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Final Report

Calibration of Nested-Logit Mode-Choice Models for Florida

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16. Abstract

This report describes the development of mode choice models for Florida. Data from the 1999 travel survey conducted in Southeast Florida were used in the calibration of the models. The calibration also involved the travels times and costs of the highway and transit systems obtained from the skim files of the southeast model. The mode choice model was estimated as a three-level nested logit structure. There were three separate trip purposes calibrated. These purposes were: home based work trips (HBW), home based non-work trips (HBNW), and non home-based trips (NHB).

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DISCLAIMER

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EXECUTIVE SUMMARY

This report describes the development of mode choice models for Florida. Data from the 1999 travel survey conducted in Southeast Florida were used in the calibration of the models. The calibration also involved the travels times and costs of the highway and transit systems obtained from the skim files of the southeast model. The mode choice model was estimated as a three-level nested logit structure. There were three separate trip purposes calibrated. These purposes were: home based work trips (HBW), home based non-work trips (HBNW), and non home-based trips (NHB).

Two separate surveys were used in the estimation process. The first is the on-board transit survey, and the second is the household survey. The portion of the nesting structure that include the different transit alternatives (the transit branch) was estimated using the on-board transit data, while the upper nest that include the choice of transit versus highway used the household travel data. This approach was used because of the very small percentage of transit trips in the household survey, and to avoid enriching the household sample, which would lead to the necessity of adjusting the coefficient estimates. The two models were linked through the use of the inclusive value of transit. The inclusive value of the transit system was defined to represent the aggregate utility of using the transit system. Both models were calibrated using the full information maximum likelihood (FIML) approach. The FIML estimation is the most efficient statistical approach, because the different nests are estimated simultaneously as opposed to sequentially in the limited information case (LIML).

The adopted structure for the three trip purposes consists of a three level-nesting structure. In the primary nest, total person trips are divided into auto and transit trips. In the secondary nest, the auto trips are split into drive-alone and shared-ride trips, and the transit trips are split into walk-access and auto-access trips. In the third nest, the transit walk-access trips are split into local-bus (LB), express bus (EP), metro rail (MR), and tri rail (TR). The transit auto-access trips are divided into express bus (EP), metro rail (MR) and tri rail (TR). This structure was adopted to achieve the best use of the available data, and to be as consistent as possible with the existing Southeast model.

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CHAPTER 1

INTRODUCTION

In recent years urban policymakers, faced with the growing and complex problems of air pollution and congestion have begun to ask for more sophisticated decision-making tools, including models to forecast travel demand and its effect under various circumstances. Discrete choice models have played an important role in transportation modeling for the last 25 years. They are namely used to provide a detailed representation of the complex aspects of transportation demand, based on strong theoretical justifications. The art of finding the appropriate model for a particular application requires from the analyst both a close familiarity with the reality under interest and a strong understanding of the methodological and theoretical background of the model.

This report describes the development of mode choice models for Florida. These mode choice modes use travel time and cost of the highway and transit systems to estimate the proportions of trips which will use the transit system, or the highway system, either as automobile drivers or as automobile passengers. The mode choice models were calibrated using the nested logit model formulation. There were three separate trip purposes calibrated. These purposes were:

1. Home based work trips
2. Home based non-work trips
3. Non home-based trips

This calibration used trip records from a large travel survey of South East Florida, 1999. The calibrations of the model choice models were performed using the program LIMDEP. This program allows the user to calibrate either multinomial or nested logit models.

The report is divided into five chapters in addition to the introduction. The first chapter discusses the common practice of mode choice modeling process in Florida. The second chapter introduces the general model process including the model structure and other unique aspects of the model. The third chapter discusses the data preparation for calibration, including the preparation of the data files. The fourth section describes the calibration of the nested logit models. This chapter does not present all the models that were estimated during the analysis, but it does present the final models that were selected. Finally, a conclusion section presents the important findings.

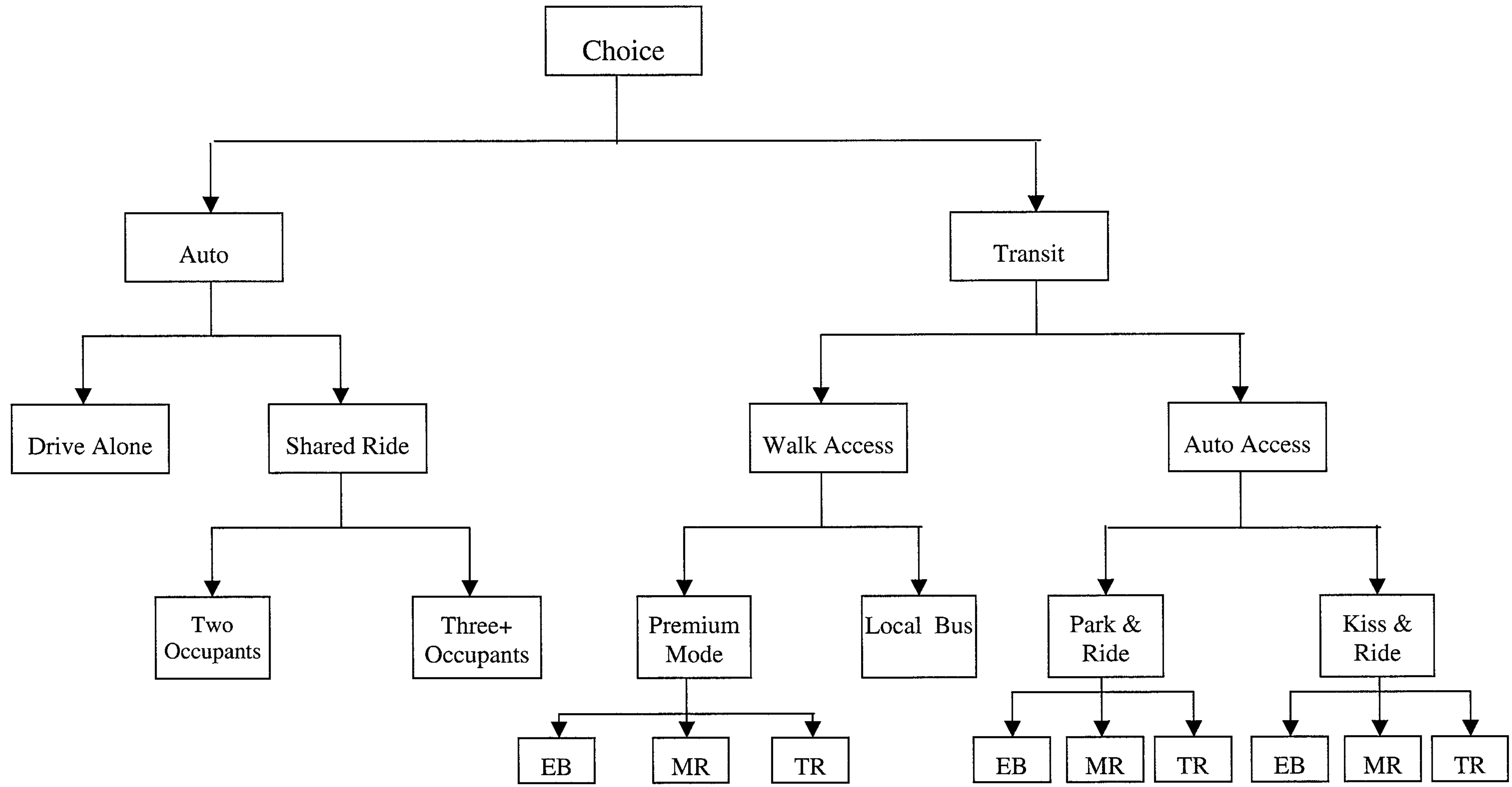
CHAPTER 2

BACKGROUND

2.1 Southeast Regional Planning Area Model (SERPM-IV)

The SERPM-IV structure (Corradino Group, 1996) have many characteristics of the Miami and 1990 Minneapolis / St. Paul models. Additional nesting below auto access to premium modes further divides trips between park-and-ride and kiss-and-ride / drop-off modes allowing for more direct estimation of parking demands at major transit stations. Three trip purposes were modeled: home based work trips (HBW), home based non-work (HBNW), and non-home based (NHB).

