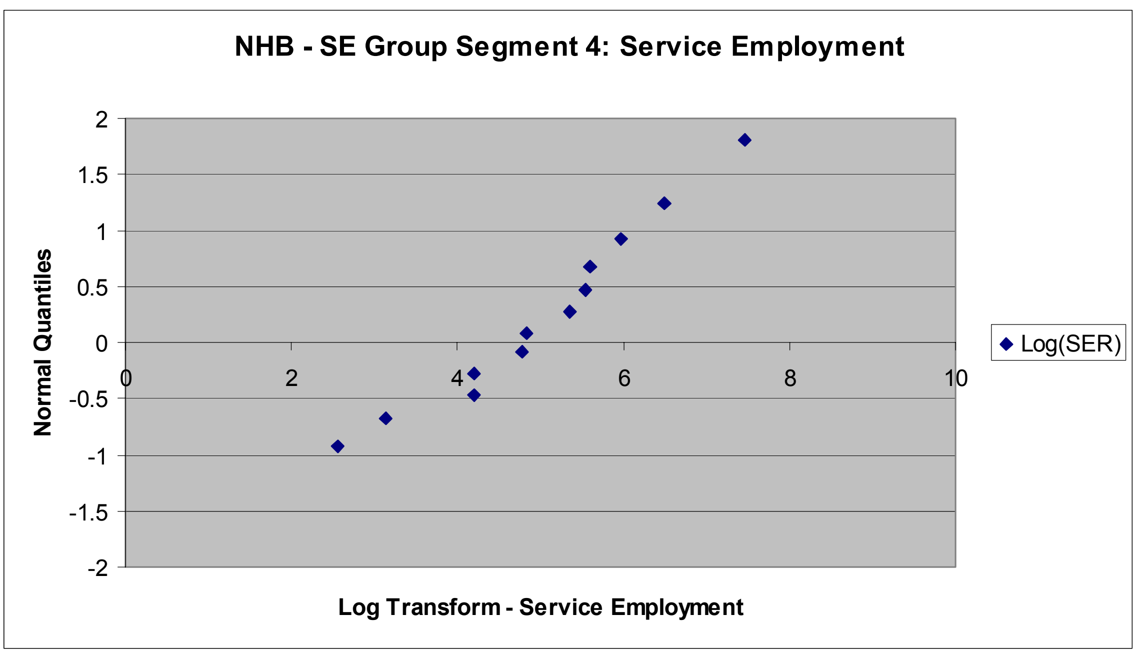

Figure E-21: Log Transform of Service Employment of the NHB SE Group Segment 4

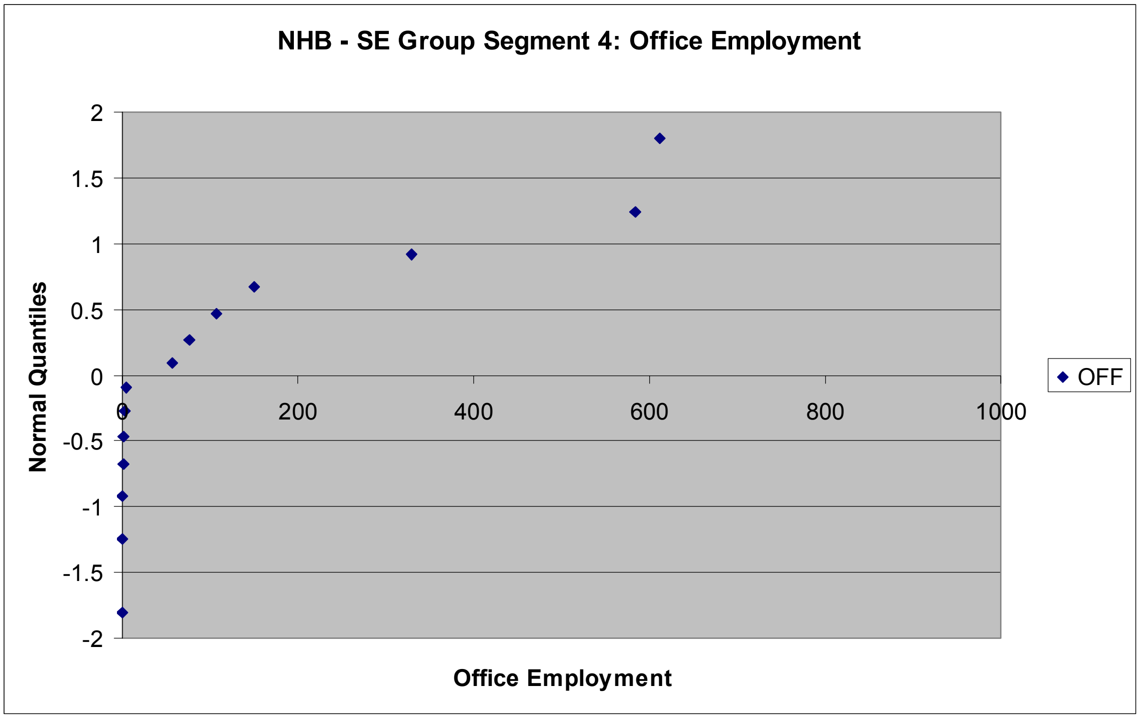

Figure E-22: Office Employment of the NHB SE Group Segment 4

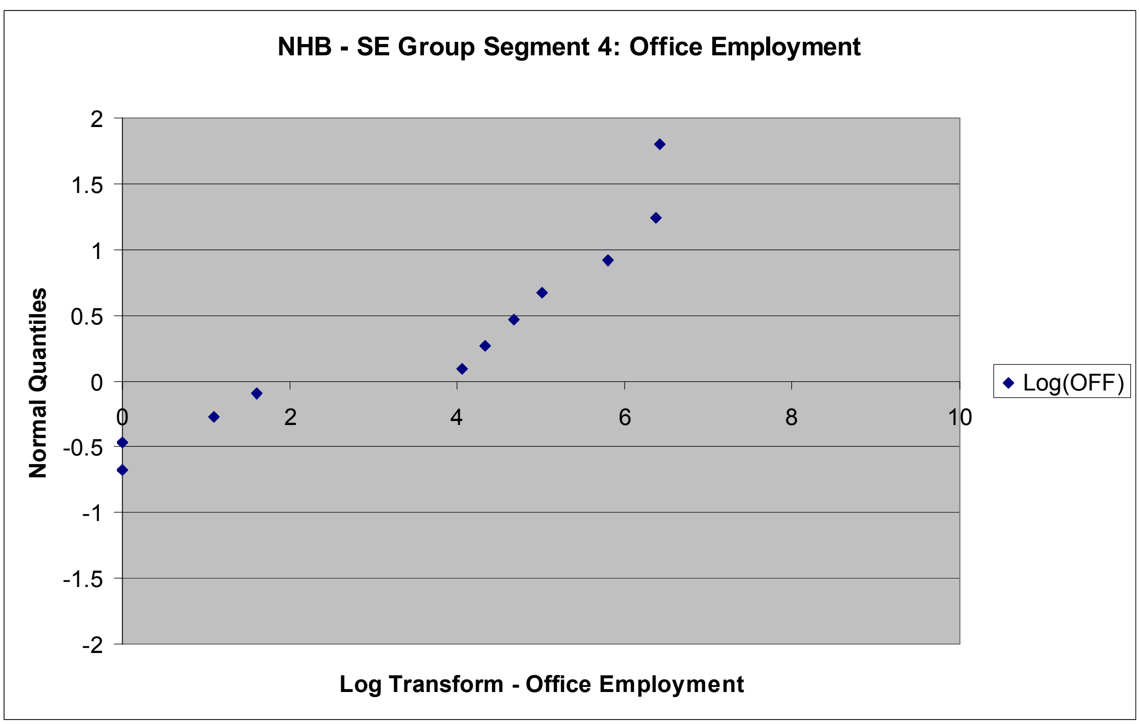

Figure E-23: Log Transform of Office Employment of the NHB SE Group Segment 4

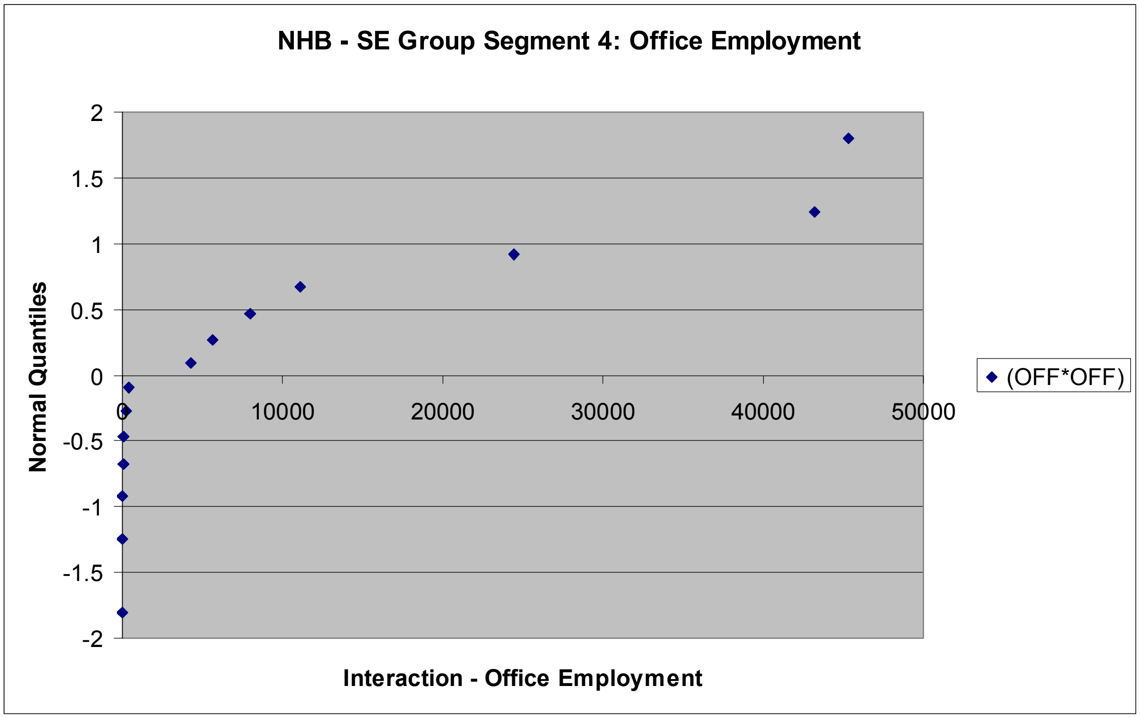

Figure E-24: Interaction of Office Employment of the NHB SE Group Segment 4

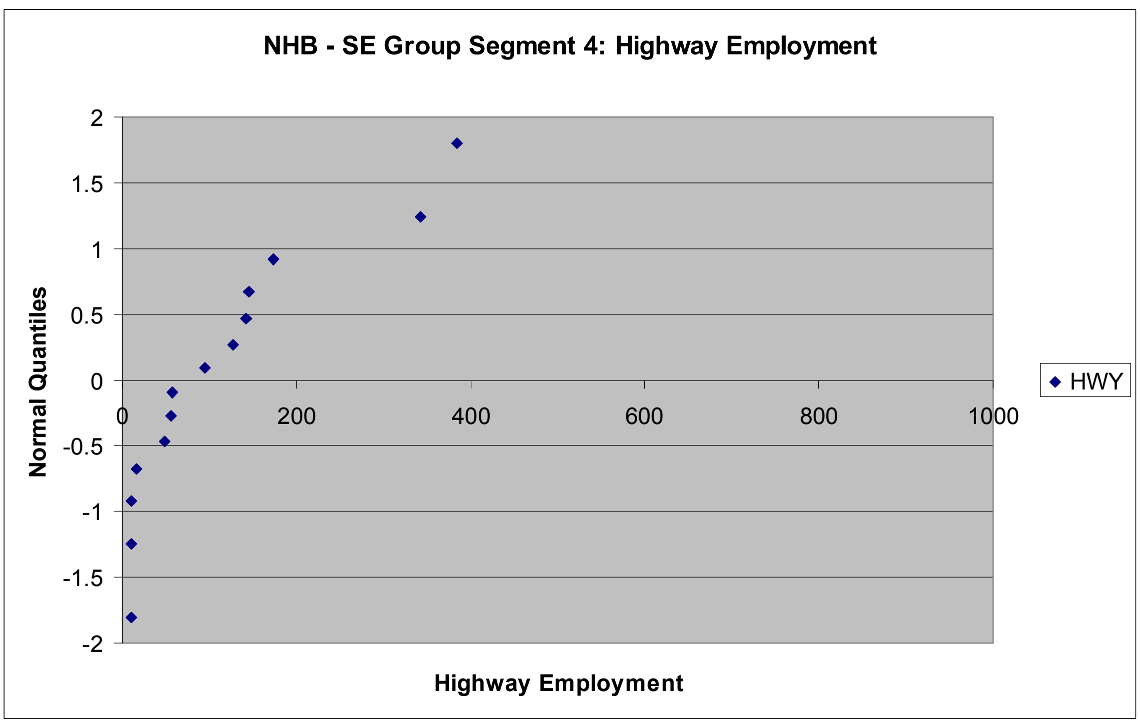

Figure E-25: Highway Employment of the NHB SE Group Segment 4

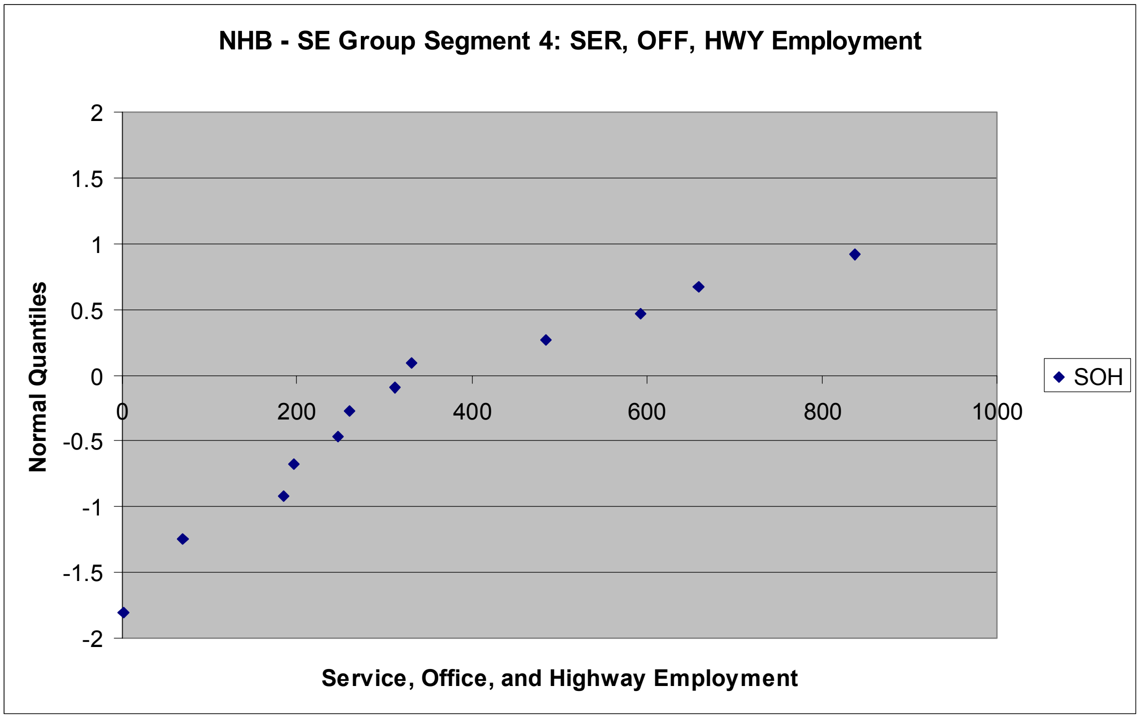

Figure E-26: The Sum of Service, Office, and Highway Employment of the NHB SE Group Segment 4

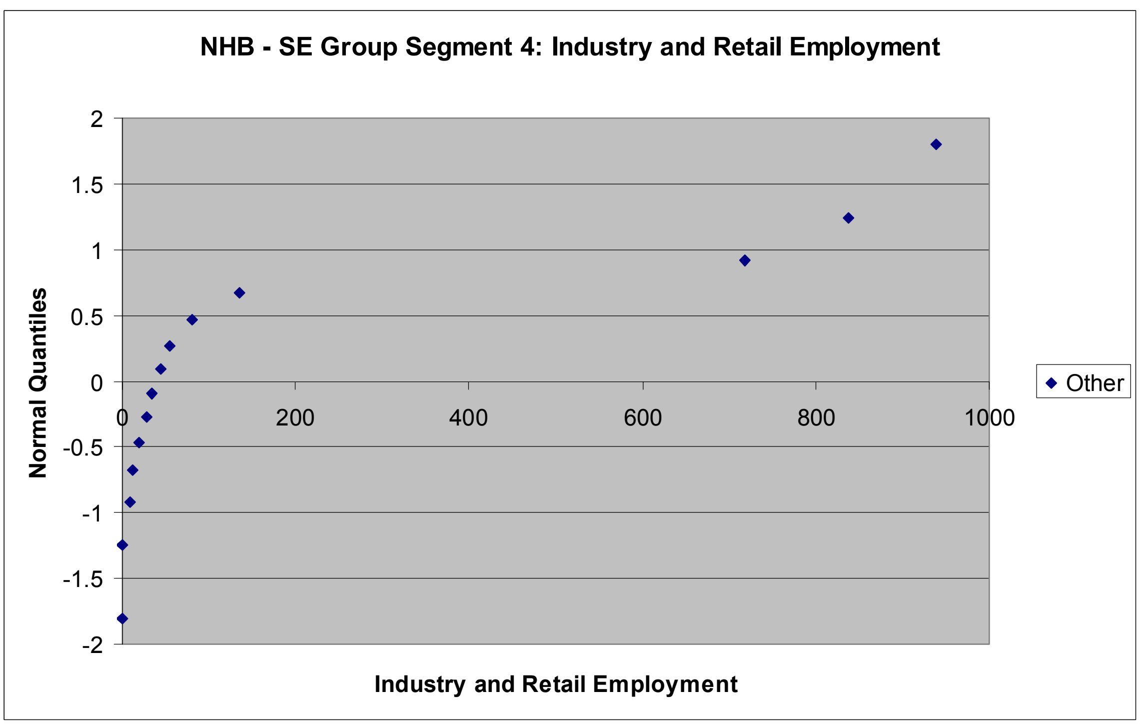

Figure E-27: Industry and Retail Employment of the NHB SE Group Segment 4

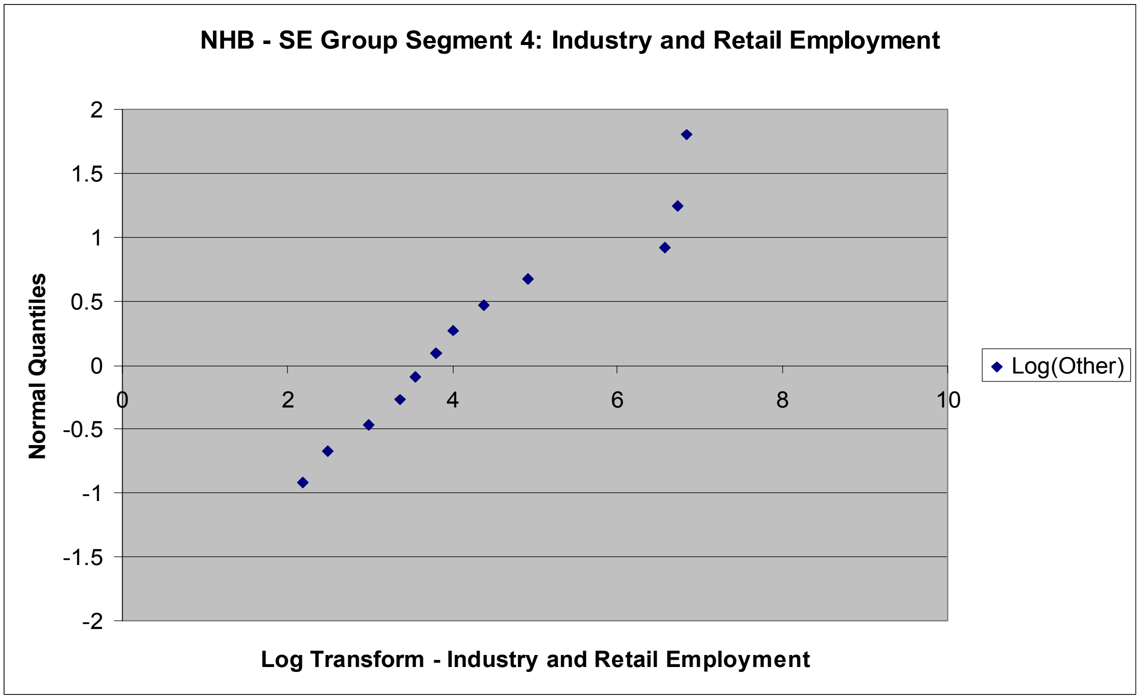

Figure E-28: Log Transform of Industry and Retail Employment of the NHB SE Group Segment 4

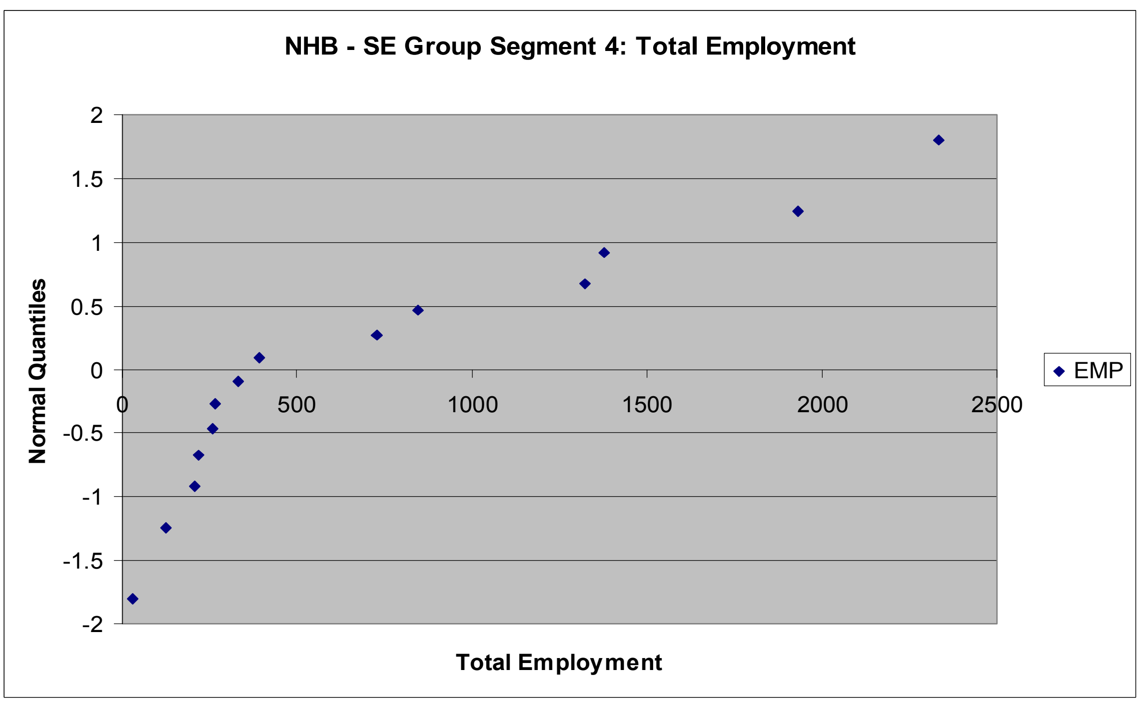

Figure E-29: Total Employment of the NHB SE Group Segment 4

Appendix F : Biogeme Input Files (*.par, *.dat, and *.mod)

Biogeme Parameter File

The parameter file provides the parameters controlling the execution of the Biogeme program. The default Biogeme parameter file is used in this study with an exception for the parameter "gevTtestThreshold." This parameter specifies the critical value of the t-statistic for a two-tailed test. The default value for this parameter