The adopted structure consists of a four-level nesting structure as illustrated in Figure 2.1. In the primary nest, total person trips are divided into auto and transit trips. In the second nest, the auto trips are split into drive-alone and shared-ride trips, and the transit trips are split into walk-access and auto-access (premium) trips. In the third nest, shared ride trips are further divided into one-passenger and two+ passengers. On the transit side, the walk access trips are split into local-bus trips and premium-modes trips, and the auto access trips are divided into park-and-ride trips and kiss-and ride trips. In the fourth nest, premium transit trips are further divided into express bus, metro rail and tri rail. There were no local transit surveys on which to base a rigorous calibration of the coefficients in the utility equation. However, the model was validated to ensure that the model replicated observed shares.



EB: Express Bus on Freeways (e.g., on HOV lane)   MR: Metro Rail   TR: TriRail
Home based Work
Home-based Non-Work
Non-Home-Based

Figure 2.1 Southeast Regional Planning Model IV Structure

The initial constants were borrowed from the Dade County Transit Corridor Transitional Analysis. Then, a spreadsheet was used to calibrate the mode-specific constants. The mode choice model requires 12 constants for each of three car-ownership categories (zero, one, and two+ car households) and for each trip purpose. The formula used for validation of the modal constants was as follows:

$$C_i = C_{i-1} + DF * \ln [(OS * ESDA) / (ES * OSDA)]_{i-1}$$

Where,

C_i	constant for iteration "i"
C_{i-1}	constant for iteration "i-1, previous iteration"
DF	damping factor for mode ranges between 0.10 and 0.75
OS	observed share of the mode
ESDA	estimated share of "drive alone DA" mode, baseline
ES	estimated share of the mode
OSDA	observed share of "drive alone DA" mode, baseline

For each model, the inputs for this iterative process are :

1. Base year observed aggregate person trips by car ownership classification
2. Initial set of constants (borrowed from the Miami model)
3. Base year estimated aggregate person trips by car ownership classification using SERPM on calibrated constants from the previous iteration

The process is repeated until the difference between the observed and estimated trips become negligible. The calibrated mode choice constants along with other coefficients of the nested logit model are shown in Table 2.1.

Table 2.1 Southeast Regional Planning Model IV Coefficients

	HBW	HBNW	NHB
Mode Choice Model Coefficients			
Transit Walk Time	-0.0450	-0.0350	-0.0450
Transit Auto Access Time	-0.0200	-0.0150	-0.0180
Transit Run Time	-0.0200	-0.0150	-0.0180
Transit First Wait $\leq$ 7 minutes	-0.0450	-0.0350	-0.0450
Transit First Wait > 7 minutes	-0.0230	-0.0350	-0.0450
Transit Transfer (2nd wait) Time	-0.0450	-0.0350	-0.0450
Transit Number of Transfers	-0.0450	-0.0350	-0.0450
Transit fare	-0.0032	-0.0048	-0.0048
Highway terminal time	-0.0450	-0.0350	-0.0450
Highway Run Time	-0.0200	-0.0150	-0.0180
Highway Auto Operating Costs	-0.0025	-0.0048	-0.0048
Highway Parking Costs	-0.0032	-0.0048	-0.0048
HOV Time Difference	-0.0180	-0.0150	-0.0180
Mode Specific Constants			
Walk to Local Transit			
- For Zero Car Households	1.9102	1.2763	-1.6191
- For One Car Households	-0.8538	-1.7852	-1.6191
- For Two+ Car Households	-1.7017	-2.1501	-1.6191
- For Downtown Attractions	0.2700	0.0000	0.0000
Walk to Express Bus Transit			
- For Zero Car Households	0.6387	1.3259	-1.2550
- For One Car Households	-2.0560	-1.3676	-1.2550
- For Two+ Car Households	-3.1897	-2.0050	-1.2550
- For Downtown Attractions	0.2700	0.0000	0.0000
Walk to Metro Rail Transit			
- For Zero Car Households	2.0456	1.5987	-1.3427
- For One Car Households	-0.0792	-1.2825	-1.3427
- For Two+ Car Households	-1.4825	-1.8364	-1.3427
- For Downtown Attractions	0.2700	0.0000	0.0000
Walk to Tri Rail Transit			
- For Zero Car Households	1.5461	0.8536	-1.3841
- For One Car Households	-1.0497	-2.4158	-1.3841
- For Two+ Car Households	-99.000	-99.000	-1.3841
- For Downtown Attractions	0.2700	0.0000	0.0000
Park-Ride to Express Bus Transit			
- For Zero Car Households	-2.4068	-8.6622	-1.3487
- For One Car Households	-1.0863	-1.2833	-1.3487
- For Two+ Car Households	-1.5892	-1.8744	-1.3487
- For Downtown Attractions	0.9000	0.0000	0.0000
Park-Ride to Metro Rail Transit			
- For Zero Car Households	-3.5353	-4.6720	-1.8651
- For One Car Households	-1.9474	-1.7558	-1.8651
- For Two+ Car Households	-2.1045	-2.4456	-1.8651
- For Downtown Attractions	0.9000	0.0000	0.0000
Park-Ride to Tri Rail Transit			
- For Zero Car Households	-7.2301	-15.758	-2.4446
- For One Car Households	-1.1613	-1.6495	-2.4446
- For Two+ Car Households	-1.5579	-2.0545	-2.4446
- For Downtown Attractions	0.9000	0.0000	0.0000

	HBW	HBNW	NHB
Kiss-Ride to Express Bus Transit			
- For Zero Car Households	-2.4053	-11.065	-2.6128
- For One Car Households	-2.7892	-2.7803	-2.6128
- For Two+ Car Households	-3.0276	-2.8451	-2.6128
- For Downtown Attractions	0.9000	0.0000	0.0000
Kiss-Ride to Metro Rail Transit			
- For Zero Car Households	-3.8719	-4.7346	-2.5769
- For One Car Households	-2.1365	-2.1632	-2.5769
- For Two+ Car Households	-2.3709	-2.8442	-2.5769
- For Downtown Attractions	0.9000	0.0000	0.0000
Kiss-Ride to Tri Rail Transit			
- For Zero Car Households	-5.1390	-14.667	-5.9764
- For One Car Households	-1.5670	-1.8104	-5.9764
- For Two+ Car Households	-1.8582	-2.4984	-5.9764
- For Downtown Attractions	0.9000	0.0000	0.0000
Auto One Passenger			
- For Zero Car Households	1.2626	0.7173	0.5043
- For One Car Households	-1.1834	0.7564	0.5043
- For Two+ Car Households	-1.4036	0.7443	0.5043
- For Downtown Attractions	0.5000	0.0000	0.0000
Auto Two+ Passengers			
- For Zero Car Households	0.9598	0.5093	0.3829
- For One Car Households	-1.3051	0.5460	0.3829
- For Two+ Car Households	-1.4974	0.5364	0.3829
- For Downtown Attractions	0.5000	0.0000	0.0000
Nesting Coefficients			
Transit Nesting	0.3000	0.3000	0.3000
Walk Access Local Bus Nesting	0.5000	0.5000	0.5000
Walk Access Premium Nesting	0.5000	0.5000	0.5000
Auto Access Nesting	0.5000	0.5000	0.5000
Park-n-Ride	0.5000	0.5000	0.5000
Kiss-n-Ride	0.5000	0.5000	0.5000
Highway Nesting	0.8000	0.8000	0.8000
Shared Ride Nesting	0.2000	0.2000	0.2000

2.2 Current Florida Modeling Practice

Several alternative nesting structures were reviewed in this report. These include the existing models that have been previously developed and validated in the state (see Table 2.2) , as well as other models from other parts of the country. The main trip purposes are home-based work, home-base non-work, and non-home-based trips. All Florida mode choice models are available for three trip purposes except the Tampa and Orlando models, which have models for other trip purposes (e.g., home-based recreational trips). The Jacksonville mode choice model has a simple multinomial logit structure for home-based non-work and non-home-based trip purposes. All Florida mode choice models have three car ownership categories (0 car, 1 car households, 2+ cars households) except the Miami model which has four categories.

2.2.1 Florida model parameters

Generally, the mode choice nested logit model is applied by a set of three model parameters. These model parameters include; nesting coefficients, mode-specific constants, and level-of-service coefficients. All mode choice models available in Florida for the home-based work are presented in Table 2.2.

The model parameters for home-based work, home-based non-work, and non-home-based trips are presented in Table 2.3 through Table 2.5. All level-of-service coefficients for Florida home-based work mode choice models were borrowed from the 1990 Minneapolis / St. Paul Region which were originally based on the Shirley highway results. These models differ from the 1990 Minneapolis/St. Paul Region in terms of coefficient of transit auto access time, coefficient of highway parking cost, and an additional nesting coefficient. All Florida home-based non-work mode choice models have the same level-of-service coefficients. Although the Jacksonville model is a simple multinomial logit structure, it has the same level-of-service coefficients. For the non-home-based mode choice models, all level-of-service coefficients are the same except for the Orlando and Volusia models. The Orlando and Volusia models are slightly different in some coefficients as shown in Table 2.5.

The common practice in developing a mode choice model in Florida is borrowing coefficients from other cities. Then, the model is implemented in the following manner : (1) adjusting the modal bias coefficients (constants of the utility equation) to replicate the transit ridership data, and (2) examining the validation results to identify any additional adjustments to coefficients or other parameters which were appropriate. The number of validated mode-specific constants depends on number of car ownership classes. All modal constants were normalized with respect to the drive alone mode. An iterative process was used to calibrate the constants. The initial mode-specific constants are borrowed from other studies.

The formula for the calibration of constants is as follows :

$$C_{ik} = C_{i-1,k} + DF_k * \ln [(OS_k * ES_B) / (ES_k * OS_B)]_{i-1,k}$$

where, C_{ik} is a constant for iteration i of mode k, C_{i-1} is a constant for iteration i-1 for mode k, DF_k is a damping factor specific to mode k, OS_k is the observed share of mode k, ES_k is the estimated share of mode k, and OS_B is the observed share of the baseline mode.

Table 2.2 Available Mode Choice Models in Florida

Area	Year	Available models	# of nesting levels	Total # of modes
Minneapolis / St. Paul	1990	Home-based work trips	3	6
Miami		Home-based work trips	4	8
		Home-based non-work trips	4	8
		Non Home-based trips	4	8
Southeast Regional Planning Area	1996	Home-based work trips	4	13
		Home-based non-work trips	4	13
		Non Home-based trips	4	13
Orlando	1996	Home based work trips	3	7
		Home based non-work trips	3	7
		Non-home based trips	3	7
		Disney trips	3	7
		Universal Studio trips	3	7
		Airport trips	3	7
Jacksonville	1996	Home-based work trips	4	9
		Home-based non-work trips	1	9
		Non Home-based trips	1	9
Broward	1998	Home-based work trips	4	13
		Home-based non-work trips	4	13
		Non Home-based trips	4	13
West Palm Beach	1998	Home-based work trips	4	13
		Home-based non-work trips	4	13
		Non Home-based trips	4	13
Tampa	1999	Home-based work trips	3	7
		Home-based shopping trips	3	7
		Home-based	3	7
		social/recreation	3	7
		Home-based other trips	3	7
		Non-home-based trips		
Volusia	1999	Home-based work trips	3	7
		Home-based non-work trips	3	7
		Non Home-based trips	3	7

Table 2.3 Mode Choice Model Coefficients for Home Based Work Trips (HBW)

	Shirley Highway	Minneapolis/St. Paul	Miami	SERPM IV	Orlando	Jackson-ville	Broward	West Palm Beach	Tampa	Volusia
Level-of-service coefficients										
Transit Walk Time	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450
Transit Auto Access Time	-0.0450	-0.0450	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200
Transit Run Time	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200
Transit First Wait $\leq$ 7 minutes	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450
Transit First Wait > 7 minutes	-0.0230	-0.0230	-0.0230	-0.0230	-0.0230	-0.0230	-0.0230	-0.0230	-0.0230	-0.0230
Transit Transfer Time	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450
Transit Number of Transfers	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450
Transit fare	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032
Highway terminal time	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450	-0.0450
Highway Run Time	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200	-0.0200
Highway Auto Operating Costs	-0.0025	-0.0025	-0.0025	-0.0025	-0.0025	-0.0025	-0.0025	-0.0025	-0.0025	-0.0025
Highway Parking Costs	-0.0080	-0.0080	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032	-0.0032
HOV Time Difference			-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180
Nesting Coefficients										
Transit mode	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
Highway auto mode	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000
Shared ride mode	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
Other nests*			0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000

*** number of other nests depends on the mode choice model structure**

Table 2.4 Mode Choice Model Coefficients for Home-Based Non-Work Trips (HBNW)

	Miami	SERPM IV	Orlando	Jackson-ville	Broward	West Palm Beach	Tampa	Volusia
Level-of-service coefficients								
Transit Walk Time	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350
Transit Auto Access Time	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150
Transit Run Time	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150
Transit First Wait $\leq$ 7 minutes	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350
Transit First Wait > 7 minutes	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350
Transit Transfer (2nd wait) Time	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350
Transit Number of Transfers	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350
Transit fare	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048
Highway terminal time	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350	-0.0350
Highway Run Time	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150
Highway Auto Operating Costs	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048
Highway Parking Costs	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048
HOV Time Difference	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150	-0.0150
Nesting Coefficients								
Transit mode	0.3000	0.3000	0.3000	1.0000	0.3000	0.3000	0.3000	0.3000
Highway auto mode	0.8000	0.8000	0.8000	1.0000	0.8000	0.8000	0.8000	0.8000
Shared ride mode	0.2000	0.2000	0.2000	1.0000	0.2000	0.2000	0.2000	0.2000
Other nests*	0.5000	0.5000	0.5000	1.0000	0.5000	0.5000	0.5000	0.5000