is 1.96 at 95% confidence level. This study changes the value to 1.28 at 80% confidence level due to the small sample size of the observed data and the asymptotic property of the MNL model parameter t-distributions. If the absolute value of a t-test is less than the "gevTtestThreshold" value, the estimated parameter will be flagged with a warning symbol * in the Biogeme output files. **Figure F-1** shows the parameter file used in this study.

```
// Michel Bierlaire, EPFL (c) 2001-2005

// BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
// Author: Michel Bierlaire, EPFL (2001-2005)

[GEV]
gevAlgo = "BIO"
gevScreenPrintLevel = 1
gevLogFilePrintLevel = 2
gevRandomDistrib = "PSEUDO"
gevPrintVarCovarAsList = 1
gevPrintVarCovarAsMatrix = 0
gevTtestThreshold = 1.28

[BasicTrustRegion]
BTRMaxIter = 1000

[cfsqp]
cfsqpMaxIter = 1000

[solvopt]
solvoptMaxIter = 1000
```

Figure F-1: Biogeme Parameter File

Biogeme Data Files

The Biogeme data files are a combination of the trip maker characteristics, the TAZ destination characteristics, and the SE group segment destination characteristics along with their corresponding data values for each observation. The first row of the data file corresponds to the labels of the available data fields and each subsequent row corresponds to an observation. Each row must have a data value for each data field. **Table F-1** through **Table F-3** show the Biogeme MNL models for each trip purposes, respectively.