*** number of other nests depends on the mode choice model structure**

Table 2.5 Mode Choice Model Coefficients for Non Home-Based Trips (NHB)

	Miami	SERPM IV	Orlando	Jackson-ville	Broward	Palm Beach	Tampa	Volusia
Level-of-service coefficients								
Transit Walk Time	-0.0450	-0.0450	-0.0400	-0.0450	-0.0450	-0.0450	-0.0450	-0.0400
Transit Auto Access Time	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180
Transit Run Time	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180
Transit First Wait ≤ 7 minutes	-0.0450	-0.0450	-0.0400	-0.0450	-0.0450	-0.0450	-0.0450	-0.0400
Transit First Wait > 7 minutes	-0.0450	-0.0450	-0.0400	-0.0450	-0.0450	-0.0450	-0.0450	-0.0400
Transit Transfer (2nd wait) Time	-0.0450	-0.0450	-0.0400	-0.0450	-0.0450	-0.0450	-0.0450	-0.0400
Transit Number of Transfers	-0.0450	-0.0450	-0.0400	-0.0450	-0.0450	-0.0450	-0.0450	-0.0400
Transit fare	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048
Highway terminal time	-0.0450	-0.0450	-0.0400	-0.0450	-0.0450	-0.0450	-0.0450	-0.0400
Highway Run Time	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180
Highway Auto Operating Costs	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048
Highway Parking Costs	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048	-0.0048
HOV Time Difference	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180	-0.0180
Nesting Coefficients								
Transit mode	0.3000	0.3000	0.3000	1.0000	0.3000	0.3000	0.3000	0.3000
Highway auto mode	0.8000	0.8000	0.8000	1.0000	0.8000	0.8000	0.8000	0.8000
Shared ride mode	0.2000	0.2000	0.2000	1.0000	0.2000	0.2000	0.2000	0.2000
Other nests*	0.5000	0.5000	0.5000	1.0000	0.5000	0.5000	0.5000	0.5000

* number of other nests depends on the mode choice model structure

For each model, the inputs for this iterative process are : base year observed aggregate person trips by car ownership classification, initial set of constants (borrowed from other areas), and base year estimated aggregate person trips by car ownership classification. The process is repeated until the difference between the observed and estimated trips become negligible.

In short, the common practice in developing a mode choice model in Florida is borrowing coefficients from other areas. Then, the mode specific constants are adjusted to replicate the transit ridership data. All level-of-service coefficients for Florida home-based work mode choice models were borrowed from the 1990 Minneapolis / St. Paul Region which were originally based on the Shirley highway results. These models have different coefficients for the transit auto access time and the highway parking cost variables and an additional nesting coefficient. Since all the models used in Florida are based on a model validated in Minneapolis (out-of-state), which in turn is based on another location (Shirley highway, 1990), the validity of the models is questionable. There is a need to calibrate a new model using Florida travel data. Therefore, the next step in this research is to calibrate a Florida-based model. Recent travel data from southeast Florida is obtained for this effort.

2.3 Southeast Florida Travel Characteristics Study

The Southeast Florida Travel Characteristics Study collected trip-making and travel behavior data encompassing Miami-Dade, Broward, and Palm Beach Counties in Southeast Florida, an area among the top dozen most populous metropolises of the nation with a combined Tri-County population of more than 4.5 million. This 1999 travel research included a household travel survey, a hotel/motel survey, a transit on-board survey, a truck survey, and a workplace survey.

The extensive data collected captures travel-making patterns essential for various transportation planning purposes such as building travel demand forecasting models, highway facility planning, and transit route planning. These data serve as the factual/knowledge foundation for planning Southeast Florida regional transportation future in the new millennium.

The study was a major collaboration of Florida Department of Transportation's Districts Four and Six, and the Metropolitan Planning Organizations of Miami-Dade, Broward, and West Palm Beach Counties. A few years before the project began, these agencies realized the opportunity of collecting a travel behavior database that could coincide with the Census 2000 for establishing travel pattern baseline information that would be able to be used for various transportation planning purposes into the new millennium. Funding was developed by each agency, consolidated into single package, and administered by FDOT District Four for project management and financing. Technical staff of these agencies comprised the Project Management Committee (PMC) to oversee the project; the PMC regularly met and actively provided oversight and guidance actions throughout the course of the Study.

A team of consultants led by Carr Smith Corradino (CSC) successfully accomplished the project. CSC provided study oversight, managing project progress, designing survey processes, ensuring data quality, and providing initial analyses of collected data. The Florida State University Survey Research Laboratory undertook the major task of household survey by implementing the state-of-the-art survey techniques, including real time address matching and Computer Aided Telephone Interviewing (CATI) techniques. PMG Associates led the fieldwork collecting hotel/motel trip-making data, directed transit on-board data collection, and collected truck trip information. Gannett Fleming, Inc. was responsible for the entire workplace survey, the first of its kind in Florida. Yvonne Ziel Traffic Consultants solicited truck operators' survey participation. Dickey Consulting Services, David Fierro & Associates, and the Department's Public Information Offices conducted media and general public awareness campaigns, provided support materials, and encouraged the participation of respondents in all sectors surveyed.

2.3.1 Household travel survey data

The primary purpose of the household travel characteristics survey was to collect data that can be used to formulate, calibrate, and validate existing and planned travel demand model structures. As such, the survey used statistical methods to ensure the best use of limited resources and to develop accurate models. Data was collected to characterize demographics of household and travel patterns of household members. The survey was designed to collect data for calibrating travel-forecasting models for:

- Lifestyle trip productions;
- Trip distribution;
- Auto occupancy;
- Time-of-day and peak spreading; and,
- Travel path selection.

Additionally, travel characteristics data may be used to enhance existing models and formulate new travel forecasting methods. The report "Southeast Florida Regional Travel Characteristics Study Household Travel Characteristics Survey Plan and Findings" provides highlights of the survey methodology, description of the data, coding, organization of the data files, and results.

Surveys were collected in households in Broward, Dade, and Palm Beach counties. In the three-county region, 5,168 households completed the survey, and out of these households, 5,067 had valid addresses. Approximately 34 percent of the surveys were collected in Broward County, and 33 percent each in Dade and Palm Beach counties.

A "non-home-based" trip was the largest category for both Palm Beach County (26%) and Broward County (24.8%), while "home-based-work" was the largest category for Dade County (26.6%). The second largest category was "home-based-work" for Broward County (23.2%), followed by "home-based-other" for Palm Beach County (23.3%), while “home-based-other” and “non-home-based” both tied for the second largest category for Miami-Dade County (22.3%). A "non-home-based" trip was the largest category for the region as a whole (24.4%), followed by "home-based-work" (23.1%).

All counties had two vehicles as the most frequent number of vehicles available to each household. Palm Beach had the most two-vehicle households (46.8%), followed by Broward (46.8%), and Dade County (43%). The next largest category was one vehicle. Palm Beach once again had the most one-vehicle households (35.9%), followed by Dade County (32.3%), and last was Broward County (31.7%). The Region showed two vehicles as the largest category (45.5%), followed by one vehicle (33.3%).

One person per vehicle was the most common occupancy for person vehicle trips for all three counties and region wide, followed at a distant second by two people per vehicle. The average auto occupancy rate is in line with the levels experienced in most large urban areas. The most common mode of travel for person trips for all three counties as well as the region was as a driver in an automobile, followed by a passenger in an automobile, and walking came in at a distant third.

The highest travel hour (hour in which the greatest number of trips began) is 7 AM. This is the same for all three counties. The highest three consecutive morning travel hours are 7-9 AM for Broward and Palm Beach counties. For Dade, it is 6-8 AM (hours beginning). The morning peak hour percentage is higher than expected. The highest afternoon travel hour is 5 PM. Somewhat surprisingly, the peak three hours for all counties is 3-5 PM (hours beginning). The afternoon peak hour carries roughly two-thirds of the peak morning hour traffic. The traffic in the 10 AM – 2 PM mid-day hours is consistently high--- characteristic of a highly congested area.

2.3.2 Transit on-board travel survey data

The transit on-board survey was conducted to provide an accurate picture of transit ridership and trip characteristics. Survey results provide a comprehensive view of transit use in the Southeast Florida region.

The Transit On-Board Travel Survey Plan and Findings report explains how the Transit On-Board Survey for the Southeast Florida Regional Travel Characteristics Study (SFRTC) was conducted and its findings. The purpose of the transit on-board survey was to gather travel information on transit riders for use in developing and calibrating the Southeast Florida Regional Planning Model. The transit ridership data is used to enhance or "enrich" the data provided by the household survey, which will not pick up enough transit riders.

The transit on-board survey was conducted for transit systems providing fixed-schedule, fixed-route services in Palm Beach, Broward, and Dade counties. The systems surveyed were:

- Miami-Dade Metro bus
- Miami-Dade Metro rail
- Broward County Transit
- Palm Tran
- Tri-Rail

A total of 11,173 transit on-board surveys were completed providing a detailed snapshot of the region's transit users. Survey responses are grouped into two categories based upon the types of questions asked of transit users: *household demographics* and *travel patterns*. The majority of the completed surveys (42%) were received from Miami Dade Metro bus. Broward County Transit patrons provided 33 percent of the total completed surveys.

Broward County respondents were more likely not to have a vehicle available to their household (47.6%) than Palm Beach and Dade County respondents (41.4% and 34.2%, respectively). Regionally, the largest number of transit survey respondents (39.9%) reported that there were no vehicles available to drivers in their household. Respondents reporting the availability of one vehicle followed closely behind at 35.4 percent.

Almost half (49.5%) of the respondents reported that they were at home prior to their first trip. Next, followed work (21.3%) and other (10%). Possible choices included home, work, shopping, social-recreational, school-class and other. Subsequent to trip completion, the highest percentage of respondents (39.5%) reported their destination as home. The next highest percentage of respondents (28.3%) reported their destinations as work.

Transit users were surveyed regarding the distance traveled (walking or driving) to reach the bus stop or train station. Dade County respondents were less likely to walk three or fewer blocks (64.7%) than Broward and Palm Beach County respondents (75.6% and 73.9%, respectively). But, Dade County respondents were more likely to walk four to eight blocks (19.5%) than Broward and Palm Beach County respondents (14% and 11.2%). Regionally, more than two-thirds of respondents (69.9%) reported walking three blocks or less to reach the transit location. The second largest response reported walking four to eight blocks (16.3%). More than 86 percent of respondents reported walking to reach transit. The second most frequent response (6.8%) reported being dropped off by auto. The third most reported mode of travel to transit was other (3.7%).

Approximately one-third (32.1%) of survey respondents reported waiting between six to 10 minutes for the arrival of a bus or train. The next largest response (27.4%) reported waiting between zero to five minutes. The type of fare paid by transit users was surveyed and included the possible choices of full cash fare, discounted cash fare, discounted pass or token. The largest number (56.5%) of respondents reported paying full cash fare. Broward County respondents were more likely to pay the full cash fare (60.3%) than Dade or Palm Beach County respondents (53.1% and 56.3%, respectively). The second largest response (22.9%) reported use of a discounted pass. Broward County respondents were more likely to use discounted passes (26.4%) than Dade or Palm Beach County respondents (20.3% and 22.9%, respectively).

The most frequently reported mode of travel from final transit stop to ultimate destination was walking (82.6%). The second most frequent response was other (8.9%). Tri-Rail users were less likely to walk to their final destination (22.5%). Instead the Tri-Rail respondents would either drive, be dropped off or would take some other form of transportation (77.5%). Most transit users (64.1%) reported walking three blocks or less to reach their ultimate destination upon completion of their final transit stops. The exception to this was Tri-Rail users. Only 18% of the Tri-Rail respondents reported walking three blocks or less while 47.1% reported driving three or more miles to reach their final destination. Walking four to eight blocks was the second most frequently reported distance (18.2%). These percentages are very similar to those reported for the distance to the transit location.

2.3.3 New southeast mode choice model

After extensive investigation for the available sources of travel surveys, the research team decided to use data from two surveys, the 1999 Southeast Florida household and on-board transit surveys, to estimate the first Florida-based nested mode choice model. Although, the two surveys provided most of the necessary data, they were designed without mode choice being specifically an objective. Therefore, the research team conducted extensive data preparation effort to merge the survey data with other network data while validating and checking for consistency.

CHAPTER 3

METHODOLOGY

3.1 Multinomial Logit Models (MNL)

The logit model allocates person trips to alternative modes. It does so by comparing the utilities of all alternative modes. The hypothesis underlying discrete choice models is that when faced with a choice situation, an individual's preferences toward each alternative can be described by an "attractiveness" or utility measure associated with each alternative. This utility function incorporates the attributes of the alternatives as well as the decision maker characteristics. The decision-maker is assumed to choose the alternative that yields the highest utility. Utilities, however, cannot be observed or measured directly. Furthermore, many of the attributes that influence individual's utilities cannot be observed and must therefore be treated as random. Consequently, the utilities themselves in models are random, meaning that choice models can give only the probability with which alternatives are chosen, not the choice itself.

Let $U = (U_1, \ldots, U_k)$ denote the vector of utilities associated with a given set of alternative, κ. this set includes k alternatives numbered 1, 2, …..k. The utility of each alternative to a specific decision maker can be expressed as a function of the observed attributes of the alternatives and the observed characteristics of this decision maker. Let **a** denote the vector of variables which include these characteristics and attributes. Thus $U_i = U_i(a)$. To incorporate the effects of unobserved attributes and characteristics, the utility of each alternative is expressed as a random variable consisting of systematic (deterministic) component, $V_K(a)$ and an additive random "error term", $\zeta_i(\theta, a)$, that is,

$$U_i(\theta,a) = V_i(\theta,a) + \zeta_i(\theta,a) \qquad \forall\, i \in \kappa$$

In this context, $U_K(a)$ is sometimes referred to as the "perceived utility of alternative K by the decision maker" and $V_K(a)$ as the "measured utility of alternative K by the analyst". The measured attractiveness functions $V_i(\theta,a)$ may take any finite real values and they need not be related in any way. The random disturbances $\zeta_i(\theta,a)$ can be interpreted as capturing different things, among them, errors in the measurement of the attributes in the data and the contribution of neglected attributes (attributes that can not be observed plus attributes that, although observed, are not included in $V_i(\theta,a)$) toward $U_i(\theta,a)$.