Table F-1: Biogeme HB MNL Model Data File

Obs_ID	INC	HS	GEN	T_Type	TAZ	Choice	INC_Level	mINC	HH	DU	HHS	TT	HH_1	HH_2	HH_3	HH_4	HH_5	DU_1	DU_2	DU_3	DU_4	DU_5	mINC_1	mINC_2	.	.
15	4	5	2	1	139	5	5	90000	574	490	2	36.25	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
13	3	6	1	1	138	5	5	84665	481	406	2	35.96	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
14	5	3	2	7	138	5	5	84665	481	406	2	35.96	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
318	5	4	1	3	2039	5	5	113345	423	452	3	34.23	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
319	5	7	2	7	2039	5	5	113345	423	452	3	34.23	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
193	3	4	2	3	1330	5	5	93615	235	244	3	34.02	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
16	5	2	1	1	142	5	5	90000	430	380	2	33.85	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
17	5	1	2	5	142	5	5	90000	430	380	2	33.85	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
207	5	3	2	3	1477	5	5	106030	214	249	3	31.83	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
44	5	4	2	7	366	5	5	99240	352	372	3	31.66	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
315	4	5	1	3	2030	5	5	118965	154	126	2	31.63	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
313	3	3	2	7	2011	5	5	94950	435	359	2	31.52	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
278	3	2	1	3	1863	5	5	80295	632	677	2	31.25	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
279	3	2	2	3	1863	5	5	80295	632	677	2	31.25	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
45	3	1	2	7	367	5	5	90000	344	358	3	31.01	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
290	5	5	2	3	1914	5	5	89445	437	360	2	30.07	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
311	3	3	1	3	2004	5	5	118290	107	88	2	30.02	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
196	4	2	2	7	1383	5	5	89050	489	522	3	28.87	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
276	4	2	2	5	1857	5	5	100000	221	237	3	28.36	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
43	3	6	1	1	362	5	5	107000	153	157	2	28.14	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
5	3	2	1	1	52	5	5	87160	134	140	2	27.29	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
244	1	1	2	7	1662	5	5	96935	911	963	3	27.17	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
245	4	1	2	1	1662	5	5	96935	911	963	3	27.17	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
246	5	4	1	1	1662	5	5	96935	911	963	3	27.17	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
247	5	4	1	1	1662	5	5	96935	911	963	3	27.17	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
248	5	4	2	3	1662	5	5	96935	911	963	3	27.17	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
277	2	2	2	7	1861	5	5	80295	209	173	2	26.91	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
296	1	1	2	7	1936	5	5	102970	394	325	2	26.82	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
106	4	1	1	1	778	5	5	87370	363	373	3	26.68	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
126	4	4	1	3	955	5	5	106215	478	494	4	26.47	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
6	5	3	1	1	70	5	5	92795	605	360	1	26.29	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
316	4	4	2	7	2036	5	5	101325	282	233	2	26.22	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
317	4	4	2	7	2036	5	5	101325	282	233	2	26.22	208	261	258	278	240	179	229	255	287	243	17003	30241	.	.
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Table F-2: Biogeme NHB MNL Model Data File

Obs_ID	INC	HS	GEN	PRIOR	T_Type	TAZ	Choice	TT	SER	OFF	HWY	SOH	Other	EMP	TT_1	TT_2	TT_3	TT_4	SER_1	SER_2	SER_3	SER_4	OFF_1	OFF_2	OFF_3	OFF_4	HWY_1	.	.
166	5	4	1	3	8	300	1	18.95	1916	461	5	2382	367	2749	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1147	5	4	1	3	2	793	1	26.51	2161	109	5	2275	183	2458	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
488	5	6	1	3	6	1028	1	23.35	1729	108	49	1886	45	1931	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
942	5	2	1	3	6	1028	1	23.35	1729	108	49	1886	45	1931	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
140	1	2	1	3	8	263	1	15.48	413	1278	4	1695	8	1703	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1406	3	1	1	3	4	266	1	14.24	271	1123	38	1432	279	1711	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1305	4	3	1	3	8	266	1	14.24	271	1123	38	1432	279	1711	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
705	5	2	1	3	6	1642	1	25.38	547	210	407	1164	2385	3549	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
690	5	3	2	3	8	1437	1	25.03	744	41	170	955	1009	1964	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
999	5	5	1	3	6	1475	1	19.69	401	14	394	809	260	1069	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
149	4	3	2	3	8	1475	1	19.69	401	14	394	809	260	1069	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1003	1	6	2	3	6	1061	1	9.46	479	58	263	800	401	1201	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
433	4	2	1	3	8	1061	1	9.46	479	58	263	800	401	1201	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
496	5	3	1	3	4	545	1	23.33	575	132	68	775	4	779	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1098	4	3	1	3	4	545	1	23.33	575	132	68	775	4	779	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1225	5	4	2	3	4	545	1	23.33	575	132	68	775	4	779	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
246	3	2	2	3	8	545	1	23.33	575	132	68	775	4	779	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
505	5	6	1	3	6	1438	1	24.66	604	140	0.9	744	988	1732	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
636	2	1	1	3	2	1627	1	26.9	529	36	61	626	32	658	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
363	5	3	1	3	8	1627	1	26.9	529	36	61	626	32	658	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1069	5	2	1	3	6	672	1	21.73	320	171	46	537	15	552	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1393	5	2	2	3	6	672	1	21.73	320	171	46	537	15	552	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
238	4	7	1	3	8	672	1	21.73	320	171	46	537	15	552	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
402	5	4	1	3	8	399	1	27.89	451	55	27	533	32	565	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
928	5	4	2	3	4	1062	1	11.77	393	41	95	529	595	1124	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
972	4	2	2	3	4	1062	1	11.77	393	41	95	529	595	1124	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1201	1	2	2	3	4	1062	1	11.77	393	41	95	529	595	1124	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1383	3	2	2	3	4	1062	1	11.77	393	41	95	529	595	1124	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1040	4	3	1	3	6	1062	1	11.77	393	41	95	529	595	1124	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
36	2	4	2	3	8	1062	1	11.77	393	41	95	529	595	1124	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
53	5	3	1	3	8	1062	1	11.77	393	41	95	529	595	1124	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1365	4	3	2	3	8	1062	1	11.77	393	41	95	529	595	1124	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1366	4	3	2	3	8	1062	1	11.77	393	41	95	529	595	1124	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1449	4	3	1	3	6	685	1	17.86	296	163	0.9	459	131	590	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
978	2	2	1	3	6	798	1	27.48	151	60	76	287	193	480	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
1357	5	6	1	3	8	1928	1	26.84	104	1	25	130	0.9	130	27.18	17.86	29.63	28.3	313	274	213	272	105	177	180	74	43	.	.
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Table F-3: Biogeme J-to-W MNL Model Data File

Obs_ID	INC	HS	Time	GEN	TAZ	Choice	INC_Level	mINC	HH	DU	HHS	TT	mINC_1	mINC_2	mINC_3	mINC_4	mINC_5	mINC_6	TT_1	TT_2	TT_3	TT_4	TT_5	TT_6	HH_1	HH_2	.	.
1991	4	2	30	2	1495	1	2	33570	77	85	2	36.92	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2102	1	1	35	2	1621	1	1	24105	276	295	1	35.74	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
366	4	1	20	1	878	1	1	20750	56	60	1	34.35	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2615	2	1	25	1	878	1	1	20750	56	60	1	34.35	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
3619	5	4	35	2	1314	1	2	28125	344	406	2	34.18	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
577	4	3	15	1	396	1	1	23855	587	522	1	31.84	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2622	4	1	25	2	890	1	2	31000	71	75	2	31.41	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1240	2	1	25	2	80	1	2	31955	1321	837	2	29.54	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2607	2	3	30	1	754	1	1	19410	230	239	1	28.49	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2125	3	3	22	1	355	1	2	28155	448	268	2	27.88	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1275	1	3	40	1	72	1	2	28890	418	261	2	27.63	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2072	1	2	30	1	72	1	2	28890	418	261	2	27.63	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1954	1	3	30	1	162	1	2	31335	108	96	2	27.55	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1259	1	5	25	2	789	1	2	32320	76	77	2	27.55	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2312	2	2	30	1	1574	1	1	22915	91	102	1	27.33	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
615	2	3	30	1	1629	1	2	34140	1164	1057	2	27.1	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
880	5	4	10	2	1556	1	1	24100	175	211	1	26.92	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
881	4	2	10	1	1556	1	1	24100	175	211	1	26.92	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
710	2	5	30	1	1575	1	1	22915	122	136	1	26.88	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2612	1	5	25	1	801	1	2	29340	343	378	2	26.64	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1262	3	2	20	2	837	1	2	27070	264	281	2	26.1	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2508	2	3	15	2	837	1	2	27070	264	281	2	26.1	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
681	3	2	35	1	765	1	2	30045	330	352	2	26.03	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1972	4	1	30	2	765	1	2	30045	330	352	2	26.03	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1272	1	5	20	2	43	1	2	27205	314	298	2	26.03	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1387	1	3	30	2	419	1	2	28125	234	254	2	25.87	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
286	3	6	20	2	350	1	1	21680	287	340	1	24.69	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
685	1	4	20	2	23	1	2	34000	132	115	2	24.68	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2086	3	3	20	1	1459	1	1	19890	238	247	1	24.67	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1226	1	4	15	2	737	1	2	34080	892	916	2	24.38	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
281	2	3	28	1	1644	1	2	25715	269	402	2	24.32	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
2051	2	1	30	2	1644	1	2	25715	269	402	2	24.32	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
1677	1	1	25	1	340	1	1	21565	268	322	1	22.97	24652	42181	43147	62954	60614	106071	29.1	20.4	37.2	20.55	36.89	26.37	239	370	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
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Biogeme Model Files

The Biogeme MNL model files contain the specifications of the MNL model to be estimated. The Biogeme format requires a description of the model, identification of the destination choice field name that is used in the corresponding data file ([Choice]), a list of the estimated parameters and their value bounds, the utility function for each destination choice, expressions of the utility function, and specification of the destination choice model type (MNL). The expressions section is used to state the availability of the choice destination (Av_# = 1), to define any characters or words not specified in the parameters section, and to incorporate non-linear functions into the linear-in-parameter utility expressions. **Figure F-2**, **Figure F-3**, and **Figure F-4** show the Biogeme MNL models for the HB, NHB, and J-to-W trip purposes, respectively.

```
[ModelDescription]
RDU Airport MNL Model for HB trips

[Choice]
Choice

[Beta]
// Name Value   LowerBound  UpperBound Status (0=variable, 1=fixed)
ASC_1        0.0   -1.00E+00   1.00E+00       1
ASC_2        0.0   -1.00E+00   1.00E+00       0
ASC_3        0.0   -1.00E+00   1.00E+00       0
ASC_4        0.0   -1.00E+00   1.00E+00       0
ASC_5        0.0   -1.00E+00   1.00E+00       0
B_HH         0.0   -1.00E+00   1.00E+00       0
B_INC        0.0   -1.00E+00   1.00E+00       0
B_HS         0.0   -1.00E+00   1.00E+00       0

[Utilities]
// ID   Name    Avail       linear-in-parameter expression (beta1*x1 + beta2*x2 + )
1       INC_1   Av_1        ASC_1 * one + B_HH * HH2_1 + B_HS * HS2_1 + B_INC * INC2_1
2       INC_2   Av_2        ASC_2 * one + B_HH * HH2_2 + B_HS * HS2_2 + B_INC * INC2_2
3       INC_3   Av_3        ASC_3 * one + B_HH * HH2_3 + B_HS * HS2_3 + B_INC * INC2_3
4       INC_4   Av_4        ASC_4 * one + B_HH * HH2_4 + B_HS * HS2_4 + B_INC * INC2_4
5       INC_5   Av_5        ASC_5 * one + B_HH * HH2_5 + B_HS * HS2_5 + B_INC * INC2_5

[Expressions]
one = 1
Av_1 = 1
Av_2 = 1
Av_3 = 1
Av_4 = 1
Av_5 = 1
$LOOP {zz 1 5 1} HH2_zz = HH_zz * HH
$LOOP {zz 1 5 1} HS2_zz = HHS_zz * HS
$LOOP {zz 1 5 1} INC2_zz = mINC_zz * INC

[Model]
$MNL
```

Figure F-2: Biogeme HB MNL Model File

```
[ModelDescription]
"RDU Airport MNL Model for NHB trips"

[Choice]
Choice

[Beta]
//       Name      Value      LowerBour UpperBour Status   (0=variable, 1=fixed)
ASC_1           0  -1.00E+00 1.00E+00        1
ASC_2           0  -1.00E+00 1.00E+00        0
ASC_3           0  -1.00E+00 1.00E+00        0
ASC_4           0  -1.00E+00 1.00E+00        0
B_OFF3          0  -1.00E+00 1.00E+00        0
B_EMP3          0  -1.00E+00 1.00E+00        0
B_TT3           0  -1.00E+00 1.00E+00        0

[Utilities]
//       ID       Name       Avail    linear-in-parameterexpression(beta1*x1+beta2*x2+)
       1 NHB_1    Av_1       ASC_1 * one + B_OFF3 * OFF3_1 + B_EMP3 * EMP3_1 + B_TT3 * TT3_1
       2 NHB_2    Av_2       ASC_2 * one + B_OFF3 * OFF3_2 + B_EMP3 * EMP3_2 + B_TT3 * TT3_2
       3 NHB_3    Av_3       ASC_3 * one + B_OFF3 * OFF3_3 + B_EMP3 * EMP3_3 + B_TT3 * TT3_3
       4 NHB_4    Av_4       ASC_4 * one + B_OFF3 * OFF3_4 + B_EMP3 * EMP3_4 + B_TT3 * TT3_4

[Expressions]
one = 1
Av_1 = 1
Av_2 = 1
Av_3 = 1
Av_4 = 1
$LOOP {zz 1 5 1} OFF3_zz = OFF_zz * OFF
$LOOP {zz 1 5 1} EMP3_zz = EMP_zz * EMP
$LOOP {zz 1 5 1} TT3_zz = TT_zz * TT

[Model]
$MNL
```