If a joint distribution of the error terms $\zeta_i(\theta,a)$ or that of $U_i(\theta,a)$ is known and attractiveness functions are specified, it is possible to obtain the choice function by calculating the probability that alternative i is the most attractive:

$$P_i(\theta,a) = \Pr\,\{V_i(\theta,a) + \zeta_i(\theta,a) > V_j(\theta,a) + \zeta_j(\theta,a);\ \forall j \neq i\} \qquad \forall\, i,j \in \kappa$$

McFadden (1973) modeled ζ by a set of independent identically distributed Gumbel variants, with zero mean and independent of θ and a. Then, the multinomial logit model (MNL) is as follow:

$$P_n(i) = \frac{e^{\beta_i x_n}}{\sum_I e^{\beta_i x_n}} \qquad i = 1, 2, \ldots, I$$

where $P_n(i)$ is the probability that person n chooses mode i, x_n is a vector of measurable characteristics of the trip maker n, and β_i is a vector of estimable coefficients by standard maximum likelihood methods.

Several statistical techniques can be used to estimate the parameter vector θ of a random utility model. The most widely used ones are discriminate analysis, data grouping, and maximum likelihood. All these techniques are applicable to disaggregate data sets (i.e., data sets in which each observation consists of an observed choice and an attribute vector of the choice maker). The maximum likelihood approach seems to be the most efficient for estimating random utility models. The maximum likelihood method consists of selecting the value of the parameter vector θ that makes the data look most reasonable. This is done by writing the probability density of the data for a given parameter value θ and finding the value of θ that maximizes the likelihood function. If, as is commonly the case, one can assume that the different individuals of the population act independently, the likelihood function is

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$$L(\theta) = \prod_{n=1}^{N} P_{c(n)}(\theta, a_{(n)}) \cdot F(a_{(n)})$$

where $a_{(n)}$ is the attribute vector of the nth individual, $c_{(n)}$ the choice of the nth individual, and N the number of individual in the data set. Since $F(a_{(n)})$ are not a function of θ, their values do not affect the maximum likelihood estimate and they can be omitted from $L(\theta)$. It is usually more convenient to find θ by maximizing the logarithm of the likelihood function, the log-likelihood function is:

$$\log L(\theta) = \sum_{n=1}^{N} \log P_{c(n)}(\theta, a_{(n)})$$

One of the most widely discussed aspects of the multinomial logit model is the independence from irrelevant alternatives property, or IIA. The IIA property holds that for a specific driver the ratio of the choice probabilities of any two modes is entirely unaffected by any other alternatives. The IIA property is a result of the assumption that the disturbance terms are mutually independent. The IIA can be easily shown to hold in the case of MNL as follows:

$$P_n(i) / P_n(j) = \Big(\frac{e^{\beta_i X_n}}{\sum_I e^{\beta_i X_n}}\Big) / \Big(\frac{e^{\beta_j X_n}}{\sum_I e^{\beta_i X_n}}\Big) = \frac{e^{\beta_i X_n}}{e^{\beta_j X_n}} = e^{(\beta_i - \beta_j) X_n}$$

McFadden and Hausman (1984) investigated a wide range of computationally feasible tests to detect violations of the IIA assumption. This involves comparisons of logit models estimated with subsets of alternatives from the universal choice set. If the IIA assumption holds for the full choice set, then the logit model also applies to a choice from any subset of alternatives. Thus, if the logit model is correctly specified, we can obtain consistent coefficient estimates of the same sub-vector of parameters from a logit model estimated with the full choice set and from a logit model estimated with a restricted choice set.

3.2 Alternatives Structures to the MNL Model

As discussed earlier, the MNL assumes that error terms of the alternatives are iid. The IID assumption on the random components can be relaxed in one of three ways:

1. Allowing the random components to be non-identical (different parameters of the selected distribution) and non-independent. Models with non-identical, non-independent random components commonly use a normal distribution for the error terms. The resulting model, referred to as the multinomial probit model (MNP), can accommodate a very general error structure. Unfortunately, the increase in flexibility of error structure comes at the expense of introducing several additional parameters in the covariance matrix. A simple alternative is

estimate the correlation matrix, **R**, and a diagonal matrix of standard deviations, **S** = diag($\sigma_1, \ldots, \sigma_{J-2}$, 1, 1) separately. The normalization $\mathbf{R}_{jj} = 1$ and exclusions $\mathbf{R}_{Jl} = 0$ are simple to impose. And the autocovariance matrix (Σ) is just **SRS**. Note that the MNL model assumes that $\Sigma = \mathbf{I}$. (the scaling is absorbed in the coefficient vector). Notice that is if **S** = diag(1,…, 1) then the model includes the IIA property. This means that you could test this property by using the LR (likelihood ratio) test of the assumption that all of the standard deviations in a model with uncorrelated disturbances are equal. This is likely to be a more powerful test than the McFadden/Hausman test because it will always use the entire sample.

2. Allowing the random components to be correlated while maintaining the assumption that they are identically distributed. The distribution of the random components in models, which use identical, non-independent random components, is generally specified to be either normal or type I extreme value. The resulting model (in case of type I extreme value, referred to as the nested logit model) allows partial relaxation of the assumption of independence among random components of alternatives. It requires a priori specification of homogenous sets if alternatives for which the IIA property holds.

3. Allowing the random components to be non-identically distributed (different variances), but maintaining the independence assumption. The concept of heterosedasticity in alternative error terms (i.e., independent but no identically distributed error terms) relaxes the IIA assumption. This is the heterosedasticity extreme value (HEV) model, Bhat (1995). If the scale parameters of the random components of all alternatives are equal, then the probability expression of HEV collapses to that of the multinomial logit.

3.3 Nested Logit Mode Choice Models

One way to relax the homoscedastiticy assumption (i.e., equal variances of distributions of errors) in the multinomial logit model that provides an intuitively appealing structure is to group the alternatives into subgroups that allow the variance to differ across the groups while maintaining the IIA assumption within the group. This specification defines a nested logit model. The nested logit model is currently the preferred extension to the simple multinomial logit discrete choice model. The appeal of the nested logit model is its ability to accommodate differential degrees of interdependence (i.e. similarity) between subsets of alternatives in a choice set. In this section, we will demonstrate a general outline of nested logit models.

A nested logit structure allows estimation of proportions among selected sub-modes, prior to the estimation of proportions between modes. For examples, a nested logit model might estimate the proportions between car occupancies, such as 2 persons per car and 3 persons per car, prior to estimating the proportions between the drive alone mode and the shared ride mode. This ability of the nested logit model reduces some of the limitations of the multinomial logit model, specially the independence from irrelevant alternatives (IIA) limitation. It has also been found that the selection between sub-modes may be more sensitive to travel times and costs than the selection between modes.

For examples, fairly small travel time changes can shift trips between the shared ride sub-modes (i.e., 2, 3, and 4+ persons per car) much more than it can shift the trips to or from the drive alone mode or the transit mode. The nested logit structure accounts for these differences in sub-mode sensitivities to a far greater extent than a multinomial logit model. Each nest within the choice set is associated with a pseudo-utility, called composite utility, expected maximum utility, inclusive value or accessibility in the literature.

The nested logit model, first derived by Ben-Akiva (1973), is an extension of the multinomial logit model designed to capture correlation among alternatives. It is based on the partitioning of the choice set C into several nests C_K. Where, for each pair $C_k \cap C_j = 0$. The utility function of each alternative is composed of a term specific to the alternative, and a term associated with the nest. If $i \in C_K$, we have

$$U_i = V_i + \varepsilon_i + V_{Ck} + \varepsilon_{Ck}$$

The error terms ε_i and ε_{Ck} are supposed to be independent. As for the multinomial logit model, error terms (ε_i's) are supposed to be independent and identically Gumbel distributed, with scale parameter σ_k. The distribution of ε_{Ck} is such that the random variable max $j \in C_K U_j$ is Gumbel distributed with scale parameter μ.

In the nested logit model the correlated alternatives are placed in a "nest", which partly removes the IIA property. There is a simple example in Figure 3.1 of the grouping of the alternatives. It must be noted that "public transport" is not available as an alternative because it is merely a label for a nest. It can be called "composite alternative" and the real alternatives "elemental alternatives".

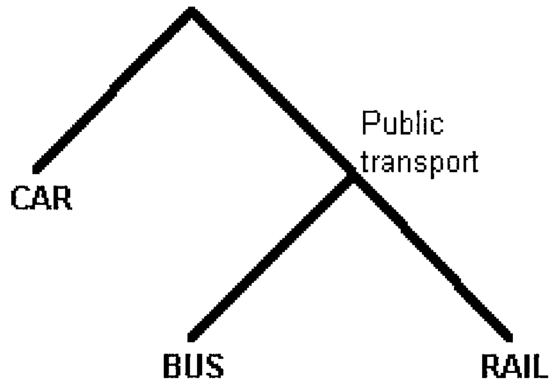

Figure 3.1 An Example for Nested Logit Mode Choice Structure

To fix the idea of a nested logit model, suppose that N alternatives can be divided into M subgroups such that the choice set can be written as: $[n_1,\ldots,n_m]_m$; $m = 1,\ldots,M$ and $\sum_m n_m = N$.

This choice-set partitioning produces a nested structure. Logically, one may think of the choice process as that of choosing among M choice sets and then making the specific choice with the chosen set. The mathematical form for a two-nested level logit model is as follows:

$$P_n = P_{n|m} P_m$$

$$P_{n|m} = \frac{\exp(\beta' x_j \mid m)}{\sum_{n_m} \exp(\beta' x_j \mid m)}$$

$$P_m = \frac{\exp(\gamma' z_m + \tau_m I_m)}{\sum_m \exp(\gamma' z_m + \tau_m I_m)}$$

$$I_m = \ln \sum_{n_m} \exp(\beta' x_j \mid m)$$

where P_n is the unconditional probability of choice n, $P_{n|m}$ is the conditional probability of choosing alterative n given that person has selected the choice-set m, P_m is the probability of selecting the choice-set m, $\mathbf{x}_{n|m}$ are attributes of the choices, $\mathbf{z}_m$ are attributes of the choice sets, I_m is called the inclusive value (log sum) of choice-set m, β and γ are vectors of coefficients to be estimated, and τ_m is the coefficient of the inclusive value of choice-set m. If we restrict all inclusive value parameters to be 1, then the nested logit model will be similar to multinomial logit model. The nested logit model is consistent with random utility maximization if the conditions' inclusive value parameter (τ) is bounded between zero and one. The nested logit model has been extended to three and higher levels. The complexity of the model increases geometrically with the number of levels. But the model has been found to be extremely flexible and is widely used for modeling individual choice.

To gain a better understanding of marginal effects of the variables included in a calibrated nested logit model, elasticities can be computed. The direct elasticity formula of an alternative n, which appears in one or more nests, is

$$E_{x_k}^{P_n} = \frac{\partial P_n}{\partial x_k} \cdot \frac{x_k}{P_n} = \frac{\Sigma_m P_m P_{n|m}[(1-P_n)+(1/\tau_m - 1)(1-P_{n|m})]}{P_n} \beta_k X_k$$

where E represents the direct elasticity, P_n is the probability of a person to chose mode n, P_m is the probability of nest m, X_k is the variable being considered to have an effect on mode n, and β_k is the estimated coefficient corresponding to the variable X_k. The terms in the summation evaluate to zero for any nest that does not include alternative n. The elasticity reduces to multinomial logit elasticity, $(1-P_n)\beta_k X_k$, if the alternative does not share a nest with any other alternative or is assigned only to nests for which the inclusive-value parameter (τ) equals one.

3.4 Tests for Specifications of Utility Functions

For a specific model structure, we explore statistical tests to be used to develop acceptable forms of the propensity functions ($U_{in} = \beta_i X_n + \varepsilon_{in}$). These statistical tests are the asymptotic t-test and the likelihood ratio tests. The asymptotic t-test is used primarily to test whether a particular parameter in the model differs from some known constant, often zero. Under the null hypothesis that all the slope coefficients are zeros, which is $\beta_1 = \beta_2 = ...= \beta_k$, the statistic $-2[L\ (0) - L\ (\beta)]$ is χ^2 distributed with k degrees of freedom.

The most useful applications of the likelihood ratio test are for more specific hypotheses. The test statistic is $-2[L\ (\beta_R) - L(\beta_U)]$, where β_R denotes the estimated coefficients of the restricted model (i.e., the model that is true under the null hypothesis) and β_U denotes the coefficient estimates of the unrestricted model. This statistic is χ^2 distributed with ($K_U - K_R$) degrees of freedom, where K_U and K_R are the number of estimated coefficients in the unrestricted and restricted models, receptively. In addition to the asymptotic t-test and the likelihood ratio tests; there are approaches for testing the significance of including nonlinear specifications in the propensity function. Two useful approaches that involve estimating models that are linear in the parameters are the piecewise linear approximation and the power series expansion. With a piecewise linear approximation we test the hypothesis that a coefficient may have different values for different ranges of the corresponding variables. The major disadvantage of he piecewise linear approximation approach is the loss of degrees of freedom. The second approach often used in practice is to represent a nonlinear function by a power series expansion that includes the linear specification as a special case.

3.5 Full Information Maximum Likelihood (FIML) Estimation

For the nested logit models, there are two ways to estimate the parameters of the nested logit model. A limited information maximum likelihood (LIML), sequential (multi-step) maximum likelihood approach can be done as follows: estimate β by treating the choice within branches as simple multinomial logit model, compute the inclusive values for all branches in the model, then estimate the parameters by treating the choice among branches as a simple multinomial logit models. Since this approach is a multi-step estimator, the estimate of the asymptotic covariance matrix of the estimates at the second step must be corrected.

The other approach of estimating a nested logit model is the full information maximum likelihood (FIML). In this approach, the entire model is estimated in a single phase. In general, the FIML estimation is more efficient than multi-step estimation. Until relatively recently, software for joint, full-information maximum likelihood estimation of all the parameters simultaneously was not available. This case is no longer true; several computer programs are available for FIML estimation of nested logit models. The LIMDEP software has the capability of estimating nested logit models using the FIML approach. Therefore, the models presented in this report are all calibrated using the FIML estimation approach.

CHAPTER 4

DATA PREPARATION

4.1 Travel Survey Data

This chapter summarizes the effort of data preparation for the two travel survey databases (household travel survey and on-board transit survey). It addresses the major steps in acquiring, checking, and completing the data in order to prepare it t support mode choice modeling. On March 2000, the research team received household-trip survey data of the Southeast Florida Regional Travel Characteristics Study. The survey data included three database files: (1) household information, (2) person characteristics, and (3) trips. The household information file (hhinfo2.sav) had information for 5,159 households. The trip information file (trips.sav) included 27,143 trips. The person characteristics file (persons2.sav) had information for 11,128 individuals that did the trips. We reviewed the three database files to make sure that it can support estimation and calibration of mode choice models. Some of our comments were:

1. The household trip file (trips.sav) did not have any network information (i.e., skim values were not provided).
2. Definitions for the variables were not clear
3. Methodology of the survey design was not included

In addition to the above comments, we needed an on-board transit survey data to enrich the sample, because the number of transit cases in the household trip file does not support the estimation of a full mode choice model. Also, we were worried about the TAZ compatibility between the FSTUMS skim tables and household travel survey data. This is because the FSTUMS skim tables were done based on the 1996 TAZs, while the household travel survey was done using the 2000 TAZs (2000 census). Finally, we directed all our questions and comments to Mr. Shi-Chiang Li from the FDOT, District 4.