Figure F-3: Biogeme NHB MNL Model File

```
[ModelDescription]
RDU Airport MNL Model for J-to-W trips

[Choice]
Choice

[Beta]
// Name Value LowerBound UpperBound  Status (0=variable, 1=fixed)
ASC_1      0.0  -1.00E+00    1.00E+00     1
ASC_2      0.0  -1.00E+00    1.00E+00     0
ASC_3      0.0  -1.00E+00    1.00E+00     0
ASC_4      0.0  -1.00E+00    1.00E+00     0
ASC_5      0.0  -1.00E+00    1.00E+00     0
ASC_6      0.0  -1.00E+00    1.00E+00     0
B_TT2      0.0  -1.00E+00    1.00E+00     0
B_HH2      0.0  -1.00E+00    1.00E+00     0
B_HS2      0.0  -1.00E+00    1.00E+00     0
B_INC2     0.0  -1.00E+00    1.00E+00     0

[Utilities]
// ID   Name  Avail      linear-in-parameter expression (beta1*x1 + beta2*x2 + )
1       INC_1 Av_1       ASC_1 * one + B_TT2 * TT2_1 + B_HH2 * HH2_1 + B_HS2 * HS2_1 + B_INC2 * INC2_1
2       INC_2 Av_2       ASC_2 * one + B_TT2 * TT2_2 + B_HH2 * HH2_2 + B_HS2 * HS2_2 + B_INC2 * INC2_2
3       INC_3 Av_3       ASC_3 * one + B_TT2 * TT2_3 + B_HH2 * HH2_3 + B_HS2 * HS2_3 + B_INC2 * INC2_3
4       INC_4 Av_4       ASC_4 * one + B_TT2 * TT2_4 + B_HH2 * HH2_4 + B_HS2 * HS2_4 + B_INC2 * INC2_4
5       INC_5 Av_5       ASC_5 * one + B_TT2 * TT2_5 + B_HH2 * HH2_5 + B_HS2 * HS2_5 + B_INC2 * INC2_5
6       INC_6 Av_6       ASC_6 * one + B_TT2 * TT2_6 + B_HH2 * HH2_6 + B_HS2 * HS2_6 + B_INC2 * INC2_6

[Expressions]
one = 1
Av_1 = 1
Av_2 = 1
Av_3 = 1
Av_4 = 1
Av_5 = 1
Av_6 = 1
$LOOP {zz 1 6 1} TT2_zz = TT_zz * TT
$LOOP {zz 1 6 1} HH2_zz = HH_zz * HH
$LOOP {zz 1 6 1} HS2_zz = HHS_zz * HS
$LOOP {zz 1 6 1} INC2_zz = mINC_zz * INC

[Model]
$MNL
```

Figure F-4: Biogeme J-to-W MNL Model File

Appendix G : Stepwise MNL Model Calibration Process

The method used to calibrate the MNL model is a backwards stepwise approach. This approach starts with a complete model of all relevant variables. The complete model is used as a base reference for all other models tested. The steps following the base model remove variables one by one to see if the model goodness-to-fit statistics improve. If the statistics improve then the variable is not added back to the model. If the statistics get worse then the variable is added back to the model and a different variable is removed. The log-likelihood ratio test is evaluated for each run compared to the previous run at 95% significance. Other goodness-to-fit statistics tested for each step model are the adjusted Rho-square and parameter t-values at 80% confidence. **Table G-1** through **Table G-4** show the stepwise calibration process for the HB MNL utility model; **Table G-5** through **Table G-9** show the stepwise calibration process for the NHB MNL utility model; and **Table G-10** through **Table G-14** show the stepwise calibration process for the J-to-W MNL utility model.

A few exponential utility model forms were tested but the goodness-to-fit statistics were not satisfactory and several of the models did not converge to the observed data. The exponential utility forms tested had a very low log-likelihood ratio and did not pass the log-likelihood ratio test at 95% confidence. Additionally, the adjusted Rho-square value was a negative number and the estimated parameter t-values were not statistically significant at 90% confidence. Therefore, the only non-linear utility forms tested are logarithmic and quadratic (interaction).

Table G-1: Variable Selection for the HB Linear Utility Model

HB LINEAR Utility Model Variable Selection:
|HH + DU + mINC + HHS| + {HH + DU + mINC + HHS} + [GEN + HS + INC] **
**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	15	168.11	N/A	0.126	No
2	[INC]	-	14	168.11	No	0.128	No
3	[HS]	-	13	168.11	No	0.130	No
4	[GEN]	-	12	168.11	No	0.132	No
5	{HHS}	-	11	168.11	No	0.134	No
6	{mINC}	-	10	168.11	No	0.135	No
7	{DU}	-	9	168.11	No	0.137	No
8	{HH}	-	8	168.11	No	0.139	No
9	|HHS|	-	7	168.11	No	0.141	No
10	|mINC|	-	6	168.11	No	0.143	No
11	|DU|	-	5	168.11	No	0.144	No

Linear parameters do not provide a good model fit

Table G-2: Variable Selection for the HB Linear Addition Interaction Utility Model

HB LINEAR Addition Interaction Utility Model Variable Selection:
(|HH| + {HH}) + (|DU| + {DU}) + (|mINC| + {mINC}) + (|HHS| + {HHS}) + (|mINC| * [INC]) + (|HHS| + [HS]) **
**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	10	168.11	No	0.135	No
13	|HHS| + [HS]	-	9	168.11	No	0.137	No
14	|mINC| * [INC]	-	8	169.11	No	0.139	No
15	|HHS| + {HHS}	-	7	170.11	No	0.141	No
16	|mINC| + {mINC}	-	6	171.11	No	0.143	No
17	|DU| + {DU}	-	5	172.11	Yes	0.144	No

Linear Addition Interaction does not provide a good model fit based on the parameter t-values

Table G-3: Variable Selection for the HB Linear Multiplication Interaction Utility Model

HB LINEAR Multiplication Interaction Utility Model Variable Selection:
(|HH| * {HH}) + (|DU| * {DU}) + (|mINC| * {mINC}) + (|HHS| * {HHS}) + (|mINC| * [INC]) + (|HHS| * [HS]) **
**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	10	151.21	No	0.120	No
18	|DU| * {DU}	-	9	151.21	No	0.122	No
19	|HHS| * {HHS}	-	8	151.21	No	0.124	No
20	|mINC| * {mINC}	-	7	184.60	Yes	0.156	Yes
21	|HHS| * [HS]	-	6	184.12	Yes	0.157	No
22	|mINC| * [INC]	|HHS| * [HS]	6	162.70	No	0.138	Yes
23	|HH| * {HH}	|mINC| * [INC]	6	184.50	Yes	0.158	No

Step 20 provides the best model fit for Linear Multiplication Interaction

Table G-4: Variable Selection for the HB Log-Linear Interaction Utility Model

HB LOG-LINEAR Interaction Utility Model Variable Selection:

(|mINC| * [INC]) + (|HHS| * [HS]) + (|HH| * {HH}) + log(|HHS| + {HHS}) + log(|HH| + {HH}) + log(|DU| + {DU}) + log(|mINC| + {mINC}) + log(|mINC| * [INC]) + log(|HHS| + [HS])**

**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	13	184.60	Yes	0.145	No
25	log(|HHS| + {HHS})	-	12	184.60	Yes	0.147	No
26	log(|HH| + {HH})	-	11	184.60	Yes	0.149	No
27	log(|DU| + {DU})	-	10	184.60	Yes	0.150	No
28	log(|HHS| + [HS])	-	9	184.60	Yes	0.152	No
29	log(|mINC| * [INC])	-	8	184.60	Yes	0.154	Yes
30	|HH| * {HH}	-	7	184.50	Yes	0.156	No
31	|mINC| + [INC]	|HH| * {HH}	7	169.60	No	0.142	Yes
32	|HH| + {HH}	|mINC| + [INC]	7	184.50	Yes	0.156	No

Step 29 provides the best model fit for Log-Linear Interaction

Based on the goodness-to-fit statistics, the parameter estimates, and the parameter t-values, Step 20 MNL utility model provides the best model fit of the observed data for the HB trip purpose.

Table G-5: Variable Selection for the NHB Linear Utility Model

NHB LINEAR Utility Model Variable Selection:

|OFF + SER + HWY + Other + EMP + TT| + {OFF + SER + HWY + Other + EMP + TT} + [GEN + HS + INC] **

**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adj. Rho Square	t-test 90% Significance
Base	N/A	-	18	36.55	N/A	0.008	No
2	[INC]	-	17	36.55	No	0.009	No
3	{EMP}	-	16	36.55	No	0.010	Yes
4	[GEN]	-	15	36.55	No	0.014	No
5	{OFF}	-	14	36.55	No	0.017	No
6	{SER}	-	13	36.55	No	0.020	No
7	{HWY}	-	12	36.55	No	0.025	No
8	|OFF|	-	11	36.55	No	0.029	No
9	{Other}	-	10	36.55	No	0.031	No
10	[HS]	-	9	36.55	No	0.037	No
11	{TT}	-	8	36.55	No	0.041	No
12	|Other|	-	7	36.55	No	0.047	No
13	|SER|	-	6	36.55	No	0.050	No
14	|TT|	-	5	36.55	No	0.057	Yes
15	|HWY|	-	4	36.55	No	0.050	No
16	|EMP|	|HWY|	4	36.55	No	0.062	No

Linear parameters do not provide a good model fit

Table G-6: Variable Selection for the NHB Linear Addition Interaction Utility Model

NHB LINEAR Addition Interaction Utility Model Variable Selection:
(|OFF + SER + HWY|) + (|OFF| + {OFF}) + (|SER| + {SER}) + (|HWY| + {HWY}) + (|Other| + {Other}) + (|EMP| + {EMP}) + (|TT| + {TT}) + ({OFF + SER + HWY}) + [GEN + HS + INC] **
**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adj. Rho Square	t-test 90% Significance
Base	N/A	-	14	36.55	No	0.018	No
18	[GEN]	-	13	36.55	No	0.022	No
19	[INC]	-	12	36.55	No	0.027	No
20	[HS]	-	11	36.55	No	0.032	No
21	|OFF| + {OFF}	-	10	36.55	No	0.036	No
22	|Other| + {Other}	-	9	36.55	No	0.039	No
23	{OSH}	-	8	36.55	No	0.044	No
24	{OFF + SER + HWY}	-	7	36.55	No	0.048	No
25	|SER| + {SER}	-	6	36.55	No	0.052	No
26	|HWY| + {HWY}	-	5	36.55	No	0.057	Yes
27	|EMP| + {EMP}	-	4	36.55	No	0.061	Yes

Linear parameters do not provide a good model fit

Table G-7: Variable Selection for the NHB Linear Multiplication Interaction Utility Model

NHB LINEAR Multiplication Interaction Utility Model Variable Selection:
(|OFF * SER * HWY|) + (|OFF| * {OFF}) + (|SER| * {SER}) + (|HWY| * {HWY}) + (|Other| * {Other}) + (|EMP| * {EMP}) + (|TT| * {TT}) + ({OFF * SER * HWY}) **
**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	11	40.885	No	0.0405	Yes
29	{OSH}	-	10	41.328	No	0.0458	No
30	{OFF * SER * HWY}	-	9	82.831	Yes	0.1392	Yes
31	|HWY| * {HWY}	-	8	82.831	Yes	0.1435	No
32	|Other| * {Other}	-	7	29.075	No	0.0324	Yes
33	|SER| * {SER}	|Other| * {Other}	7	82.624	Yes	0.1473	No
34	|OFF| * {OFF}	-	6	72.170	Yes	0.1292	Yes
35	|EMP| * {EMP}	|OFF| * {OFF}	6	75.129	Yes	0.1355	Yes
36	|TT| * {TT}	|EMP| * {EMP}	6	42.963	No	0.0665	Yes

Step 34 and 35 provide the best model fit for Linear Multiplication Interaction

Table G-8: Variable Selection for the NHB Log-Linear Utility Model

NHB LOG-LINEAR Utility Model Variable Selection:
log(|OFF|) + log(|SER|) + log(|HWY|) + log(|Other|) + log(|EMP|) + log(|TT|) + log({OFF}) + log({SER}) + log({HWY}) + log({Other}) + log({EMP}) + log({TT}) + [GEN] + [HS] + [INC] + (|OFF| * {OFF}) + (|SER| * {SER}) + (|HWY| * {HWY}) + (|Other| * {Other}) + (|EMP| * {EMP}) + (|TT| * {TT})**

**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adj. Rho Square	t-test 90% Significance
37	Base	-	24	110.67	Yes	0.135	No
38	log([INC])	-	23	110.00	Yes	0.137	No
39	log([HS])	log([INC])	23	109.97	Yes	0.137	No
40	log({TT})	-	22	110.00	Yes	0.142	No
41	log({HWY})	-	21	110.00	Yes	0.146	No
42	log([GEN])	-	20	109.94	Yes	0.150	No
43	log({EMP})	-	19	109.97	Yes	0.155	No
44	log({Other})	-	18	109.95	Yes	0.159	No
45	log({OFF})	-	17	109.18	Yes	0.161	No
46	log({SER})	log({OFF})	17	110.00	Yes	0.163	No
47	log([INC])	-	16	110.00	Yes	0.168	No
48	log({OFF})	-	15	109.97	Yes	0.172	No
49	log(|Other|)	-	14	104.60	Yes	0.164	No
50	log(|EMP|)	log(|Other|)	14	105.85	Yes	0.167	No
51	log(|TT|)	log(|EMP|)	14	103.72	Yes	0.163	No
52	log(|Other|)	log(|TT|)	14	104.60	Yes	0.164	No
53	|SER| * {SER}	log(|Other|)	14	108.14	Yes	0.172	No
54	log(|EMP|)	|SER| * {SER}	14	105.85	Yes	0.167	No
55	|OFF| * {OFF}	log(|EMP|)	14	17.50	No	-0.023	No
56	log(|OFF|)	|OFF| * {OFF}	14	101.79	Yes	0.158	No
57	log(|SER|)	log(|OFF|)	14	109.62	Yes	0.175	Yes
58	log(|HWY|)	log(|SER|)	14	108.00	Yes	0.172	No
59	|HWY| * {HWY}	log(|HWY|)	14	107.02	Yes	0.170	No
60	|EMP| * {EMP}	|HWY| * {HWY}	14	66.50	No	0.083	No
61	|Other| * {Other}	|EMP| * {EMP}	14	109.40	Yes	0.175	No
62	|TT| * {TT}	|Other| * {Other}	14	43.93	No	0.034	No
63	log(|SER|) & |Other| * ·	|TT| * {TT}	13	107.84	Yes	0.176	No
64	log(|HWY|)	|Other| * {Other}	13	108.08	Yes	0.176	No
65	|TT| * {TT}	log(|HWY|)	13	86.40	Yes	0.140	No
66	log |Hwy, EMP, TT|	-	10	88.90	Yes	0.152	Yes
67	|EMP| * {EMP}	log(|EMP|)	10	86.45	Yes	0.147	Yes

Step 57 provides the best model fit for Log-Linear

Table G-9: Variable Selection for the NHB Log-Linear Interaction Utility Model

NHB LOG-LINEAR Interaction Utility Model Variable Selection:
log(|OFF + SER + HWY|) + log(|OFF| + {OFF}) + log(|SER| + {SER}) + log(|HWY| + {HWY}) + log(|Other| + {Other}) + log(|EMP| + {EMP}) + log(|TT| + {TT}) + log({OFF + SER + HWY}) + [GEN] + [HS] + [INC] + (|OFF| * {OFF}) + (|SER| * {SER}) + (|HWY| * {HWY}) + (|Other| * {Other}) + (|EMP| * {EMP}) + (|TT| * {TT}) **

**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adj. Rho Square	t-test 90% Significance
Base	N/A	-	21	107.98	Yes	0.142	No
69	GEN, HS, INC	-	18	107.98	Yes	0.155	No
70	log(|Other| + {Other})	-	17	110.16	Yes	0.164	No
71	log(|HWY| + {HWY})	-	16	114.79	Yes	0.178	No
72	log(|EMP| + {EMP})	-	15	105.90	Yes	0.163	No
73	log(|SER| + {SER})	log(|EMP| + {EMP})	15	108.81	Yes	0.169	No
74	log(|OFF| + {OFF})	log(|SER| + {SER})	15	109.30	Yes	0.170	No
75	log (|TT| + {TT})	log(|OFF| + {OFF})	15	109.72	Yes	0.171	No
76	|EMP| * {EMP}	log (|TT| + {TT})	15	64.87	No	0.075	No
77	log(|EMP|)	|EMP| * {EMP}	15	104.96	Yes	0.161	No
78	|HWY| * {HWY}	log(|EMP|)	15	112.15	Yes	0.176	No
79	log(|HWY|)	|HWY| * {HWY}	15	109.83	Yes	0.171	No
80	|OFF| * {OFF}	log(|HWY|)	15	18.00	No	-0.026	No
81	log(|OFF|)	|OFF| * {OFF}	15	106.01	Yes	0.163	No
82	|Other| * {Other}	log(|OFF|)	15	104.85	Yes	0.161	No
83	|SER| * {SER}	|Other| * {Other}	15	109.41	Yes	0.170	No
84	|TT| * {TT}	|SER| * {SER}	15	43.93	No	0.130	No
85	EMP & OFF & TT	-	12	81.56	Yes	0.149	Yes
86	log(|EMP| + {EMP})	-	11	84.00	Yes	0.150	No
87	|EMP| * {EMP}	-	10	76.36	Yes	0.138	No
88	log(|EMP| + {EMP})	EMP & Other	10	82.62	Yes	0.147	No

Step 85 provides the best model fit for Log-Linear Interaction

Based on the goodness-to-fit statistics, the parameter estimates, and the parameter t-values, Step 85 MNL utility model provides the best model fit of the observed data for the NHB trip purpose.

Table G-10: Variable Selection for the J-to-W Linear Utility Model

J-to-W LINEAR Utility Model Variable Selection:
|HH + DU + mINC + HHS + TT| + {HH + DU + mINC + HHS + TT} + [GEN + HS + INC + Time] **
**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	19	14.27	N/A	-0.019	No
2	[Time]	-	18	14.27	No	-0.017	No
3	[INC]	-	17	14.27	No	-0.016	No
4	[HS]	-	16	14.27	No	0.014	No
5	[GEN]	-	15	14.27	No	-0.012	No
6	{TT}	-	14	14.27	No	-0.011	No
7	{HHS}	-	13	14.27	No	-0.009	No
8	{mINC}	-	12	14.27	No	-0.008	No
9	{DU}	-	11	14.27	No	-0.006	No
10	{HH}	-	10	14.27	No	-0.005	No
11	|TT|	-	9	14.27	No	-0.003	No
12	|HHS|	-	8	14.27	No	-0.001	No
13	|mINC|	-	7	14.27	No	0.000	No
14	|DU|	-	6	14.27	No	0.002	No

Linear parameters do not provide a good model fit

Table G-11: Variable Selection for the J-to-W Linear Addition Interaction Utility Model

J-to-W LINEAR Addition Interaction Utility Model Variable Selection:
(|HH| + {HH}) + (|DU| + {DU}) + (|mINC| + {mINC}) + (|HHS| + {HHS}) + (|TT| + {TT}) + (|mINC| * [INC]) + (|HHS| + [HS]) + (|TT| + [Time]) **
**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	13	14.27	No	-0.009	No
16	|TT| + [Time]	-	12	14.27	No	-0.008	No
17	|HHS| + [HS]	-	11	14.27	No	-0.006	No
18	|mINC| * [INC]	-	10	14.27	No	-0.005	No
19	|HHS| + {HHS}	-	9	14.27	No	-0.003	No
20	|mINC| + {mINC}	-	8	14.27	No	-0.001	No
21	|TT| + {TT}	-	7	14.27	No	0.000	No
22	|DU| + {DU}	-	6	14.27	No	0.001	Yes

Linear Addition Interaction does not provide a good model fit

Table G-12: Variable Selection for the J-to-W Linear Multiplication Interaction Utility Model

J-to-W LINEAR Multiplication Interaction Utility Model Variable Selection:
LUM + (|HH| * {HH}) + (|DU| * {DU}) + (|mINC| * {mINC}) + (|HHS| * {HHS}) + (|TT| * {TT}) + (|mINC| * [INC]) + (|HHS| * [HS]) + (|TT| * [Time])**
**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	13	111.54	Yes	0.068	No
24	|mINC| * {mINC}	-	12	286.46	Yes	0.208	Yes
25	|DU| * {DU}	-	11	300.29	Yes	0.221	No
26	|TT| * [Time]	-	10	305.87	Yes	0.227	Yes
27	|HHS| * [HS]	-	9	261.26	Yes	0.193	No
28	|mINC| * [INC]	|HHS| * [HS]	8	290.66	Yes	0.216	Yes
29	|HHS| * {HHS}	|mINC| * [INC]	7	279.16	Yes	0.207	Yes
30	|HH| * {HH}	|HHS| * {HHS}	6	220.52	Yes	0.161	No
31	|TT| * {TT}	|HH| * {HH}	5	159.76	Yes	0.112	No

Steps 26, 28, and 29 provide the best model fit for Linear Multiplication Interaction

Table G-13: Variable Selection for the J-to-W Log-Linear Utility Model

J-to-W LOG-LINEAR Utility Model Variable

log(|HH|) + log(|DU|) + log(|mINC|) + log(|TT|) + log(|HHS|) + log({HH}) + log({DU}) + log({mINC}) + log({HHS}) + log({TT}) + log([Time]) + log([GEN]) + log([HS]) + (|HH| * {HH}) + (|mINC| * {mINC}) + (|HHS| * {HHS}) + (|TT| * {TT}) + (|HHS| * [HS]) **

**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	24	353.66	Yes	0.242	No
33	log([GEN])	-	23	353.66	Yes	0.244	No
34	log({HHS})	-	22	353.66	Yes	0.246	No
35	log([HHS])	-	21	353.66	Yes	0.247	No
36	log({TT})	-	20	353.66	Yes	0.249	No
37	log({HH})	-	19	353.66	Yes	0.250	No
38	log({mINC})	-	18	353.66	Yes	0.252	No
39	log({HHS})	-	17	350.88	Yes	0.251	No
40	|HHS| * {HHS}	log({HHS})	17	324.96	Yes	0.231	No
41	log({DU})	|HHS| * {HHS}	17	353.66	Yes	0.253	No
42	log(|TT|)	-	16	341.81	Yes	0.246	No
43	log(|mINC|)	log(|TT|)	16	321.20	Yes	0.229	No
44	log(|HH|)	log(|mINC|)	16	353.41	Yes	0.255	No
45	log([Time])	log(|HH|)	16	353.66	Yes	0.255	No
46	log([INC])	-	15	353.66	Yes	0.257	No
47	|mINC| * [INC]	-	14	309.58	Yes	0.225	No
48	log(|DU|)	|mINC| * [INC]	14	353.58	Yes	0.258	No
49	|TT| * {TT}	-	13	185.42	Yes	0.126	No
50	|HHS| * [HS]	|TT| * {TT}	13	337.90	Yes	0.247	No
51	log(|HH|) & log(|HHS|)	|HHS| * [HS]	13	345.35	Yes	0.255	No
52	|HHS| * {HHS}	-	12	313.80	Yes	0.231	No
53	log(|TT|)	|HHS| * {HHS}	12	330.94	Yes	0.245	No
54	log(|TT|), |HHS| * [HS]	-	11	309.70	Yes	0.230	No
55	log(|TT|), HHS & mINC	-	10	296.16	Yes	0.221	No

Log-Linear does not provide a good model fit based on the parameter t-values

Table G-14: Variable Selection for the J-to-W Log-Linear Interaction Utility Model

J-to-W LOG-LINEAR Interaction Utility Model Variable Selection:

log(|HH| * {HH}) + log(|DU| * {DU}) + log(|mINC| * {mINC}) + log(|HHS| * {HHS}) + log(|HHS * [HS]) + log(|TT| * {TT}) + log(|mINC| * [INC]) + log(|TT| * [Time]) + (|HH| * {HH}) + (|mINC| * [INC]) + (|HHS| * {HHS}) + (|TT| * {TT}) + (|HHS| * [HS]) + log(TT) + log(HH) **

**|SE Group Segment Destination Characteristic|, {Trip Maker TAZ Destination Characteristic}, [Trip Maker Personal Characteristic]

Step	Variable Removed	Variable Added	# of Estimated Parameters	Log-Likelihood Ratio	Chi-square 95% Significance	Adjusted Rho-square	t-test 90% Significance
Base	N/A	-	20	394.58	Yes	0.281	No
57	log(|TT| * [Time])	-	19	383.73	Yes	0.270	No
58	log(|mINC| * [INC])	log(|TT| * [Time])	19	391.01	Yes	0.280	No
59	log(|HHS| * [HS])	-	18	386.04	Yes	0.278	No
60	log(|TT| * {TT})	log(|HHS| * [HS])	18	378.62	Yes	0.300	No
61	log(|mINC| * {mINC})	log(|TT| * {TT})	18	346.13	Yes	0.246	No
62	log(|DU| * {DU})	log(|mINC| * {mINC})	18	390.32	Yes	0.281	No
63	log(|HH| * {HH})	-	17	367.82	Yes	0.265	No
64	log(|HH|)	log(|HH| * {HH})	17	367.82	Yes	0.265	No
65	log(|TT|)	log(|HH|)	17	377.22	Yes	0.272	No
66	|HHS| * {HHS}	log(|TT|)	17	355.43	Yes	0.255	No
67	|mINC| * [INC]	|HHS| * {HHS}	17	357.26	Yes	0.256	No
68	|HHS| * [HS]	|mINC| * [INC]	17	375.33	Yes	0.271	No
69	|HH| * {HH}	|HHS| * [HS]	17	286.46	Yes	0.200	No
70	|TT| * {TT}	|HH| * {HH}	17	188.97	Yes	0.123	No

Log-Linear Interaction does not provide a good model fit based on the parameter t-values

Based on the goodness-to-fit statistics, the parameter estimates, and the parameter t-values, Step 29 MNL utility model provides the best model fit of the observed data for the J-to-W trip purpose.

Appendix H：Biogeme Output Files (*.sta, *.rep, and *.enu)

The output files with the .sta extension present the statistics of the data file used in the MNL model estimation. The output files with the .rep extension present the statistics of the model file including model goodness-to-fit statistics and model parameter estimates statistics. The output files with the .enu extension present the choice probability estimates of each observed trip maker choosing the choice destination.

Data Statistics File (*.sta)

The data statistic files of the data used in final MNL models of each trip purpose are shown in **Figure H-1**, **Figure H-2**, and **Figure H-3**. These files give the mean, minimum, and maximum values of each variable. Additionally, this file presents the number of total observations used in the model estimation and the number of observations per choice destination.

Model Statistics File (*.rep)

The model statistic files of the final MNL models of each trip purpose are shown in **Figure H-4**, **Figure H-5**, and **Figure H-6**. The first sections of these files provide the overall statistics of the MNL models. This section is checked for model goodness-to-fit statistics such as the final log-likelihood, log-likelihood ratio test, and the adjusted Rho-square estimates to help determine if the model is a good fit of the observed data. The second sections of these output files provide the parameter estimates and parameter t-statistics. This section is checked for reasonable signs and values of the parameter estimates and t-statistics. The t-statistics are used to help indicate the significance of the variables and the variables are flagged with an asterisk as insignificant if the absolute value of the t-statistic is less than or equal to the critical t-statistic of 1.28 at 80 percent confidence level.

Choice Probability Output Files (*.enu)

The simulated choice probability files of the final MNL models of each trip purpose are shown in **Figure H-7**, **Figure H-8**, and **Figure H-9**. These files are output from the Biosim application of the Biogeme software and they provide the probability of the trip maker choosing the actual chosen SE group segment destination for every observed record. To get the overall SE group segment probabilities based on all the observations, the trip maker probabilities are averaged by SE group segment. These results are shown in a summary table of the average MNL choice probability estimates by trip purpose and by SE group segment (**Table H-1**).

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Data Statistics for HB trips

Sample   size=340
Excluded Obs.:          0
Total    obs.     in       files:        340
Number   of       cases:       1360
Statistic of      attributes
++++++++++++++++++++++++
Name     Mean     Min      Max
Choice    3.79472        1        5
HH2_1     82912.1      208   309088
HH2_2      104039      261   387846
HH2_3      102843      258   383388
HH2_4      110815      278   413108
HH2_5     95667.8      240   356640
HS2_1     6.15806      2.3     16.1
HS2_2     5.89032      2.2     15.4
HS2_3     6.42581      2.4     16.8
HS2_4     6.69355      2.5     17.5
HS2_5     7.22903      2.7     18.9
INC2_1    65518.9    17003    85015
INC2_2     116530    30241   151205
INC2_3     165383    42919   214595
INC2_4     235996    61244   306220
INC2_5     408731   106071   530355
one             1        1        1
Nbr      of       chosen   alternatives
Alt      #
       1       16
       2       28
       3       57
       4      149
       5       90
Group    membership
Group    #
       1      340
```

Figure H-1: HB Data Statistics

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Data Statistics for NHB trips

Sample   size=168
Excluded Obs.:           0
Total    obs.     in       files:         167
Number   of       cases:          504
Statistic of      attributes
++++++++++++++++++++++++
Name     Mean     Min      Max
Choice    2.28402        1        4
EMP3_1     817117     5706 3.63E+06
EMP3_2     922801     6444 4.10E+06
EMP3_3     712722     4977 3.17E+06
EMP3_4     832583     5814 3.70E+06
OFF3_1    28656.1     94.5   194985
OFF3_2      48306    159.3   328689
OFF3_3    49124.8      162   334260
OFF3_4    20195.7     66.6   137418
TT3_1     574.196  257.123  911.074
TT3_2     377.305  168.956  598.667
TT3_3     625.954    280.3  993.198
TT3_4     597.857  267.718  948.616
one             1        1        1
Nbr of chosen alternatives
Alt       #
       1       38
       2       57
       3       59
       4       14
Group    membership
Group    #
       1      168
```

Figure H-2: NHB Data Statistics

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Data Statistics for J-to-W trips

Total     obs.      in        files:         352
Number    of        cases:        1760
Statistic of        attributes
++++++++++++++++++++++++
Name      Mean      Min       Max
Choice     3.62606         1         6
HH2_1       125884      3824    512177
HH2_2       194883      5920    792910
HH2_3       117983      3584    480032
HH2_4       179608      5456    730763
HH2_5       134311      4080    546465
HH2_6       126411      3840    514320
HS2_1      6.30085       2.2      17.6
HS2_2      6.58725       2.3      18.4
HS2_3      7.16006       2.5        20
HS2_4      6.87365       2.4      19.2
HS2_5      7.44646       2.6      20.8
HS2_6      7.73286       2.7      21.6
INC2_1     75143.2     24652    123260
INC2_2      128574     42181    210905
INC2_3      131519     43147    215735
INC2_4      191894     62954    314770
INC2_5      184761     60614    303070
INC2_6      323321    106071    530355
TT2_1      779.756   364.914   1491.38
TT2_2      546.633   255.816    1045.5
TT2_3      996.802   466.488    1906.5
TT2_4      550.653   257.697   1053.19
TT2_5      988.495   462.601   1890.61
TT2_6      706.604    330.68   1351.46
one              1         1         1
Nbr of chosen alternatives
Alt        #
        1        39
        2        60
        3        62
        4        70
        5        72
        6        49
Group     membership
Group      #
        1       352
```

Figure H-3: J-to-W Data Statistics

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Statistics for HB trips

Model: Multinomial Logit
Number of estimated parameters: 7
Number of observations: 340
Number of individuals: 340
Null log-likelihood:         -547.209
Init log-likelihood:         -547.209
Final log-likelihood:        -454.911
Likelihood ratio test:        184.596
Rho-square:                  0.168671
Adjusted rho-square:         0.155879
Final gradient norm:         0.281059
Variance-covariance:    from finite difference hessian

Utility parameters
******************
            Name Value                 Std err      t-test      Robust Std err Robust t-test
                  ASC_1      0.00E+00     fixed
                  ASC_2      2.56E-01   3.89E-01    6.58E-01 *     4.19E-01      6.12E-01   *
                  ASC_3      5.54E-01   3.78E-01    1.47E+00       4.05E-01      1.37E+00
                  ASC_4      9.73E-01   4.82E-01    2.02E+00       5.22E-01      1.86E+00
                  ASC_5     -8.62E-01   7.33E-01   -1.18E+00 *     8.11E-01     -1.06E+00   *
                   B_HH      1.94E-06   9.76E-06    1.99E-01 *     1.05E-05      1.85E-01   *
                   B_HS      1.98E-01   2.92E-01    6.79E-01 *     3.08E-01      6.45E-01   *
                  B_INC      6.93E-06   1.86E-06    3.72E+00       2.01E-06      3.45E+00
Scale parameters
****************
            Name       Value         Std err        t-test1      Robust Std err  Robust t-test1
                 Scale1      1.00E+00  fixed

Utility functions
*****************
INC_1                  Av_1         ASC_1 * one + B_HH * HH2_1 + B_HS * HS2_1 + B_INC * INC2_1
INC_2                  Av_2         ASC_2 * one + B_HH * HH2_2 + B_HS * HS2_2 + B_INC * INC2_2
INC_3                  Av_3         ASC_3 * one + B_HH * HH2_3 + B_HS * HS2_3 + B_INC * INC2_3
INC_4                  Av_4         ASC_4 * one + B_HH * HH2_4 + B_HS * HS2_4 + B_INC * INC2_4
INC_5                  Av_5         ASC_5 * one + B_HH * HH2_5 + B_HS * HS2_5 + B_INC * INC2_5
```

Figure H-4: HB MNL Model Statistics

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Statistics for NHB trips

Model: Multinomial Logit
Number of estimated parameters: 6
Number of observations: 168
Number of individuals: 168
Null log-likelihood:       -232.897
Init log-likelihood:       -232.897
Final log-likelihood:      -192.118
Likelihood ratio test:      81.5588
Rho-square:                0.175096
Adjusted rho-square:       0.149334
Final gradient norm:        12.3526
Variance-covariance:   from finite difference hessian
Utility parameters
******************
              Name       Value        Std err       t-test      Robust Std err  Robust t-test
                ASC_1     0.00E+00      fixed
                ASC_2     1.00E+00    3.91E-05        2.56E+04
                ASC_3    -1.35E-01    2.42E-01       -5.60E-01 *
                ASC_4    -1.00E+00    6.71E-06       -1.49E+05
               B_EMP3     3.08E-06    1.13E-06        2.73E+00
               B_OFF3     1.61E-05    6.16E-06        2.62E+00
                B_TT3     8.59E-03    1.33E-03        6.47E+00
Scale parameters
****************
           Name       Value        Std err        t-test         Robust Std err  Robust t-test1
         Scale1 +1.00( fixed

Utility functions
*****************
        NHB_1        Av_1        ASC_1 * one + B_OFF3 * OFF3_1 + B_EMP3 * EMP3_1 + B_TT3 * TT3_1   * EMP3_1 + B_TT3 * TT3_1
        NHB_2        Av_2        ASC_2 * one + B_OFF3 * OFF3_2 + B_EMP3 * EMP3_2 + B_TT3 * TT3_2   * EMP3_2 + B_TT3 * TT3_2
        NHB_3        Av_3        ASC_3 * one + B_OFF3 * OFF3_3 + B_EMP3 * EMP3_3 + B_TT3 * TT3_3   * EMP3_3 + B_TT3 * TT3_3
        NHB_4        Av_4        ASC_4 * one + B_OFF3 * OFF3_4 + B_EMP3 * EMP3_4 + B_TT3 * TT3_4   * EMP3_4 + B_TT3 * TT3_4
```

Figure H-5: NHB MNL Model Statistics

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Statistics for J-to-W trips

Model: Multinomial Logit
Number of estimated parameters: 9
Number of observations: 352
Number of individuals: 352
Null log-likelihood:        -630.699
Init log-likelihood:        -630.699
Final log-likelihood:       -491.119
Likelihood ratio test:        279.16
Rho-square:                  0.22131
Adjusted rho-square:         0.20704
Final gradient norm:         3212.71
Variance-covariance:   from finite difference hessian
Utility parameters
******************
            Name          Value        Std err       t-test      Robust Std err  Robust t-test
                 ASC_1   0.00E+00        fixed
                 ASC_2   3.84E-01      4.64E-01      8.27E-01   *
                 ASC_3  -9.99E-01      1.88E-01     -5.33E+00
                 ASC_4   8.79E-01      4.50E-01      1.95E+00
                 ASC_5  -1.00E+00      4.74E-05     -2.11E+04
                 ASC_6  -1.44E-01      5.53E-01     -2.61E-01   *
                 B_HH2   2.58E-05      3.78E-06      6.84E+00
                 B_HS2  -8.24E-01      2.11E-01     -3.91E+00
                B_INC2   9.47E-06      1.89E-06      5.00E+00
                 B_TT2   9.34E-03      1.11E-03      8.38E+00
Scale parameters
****************
            Name      Value        Std err        t-test1        Robust Std err  Robust t-test1
          Scale1 +1.00( fixed

Utility functions
*****************
        INC_1        Av_1        ASC_1 * one + B_TT2 * TT2_1 + B_HH2 * HH2_1 + B_HS2 * HS2_1 + B_INC2 * INC2_1
        INC_2        Av_2        ASC_2 * one + B_TT2 * TT2_2 + B_HH2 * HH2_2 + B_HS2 * HS2_2 + B_INC2 * INC2_2
        INC_3        Av_3        ASC_3 * one + B_TT2 * TT2_3 + B_HH2 * HH2_3 + B_HS2 * HS2_3 + B_INC2 * INC2_3
        INC_4        Av_4        ASC_4 * one + B_TT2 * TT2_4 + B_HH2 * HH2_4 + B_HS2 * HS2_4 + B_INC2 * INC2_4
        INC_5        Av_5        ASC_5 * one + B_TT2 * TT2_5 + B_HH2 * HH2_5 + B_HS2 * HS2_5 + B_INC2 * INC2_5
        INC_6        Av_6        ASC_6 * one + B_TT2 * TT2_6 + B_HH2 * HH2_6 + B_HS2 * HS2_6 + B_INC2 * INC2_6
```

Figure H-6: J-to-W MNL Model Statistics

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Choice Probabilities for HB trips


Choice_Id  Choice    P_choice
         1 INC_1      2.60E-02
         1 INC_1      4.14E-02
         1 INC_1      4.34E-02
         1 INC_1      5.52E-02
         1 INC_1      7.54E-02
         1 INC_1      3.22E-02
         1 INC_1      4.15E-02
         1 INC_1      5.35E-02
         1 INC_1      1.04E-01
         1 INC_1      3.26E-02
         1 INC_1      1.03E-01
         1 INC_1      4.07E-02
         1 INC_1      4.10E-02
         1 INC_1      4.49E-02
         1 INC_1      8.34E-02
         1 INC_1      4.52E-02
         2 INC_2      7.17E-02
         2 INC_2      1.02E-01
         2 INC_2      5.11E-02
         . .          .
         . .          .
         . .          .
         . .          .
         5 INC_5      2.51E-01
         5 INC_5      3.41E-01
         5 INC_5      3.64E-01
         5 INC_5      3.31E-01
         5 INC_5      2.73E-01
         5 INC_5      1.85E-01
         5 INC_5      3.39E-01
         5 INC_5      3.43E-01
         5 INC_5      2.63E-01
         5 INC_5      3.45E-01
         5 INC_5      3.40E-01
```

Figure H-7: HB MNL Choice Probability Estimates

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Choice Probabilities for NHB trips


Choice_Id  Choice    P_choice
        1 NHB_1      2.19E-01
        1 NHB_1      3.20E-01
        1 NHB_1      3.08E-01
        1 NHB_1      3.08E-01
        1 NHB_1      9.70E-02
        1 NHB_1      1.09E-01
        1 NHB_1      1.09E-01
        1 NHB_1      2.95E-01
        1 NHB_1      3.25E-01
        1 NHB_1      3.09E-01
        1 NHB_1      3.09E-01
        1 NHB_1      2.44E-01
        1 NHB_1      2.44E-01
        1 NHB_1      2.93E-01
        1 NHB_1      2.93E-01
        1 NHB_1      2.93E-01
        1 NHB_1      2.93E-01
        1 NHB_1      3.05E-01
        1 NHB_1      3.09E-01
        . .          .
        . .          .
        . .          .
        . .          .
        4 NHB_4      9.07E-02
        4 NHB_4      6.58E-02
        4 NHB_4      1.38E-01
        4 NHB_4      1.43E-01
        4 NHB_4      1.36E-01
        4 NHB_4      9.24E-02
        4 NHB_4      1.22E-01
        4 NHB_4      1.36E-01
        4 NHB_4      1.49E-01
        4 NHB_4      1.40E-01
        4 NHB_4      1.33E-01
        4 NHB_4      1.30E-01
        4 NHB_4      1.40E-01
```

Figure H-8: NHB MNL Choice Probability Estimates

```
// Michel Bierlaire, EPFL (c) 2001-2005

BIOGEME Version 1.4 [Mon Dec 12 15:00:43 GMT 2005]
Author: Michel Bierlaire, EPFL (2001-2005)

RDU Airport MNL Model Choice Probabilities for JtoW trips


Choice_Id Choice    P_choice
        1 INC_1      4.3E-02
        1 INC_1      8.1E-02
        1 INC_1      3.6E-02
        1 INC_1      6.9E-02
        1 INC_1      5.8E-02
        1 INC_1      5.9E-02
        1 INC_1      4.1E-02
        1 INC_1      2.5E-02
        1 INC_1      1.5E-01
        1 INC_1      9.8E-02
        1 INC_1      1.8E-01
        1 INC_1      1.4E-01
        1 INC_1      2.0E-01
        1 INC_1      3.1E-01
        1 INC_1      1.3E-01
        1 INC_1      4.4E-02
        1 INC_1      7.5E-02
        1 INC_1      6.3E-02
        1 INC_1      2.5E-01
        . .         .
        . .         .
        . .         .
        . .         .
        6 INC_6      9.5E-02
        6 INC_6      4.1E-01
        6 INC_6      9.0E-02
        6 INC_6      2.2E-01
        6 INC_6      2.9E-01
        6 INC_6      4.1E-01
        6 INC_6      5.1E-01
        6 INC_6      3.4E-01
        6 INC_6      1.3E-01
        6 INC_6      1.9E-01
        6 INC_6      3.2E-01
        6 INC_6      4.3E-01
        6 INC_6      3.2E-01
        6 INC_6      2.1E-01
        6 INC_6      3.1E-01
```

Figure H-9: J-to-W MNL Choice Probability Estimates

Table H-10: Summary of the MNL Choice Probability Estimates

Trip Purpose	SE Group Segment	Average Choice Probability
HB	INC_1	5.1%
	INC_2	8.9%
	INC_3	16.5%
	INC_4	41.7%
	INC_5	27.7%
	Total	100%
NHB	NHB_1	22.6%
	NHB_2	31.6%
	NHB_3	35.3%
	NHB_4	10.5%
	Total	100%
J-to-W	INC_1	8.3%
	INC_2	17.8%
	INC_3	14.5%
	INC_4	19.1%
	INC_5	25.9%
	INC_6	14.3%
	Total	100%

Appendix I：Application to 2002XP TRM TAZs

Person Trips

The average SE group segment choice probabilities are applied to the 2002XP TRM TAZs to get the TAZ choice probabilities by SE group segment. These probabilities reflect the likelihood of air passenger and airport employee trips between the RDU airport and the 2002XP TRM zones. Then, the TAZ probabilities are applied to the person trips developed in the trip generation step of the RDU airport sub-model to get the number of person trips per TAZ by SE group segment. These tables are shown in **Table I-1** through **Table I-3**. Finally, the person trips are summed across the SE group segments to get the total person trips per 2002XP TRM TAZ for each trip purpose. This table is shown in **Table I-4**.

Vehicle Trips

The person trips by trip purpose are converted to vehicle trips by trip purpose by using vehicle occupancy factors. The vehicle occupancy factors are developed from the observed survey day using the number of companions and the travel method fields of the survey files. These two fields reflect the mode of travel for the trip maker (car, carpool, bus, taxi, etc.) and the number of travelers that traveled together to the airport. The results from the survey show that most trip makers traveled via car and by themselves. The trip table of vehicle trips between the RDU airport and the 2002XP TRM zones by trip purpose is shown in **Table I-5**.

O-D Vehicle Trips

The vehicle trips by trip purpose are split in half assuming that the trip productions equal the trip attractions for each trip purpose. This results in a balanced O-D trip table of vehicle trip interchanges between the RDU airport and the 2002XP TRM zones. The sum of the origins and destination across the three trip purposes result in a total O-D trip table that can be input for traffic assignment of a travel demand model. The O-D vehicle trip table of vehicle trips between the RDU airport and the 2002XP TRM zones is shown in **Table I-6**.

Table I-1: HB Person Trips per 2002XP TRM TAZ by SE Group Segment

TOTAL HB Person Trips		10,057						
TAZ	HH	DU	HH + DU	INC_Level	Relative Factor	SE Group Pr	TAZ Pr	**Trips per TAZ**
8	7	6	13	1	0.000170	0.051378	8.71E-06	0.088
13	33	35	68	1	0.000887	0.051378	4.56E-05	0.458
15	8	10	18	1	0.000235	0.051378	1.21E-05	0.121
18	167	114	281	1	0.003664	0.051378	1.88E-04	1.893
19	123	137	260	1	0.003390	0.051378	1.74E-04	1.752
28	23	23	46	1	0.000600	0.051378	3.08E-05	0.310
36	55	39	94	1	0.001226	0.051378	6.30E-05	0.633
56	39	48	87	1	0.001134	0.051378	5.83E-05	0.586
61	132	139	271	1	0.003534	0.051378	1.82E-04	1.826
84	62	57	119	1	0.001552	0.051378	7.97E-05	0.802
85	4	4	8	1	0.000104	0.051378	5.36E-06	0.054
98	131	88	219	1	0.002856	0.051378	1.47E-04	1.476
124	218	258	476	1	0.006207	0.051378	3.19E-04	3.207
125	227	208	435	1	0.005672	0.051378	2.91E-04	2.931
166	72	63	135	1	0.001760	0.051378	9.04E-05	0.910
169	398	343	741	1	0.009663	0.051378	4.96E-04	4.993
175	140	150	290	1	0.003782	0.051378	1.94E-04	1.954
204	175	178	353	1	0.004603	0.051378	2.37E-04	2.378
207	33	34	67	1	0.000874	0.051378	4.49E-05	0.451
212	21	27	48	1	0.000626	0.051378	3.22E-05	0.323
213	142	150	292	1	0.003808	0.051378	1.96E-04	1.967
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
2033	187	200	387	5	0.002538	0.276698	7.02E-04	7.062
2036	282	233	515	5	0.003377	0.276698	9.34E-04	9.397
2037	207	118	325	5	0.002131	0.276698	5.90E-04	5.930
2039	423	452	875	5	0.005738	0.276698	1.59E-03	15.966
2044	71	58	129	5	0.000846	0.276698	2.34E-04	2.354
2047	165	168	333	5	0.002184	0.276698	6.04E-04	6.076
2073	72	73	145	5	0.000951	0.276698	2.63E-04	2.646
2095	41	46	87	5	0.000570	0.276698	1.58E-04	1.588
2103	197	224	421	5	0.002761	0.276698	7.64E-04	7.682
2161	293	326	619	5	0.004059	0.276698	1.12E-03	11.295
2169	605	599	1204	5	0.007895	0.276698	2.18E-03	21.970
2181	438	461	899	5	0.005895	0.276698	1.63E-03	16.404
2249	848	1009	1857	5	0.012177	0.276698	3.37E-03	33.885
2250	163	194	357	5	0.002341	0.276698	6.48E-04	6.514
2251	197	234	431	5	0.002826	0.276698	7.82E-04	7.865
2252	26	29	55	5	0.000361	0.276698	9.98E-05	1.004
							Total HB Person Trips	**10,057**

SE Group Segment	SE Group Segment Choice Probability	SE Group Segment HH + DU	**Trips per SE Group Segment**
1	5.1%	76,686	517
2	8.9%	132,747	899
3	16.5%	277,800	1,661
4	41.7%	411,371	4,198
5	27.7%	152,502	2,783

Relative Factor = TAZ DU+HH / SE Group Segment DU+HH
- Example (TAZ 8 of SE group segment 1): Relative Factor = 13/76,686 = 0.000170

TAZ Pr = Relative Factor * SE Group Segment Pr
- Example (TAZ 8 of SE group segment 1): TAZ Pr = 0.000170 * 0.051378 = 8.71E-06

Trips per TAZ = Total HB Person Trips * TAZ Pr
- Example (TAZ 8 of SE group segment 1): Trips per TAZ = 10,057 * 8.71E-06 = 0.088

Table I-2: NHB Person Trips per 2002XP TRM TAZ by SE Group Segment

TOTAL NHB Person Trips =		7,283					
TAZ	Spec. Gen	EMP	LUTT_Level	Relative Factor	SE Group Pr	TAZ Pr	Trips per TAZ
1		1500	1	0.002492	0.225755	5.63E-04	4.098
2		569	1	0.000945	0.225755	2.13E-04	1.555
3		600	1	0.000997	0.225755	2.25E-04	1.639
4		944	1	0.001569	0.225755	3.54E-04	2.579
5		419	1	0.000696	0.225755	1.57E-04	1.145
7		41	1	0.000068	0.225755	1.54E-05	0.112
8		323	1	0.000537	0.225755	1.21E-04	0.882
10		226	1	0.000376	0.225755	8.48E-05	0.617
11		24	1	0.000040	0.225755	9.00E-06	0.066
15		60	1	0.000100	0.225755	2.25E-05	0.164
16		541	1	0.000899	0.225755	2.03E-04	1.478
17		342	1	0.000568	0.225755	1.28E-04	0.934
18		16	1	0.000027	0.225755	6.00E-06	0.044
19		52	1	0.000086	0.225755	1.95E-05	0.142
20		60	1	0.000100	0.225755	2.25E-05	0.164
21		17	1	0.000028	0.225755	6.38E-06	0.046
22		16	1	0.000027	0.225755	6.00E-06	0.044
23		54	1	0.000090	0.225755	2.03E-05	0.148
25		132	1	0.000219	0.225755	4.95E-05	0.361
26		134	1	0.000223	0.225755	5.03E-05	0.366
27		35	1	0.000058	0.225755	1.31E-05	0.096
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
2212		94	4	0.000295	0.104936	3.10E-05	0.226
2214		855	4	0.002686	0.104936	2.82E-04	2.053
2217		394	4	0.001238	0.104936	1.30E-04	0.946
2218		870	4	0.002733	0.104936	2.87E-04	2.089
2223		287	4	0.000902	0.104936	9.46E-05	0.689
2224		364	4	0.001143	0.104936	1.20E-04	0.874
2226		271	4	0.000851	0.104936	8.93E-05	0.651
2228		88	4	0.000276	0.104936	2.90E-05	0.211
2233		85	4	0.000267	0.104936	2.80E-05	0.204
2234		70	4	0.000220	0.104936	2.31E-05	0.168
2245		97	4	0.000305	0.104936	3.20E-05	0.233
2250		489	4	0.001536	0.104936	1.61E-04	1.174
2255		52	4	0.000163	0.104936	1.71E-05	0.125
2257		66	4	0.000207	0.104936	2.18E-05	0.158
2260		235	4	0.000738	0.104936	7.75E-05	0.564
2265		93	4	0.000292	0.104936	3.07E-05	0.223
2267		61	4	0.000192	0.104936	2.01E-05	0.146
2270		7662	4	0.024069	0.104936	2.53E-03	18.394
2274		1014	4	0.003185	0.104936	3.34E-04	2.434
2277		60	4	0.000188	0.104936	1.98E-05	0.144
2281		1114	4	0.003499	0.104936	3.67E-04	2.674
2301		259	4	0.000814	0.104936	8.54E-05	0.622
2302		61	4	0.000192	0.104936	2.01E-05	0.146
						Total NHB Person Trips	**7,283**

SE Group Segment	SE Group Segment Choice Probabiltiy	SE Group Segment Employment	**Trips per SE Group Segment**
1	22.6%	601,816	1,644
2	31.6%	179,665	2,302
3	35.3%	260,740	2,573
4	10.5%	318,340	764

Relative Factor = TAZ EMP / SE Group Segment EMP
- Example (TAZ 1 of SE group segment 1): Relative Factor = 1500/601,816 = 0.002492

TAZ Pr = Relative Factor * SE Group Segment Pr
- Example (TAZ 1 of SE group segment 1): TAZ Pr = 0.002792 * 0.225755 = 5.63E-04

Trips per TAZ = Total NHB Person Trips * TAZ Pr
- Example (TAZ 1 of SE group segment 1): Trips per TAZ = 7,283 * 5.63E-04 = 4.098

Table I-3: J-to-W Person Trips per 2002XP TRM TAZ by SE Group Segment

TOTAL Journey-to-Work Person Trips :			2,866					
TAZ	HH	DU	HH + DU	INCTT_Level	Relative Factor	SE Group Pr	TAZ Pr	**Trips per TAZ**
7	453	486	939	1	0.004484	0.083310	3.74E-04	1.071
8	7	6	13	1	0.000062	0.083310	5.17E-06	0.015
13	33	35	68	1	0.000325	0.083310	2.70E-05	0.078
15	8	10	18	1	0.000086	0.083310	7.16E-06	0.021
18	167	114	281	1	0.001342	0.083310	1.12E-04	0.320
19	123	137	260	1	0.001241	0.083310	1.03E-04	0.296
20	218	202	420	1	0.002005	0.083310	1.67E-04	0.479
21	103	105	208	1	0.000993	0.083310	8.27E-05	0.237
22	70	68	138	1	0.000659	0.083310	5.49E-05	0.157
23	132	115	247	1	0.001179	0.083310	9.83E-05	0.282
24	112	131	243	1	0.001160	0.083310	9.67E-05	0.277
25	33	35	68	1	0.000325	0.083310	2.70E-05	0.078
26	1060	613	1673	1	0.007988	0.083310	6.65E-04	1.907
28	23	23	46	1	0.000220	0.083310	1.83E-05	0.052
30	290	331	621	1	0.002965	0.083310	2.47E-04	0.708
33	247	251	498	1	0.002378	0.083310	1.98E-04	0.568
35	150	159	309	1	0.001475	0.083310	1.23E-04	0.352
36	55	39	94	1	0.000449	0.083310	3.74E-05	0.107
42	260	277	537	1	0.002564	0.083310	2.14E-04	0.612
43	314	298	612	1	0.002922	0.083310	2.43E-04	0.698
45	212	225	437	1	0.002087	0.083310	1.74E-04	0.498
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
2022	82	88	170	6	0.001115	0.143423	1.60E-04	0.458
2024	111	91	202	6	0.001325	0.143423	1.90E-04	0.544
2030	154	126	280	6	0.001836	0.143423	2.63E-04	0.755
2031	45	48	93	6	0.000610	0.143423	8.75E-05	0.251
2032	194	161	355	6	0.002328	0.143423	3.34E-04	0.957
2033	187	200	387	6	0.002538	0.143423	3.64E-04	1.043
2036	282	233	515	6	0.003377	0.143423	4.84E-04	1.388
2037	207	118	325	6	0.002131	0.143423	3.06E-04	0.876
2039	423	452	875	6	0.005738	0.143423	8.23E-04	2.358
2044	71	58	129	6	0.000846	0.143423	1.21E-04	0.348
2047	165	168	333	6	0.002184	0.143423	3.13E-04	0.898
2073	72	73	145	6	0.000951	0.143423	1.36E-04	0.391
2095	41	46	87	6	0.000570	0.143423	8.18E-05	0.234
2103	197	224	421	6	0.002761	0.143423	3.96E-04	1.135
2161	293	326	619	6	0.004059	0.143423	5.82E-04	1.668
2169	605	599	1204	6	0.007895	0.143423	1.13E-03	3.245
2181	438	461	899	6	0.005895	0.143423	8.45E-04	2.423
2249	848	1009	1857	6	0.012177	0.143423	1.75E-03	5.005
2250	163	194	357	6	0.002341	0.143423	3.36E-04	0.962
2251	197	234	431	6	0.002826	0.143423	4.05E-04	1.162
2252	26	29	55	6	0.000361	0.143423	5.17E-05	0.148
							Total J-to-W Person Trips	**2,866**

SE Group Segment	SE Group Segment Choice Probability	SE Group Segment HH + DU	**Trips per SE Group Segment**
1	8.3%	209,433	239
2	17.8%	94,772	509
3	14.5%	183,028	416
4	19.1%	136,269	547
5	25.9%	275,102	744
6	14.3%	152,502	411

Relative Factor = TAZ DU+HH / SE Group Segment DU+HH
- Example (TAZ 7 of SE group segment 1): Relative Factor = 939/209,433 = 0.004484

TAZ Pr = Relative Factor * SE Group Segment Pr
- Example (TAZ 7 of SE group segment 1): TAZ Pr = 0.004484 * 0.083310 = 3.74E-04

Trips per TAZ = Total J-to-W Person Trips * TAZ Pr
- Example (TAZ 7 of SE group segment 1): Trips per TAZ = 2,866 * 3.74E-04 = 1.071

Table I-4: Summary of Person Trips per 2002XP TRM TAZ

TOTAL HB Person Trips = 10,057
TOTAL NHB Person Trips = 7,283
TOTAL Journey-to-Work Person Trips = 2,866

TAZ	HB TOTAL Person Trips	NHB TOTAL Person Trips	J-to-W TOTAL Person Trips	TOTAL RDU PERSON TRIPS
1	0.00	18.90	0.00	18.90
2	0.00	7.17	0.00	7.17
3	0.00	7.56	0.00	7.56
4	0.00	11.89	0.00	11.89
5	0.00	5.28	0.00	5.28
6	0.00	0.00	0.00	0.00
7	6.36	0.21	1.07	7.64
8	0.09	0.88	0.01	0.98
9	0.78	0.00	0.12	0.90
10	0.00	0.62	0.00	0.62
11	0.34	0.07	0.13	0.53
12	1.11	0.10	0.16	1.38
13	0.46	0.00	0.08	0.54
14	0.07	0.00	0.06	0.12
15	0.12	0.16	0.02	0.31
16	0.13	2.78	0.05	2.96
17	0.94	1.76	0.84	3.54
18	1.89	0.04	0.32	2.26
19	1.75	0.14	0.30	2.19
20	2.84	0.16	0.48	3.49
21	1.41	0.05	0.24	1.69
22	0.93	0.04	0.16	1.14
23	1.67	0.15	0.28	2.10
24	1.65	0.81	0.28	2.73
25	0.46	0.36	0.08	0.90
26	11.33	0.37	1.91	13.60
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
2307	4.09	0.30	1.56	5.95
2308	0.90	0.00	0.34	1.25
2309	1.75	0.00	0.46	2.21
2310	1.49	0.00	0.39	1.88
2311	10.67	3.26	2.83	16.76
2312	1.94	0.00	0.74	2.68
2313	1.78	0.31	0.68	2.76
2314	3.26	0.00	1.24	4.51
2315	0.78	0.00	0.30	1.07
2316	1.27	0.00	0.48	1.76
2317	1.96	0.00	0.75	2.71
TOTAL	**10,057**	**7,282**	**2,866**	**20,205**

Home Based

SE Group	Probability	Trips per SE Group
1	5.1%	517
2	8.9%	899
3	16.5%	1,661
4	41.7%	4,199
5	27.7%	2,783
	Total	**10,058**

Non-Home Based

SE Group	Probability	Trips per SE Group
1	22.6%	1,644
2	31.6%	2,302
3	35.3%	2,572
4	10.5%	764
	Total	**7,282**

Journey-to-Work

SE Group	Probability	Trips per SE Group
1	8.3%	239
2	17.8%	509
3	14.5%	416
4	19.1%	547
5	25.9%	744
6	14.3%	411
	Total	**2,866**

Table I-5: Vehicle Trips per 2002XP TRM TAZ

TOTAL HB Vehicle Trips = 9,670
TOTAL NHB Vehicle Trips = 5,201
TOTAL J-to-W Vehicle Trips : 2,810
TOTAL RDU Vehicle Trips = 17,681

TAZ	HB TOTAL Vehicle Trips	NHB TOTAL Vehicle Trips	J-to-W TOTAL Vehicle Trips	TOTAL RDU Vehicle Trips
1	0.00	13.50	0.00	13.50
2	0.00	5.12	0.00	5.12
3	0.00	5.40	0.00	5.40
4	0.00	8.49	0.00	8.49
5	0.00	3.77	0.00	3.77
6	0.00	0.00	0.00	0.00
7	6.11	0.15	1.05	7.31
8	0.08	0.63	0.01	0.73
9	0.75	0.00	0.11	0.87
10	0.00	0.44	0.00	0.44
11	0.32	0.05	0.13	0.50
12	1.07	0.07	0.16	1.30
13	0.44	0.00	0.08	0.52
14	0.06	0.00	0.06	0.12
15	0.12	0.12	0.02	0.25
16	0.13	1.98	0.05	2.16
17	0.90	1.25	0.83	2.98
18	1.82	0.03	0.31	2.17
19	1.68	0.10	0.29	2.08
20	2.73	0.12	0.47	3.32
21	1.35	0.03	0.23	1.62
22	0.90	0.03	0.15	1.08
23	1.61	0.11	0.28	1.99
24	1.58	0.58	0.27	2.43
25	0.44	0.26	0.08	0.78
26	10.89	0.26	1.87	13.02
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
2306	4.21	0.00	1.14	5.35
2307	3.94	0.21	1.53	5.68
2308	0.87	0.00	0.34	1.20
2309	1.68	0.00	0.45	2.13
2310	1.43	0.00	0.39	1.82
2311	10.26	2.33	2.77	15.37
2312	1.87	0.00	0.72	2.59
2313	1.71	0.22	0.66	2.59
2314	3.14	0.00	1.22	4.36
2315	0.75	0.00	0.29	1.04
2316	1.22	0.00	0.47	1.70
2317	1.89	0.00	0.73	2.62
TOTAL	**9,670**	**5,201**	**2,810**	**17,681**

Vehicle Occupancy Factors	
HB	1.04
NHB	1.40
J-to-W	1.02

Table I-6: O-D Vehicle Trips per 2002XP TRM TAZ

TAZ	HB Vehicle Origins	HB Vehicle Destinations	NHB Vehicle Origins	NHB Vehicle Destinations	J-to-W Vehicle Origins	J-to-W Vehicle Destinations	Total Vehicle Origins	Total Vehicle Destinations
1	0.00	0.00	6.75	6.75	0.00	0.00	6.75	6.75
2	0.00	0.00	2.56	2.56	0.00	0.00	2.56	2.56
3	0.00	0.00	2.70	2.70	0.00	0.00	2.70	2.70
4	0.00	0.00	4.25	4.25	0.00	0.00	4.25	4.25
5	0.00	0.00	1.89	1.89	0.00	0.00	1.89	1.89
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	3.06	3.06	0.08	0.08	0.52	0.52	3.66	3.66
8	0.04	0.04	0.32	0.32	0.01	0.01	0.36	0.36
9	0.38	0.38	0.00	0.00	0.06	0.06	0.43	0.43
10	0.00	0.00	0.22	0.22	0.00	0.00	0.22	0.22
11	0.16	0.16	0.02	0.02	0.06	0.06	0.25	0.25
12	0.54	0.54	0.04	0.04	0.08	0.08	0.65	0.65
13	0.22	0.22	0.00	0.00	0.04	0.04	0.26	0.26
14	0.03	0.03	0.00	0.00	0.03	0.03	0.06	0.06
15	0.06	0.06	0.06	0.06	0.01	0.01	0.13	0.13
16	0.06	0.06	0.99	0.99	0.02	0.02	1.08	1.08
17	0.45	0.45	0.63	0.63	0.41	0.41	1.49	1.49
18	0.91	0.91	0.02	0.02	0.16	0.16	1.08	1.08
19	0.84	0.84	0.05	0.05	0.15	0.15	1.04	1.04
20	1.37	1.37	0.06	0.06	0.23	0.23	1.66	1.66
21	0.68	0.68	0.02	0.02	0.12	0.12	0.81	0.81
22	0.45	0.45	0.02	0.02	0.08	0.08	0.54	0.54
23	0.80	0.80	0.05	0.05	0.14	0.14	0.99	0.99
24	0.79	0.79	0.29	0.29	0.14	0.14	1.22	1.22
25	0.22	0.22	0.13	0.13	0.04	0.04	0.39	0.39
26	5.45	5.45	0.13	0.13	0.93	0.93	6.51	6.51
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
2305	0.74	0.74	0.00	0.00	0.29	0.29	1.03	1.03
2306	2.10	2.10	0.00	0.00	0.57	0.57	2.67	2.67
2307	1.97	1.97	0.11	0.11	0.76	0.76	2.84	2.84
2308	0.43	0.43	0.00	0.00	0.17	0.17	0.60	0.60
2309	0.84	0.84	0.00	0.00	0.23	0.23	1.07	1.07
2310	0.72	0.72	0.00	0.00	0.19	0.19	0.91	0.91
2311	5.13	5.13	1.17	1.17	1.39	1.39	7.68	7.68
2312	0.93	0.93	0.00	0.00	0.36	0.36	1.30	1.30
2313	0.85	0.85	0.11	0.11	0.33	0.33	1.29	1.29
2314	1.57	1.57	0.00	0.00	0.61	0.61	2.18	2.18
2315	0.37	0.37	0.00	0.00	0.14	0.14	0.52	0.52
2316	0.61	0.61	0.00	0.00	0.24	0.24	0.85	0.85
2317	0.94	0.94	0.00	0.00	0.37	0.37	1.31	1.31
TOTAL	**4,835**	**4,835**	**2,601**	**2,601**	**1,405**	**1,405**	**8,841**	**8,841**