On April 26th, Mr. Li sent to us a copy of the users manual (PC-X32) version of the Southeast Regional Planning Model (SERPM) as well as the data on two compact diskettes (CDs). One of the two CDs contains the entire SERPM inputs, scripts, special program, outputs and reports. The other CD has transit skim, fare, and path tables. Regarding the issue of TAZ compatibility, Mr. Li indicated that the TAZ conversion was underway and it should be ready by August 2000. In the meanwhile, the research team started looking at the SERPM model to get familiar with it. The manual helped us in understanding the FSTUMS modules of the SERPM model. We went though the manual as well as the FSTUMS manual for better understanding.

On August 2000, we received a new version of the three database files of the household travel survey as well as a new database file for the on-board transit travel survey. The research team compared the new set of household travel survey database files with the old set that we had received before. We found major differences between the two sets in terms of number of cases and variables. For instance, the old trip information file (trips.sav) had 27,143 cases, while the new file (trips.dbf) had 33,082. This means that there are 5,939 more extra trips. Also, the new file did not have the "mode of travel". Without this variable, it is impossible to estimate a mode choice model. After reviewing the household travel survey database files and the on-board transit survey, we raised the following questions to Mr. Li.

1. The new trips.dbf does not have a lot of relevant information as compared to the old file. Some of the missing variables are:

- QH2 Mode of Travel
- QJ Pay to Park at Stop
- QK Cost to Park?
- QN Fare for Bus/Train for Stop?
- QP Cost of Transfer
- QR Taxi Fare to Stop

2. We need more clear definition for the variables, providing only the variable name is not enough.
3. For the transit file, there is no information about the TAZs, whether 90 or 96.
4. We need clear definition of premium transit service versus local service.

In Sept. 27th, we received a new data file for the household travel survey (Trplgab2.txt). This file has 33,082 cases and includes the mode of travel for each trip. However, this file was not the final version of the household travel survey. On Feb 2001, the research team received the final version of the survey data of the Southeast Florida Regional Travel Characteristics Study. The survey data includes six database files; (1) household trips, (2) Transit, (3) Trucks, (4) Visitors, and (5) Workplace data. Our focus will be on the household trip file and the transit file. A complete description for these databases can be found in the final report of the Southeast Florida Regional Travel Characteristics Study. In this report, we will just outline a general description for those databases.

The total number of trips in the household survey file is 33,082 (trplgab.xls). There are 1,552 trips with incomplete origin-destination data distributed as follows: 169 trips with blank origins, 403 trips with blank destinations, 980 trips with both blanks, 39 trips with zero origins, 38 trips with zero destinations, and 161 trips with both zeros. Excluding trips with incomplete O-D ends; the remaining total number of trips is 31,291. There are also 4,766 trips with unsupportable categorized mode (QH2) of travel as follows: 3,633 trips with QH2 of zero (missing, refused, or DN), 34 trips with QH2 of 9 (other), 952 trips with QH2 of 12 (walk), and 147 trips of QH2 (bike). Therefore, The remaining total number of trips is 26,525. Out of these 26,525, there are 337 transit trips (1.27%) divided into: 273 trips with QH2 of 3 (bus) and , 64 trips with QH2 of 4 (transit other).

The total number of trips in the on-board transit survey was 11,173. There were 3,831 trips with incomplete origin-destination data distributed as follows: 1,390 trips with blank origins, 1,405 trips with blank destinations, and 1,036 trips with both blanks. Excluding trips with incomplete O-D ends; the remaining total number of transit trips is 7,342. In the transit survey, the following modes are available:

- Metro Rail (MR)
- Tri Rail (TR)
- Palm Tran
- Miami Dade Metro Bus
- Broward County Metro Rail

These five modes did not match the FSTUMS available modes. We needed to know the relationship between modes 3, 4 and 5 and the skims. In other words, for example whether Palm Tran is considered a local bus, express bus (EB), metro rail (MR) or tri rail (TR). Also whether

Broward MR serves Dade County. A list of modes available in each county in the study would be useful.

On November 10th, Mr. Kaltenbach from Corradino Group kindly responded that there is no Broward County Metro Rail. Mode 5 in the survey is Broward County Transit. An early draft report had this error, which has been corrected. For Modes 3, 4 and 5, which are bus, the determination of whether the route is local bus or express route must be made on a route-by-route basis. A separate memo from Sunil Saha from Corradino Group has attached a table that contained the latest route definitions for Broward County Transit (BCT) and Palm Beach Train. We used this table to determine whether the routes are local or express. We did not have a corresponding table for Miami-Dade. Please note that in the SERPM transit networks and skims, Metro mover (Miami people-mover) is lumped together with Metrorail. The survey mode availability is:

- Metro Rail (Dade)
- Tri Rail (Dade, Broward, Palm Beach)
- Palm Tran (Palm Beach)
- Miami Dade Metro Bus (Dade, but a few routes cross the Broward line to nearby attractions)
- Broward County Transit (Broward)

Also, an excel file (routeinfo.xls) was attached for transit service by route. The file contains four sheets and those are:

- ampb : Peak Period Palm Beach Routes
- mdpb : Off-Peak Period Palm Beach Routes

- ambo : Peak Period Broward Routes
- mdbo : Off-Peak Period Broward Routes

The transit modes are as follows:

- 4 : Local Bus
- 12 : Local Bus (Tri-Rail Feeder)
- 6 : Express Bus
- 8 : Tri-Rail.

An example of the route information is presented in Table 4.1.

The Miami Dade County has a large transit network. The Miami-Dade Transit Agency (MDTA) Website is http://www.metro-dade.com/transportation.htm. Table 4.2 summarizes the major characteristics of the Miami transit network. The 21.5-mile Metrorail represents the longest elevated rapid transit system in the country. With completion of a 1.9-mile downtown Metro mover, Miami-Dade County became the first community in the world to have a people mover connected to a rail system. The size of Metro mover doubled with the opening of the Brickell financial district and Omni-Biscayne Metro mover stops. Tri-Rail, the 65-mile tri-county commuter rail, transports commuters from as far north as West Palm Beach to Miami-Dade County, and the extensive Metrobus network completes Miami-Dade's fully integrated transit system. Miami-Dade's highways, causeways and access roads connect all corners of the County, including the islands of Miami Beach and Key Biscayne.

Table 4.1 Broward Transit Route Card Information: Off-Peak Period

Company	Mode	Line	Headway (minute)	1-way Flag	Route Group	Route ID	Remark on Ridership Data (*)	AM or MD ONLY
1	4	1	20	T	1	RTE 1 SB:FT LD AVENTURA M		
1	4	201	20	T	1	RTE 1 NB:AVENTURA M FT LD		
1	4	2	30	F	2	RTE 2:HOLLYWOOD BLVD		
1	4	3	60	F	3	RTE 3:RAVENSWOOD GARAGE		
1	4	5	60	F	5	RTE 5:HOLLYWOOD BLVD		
1	4	6	30	T	6	RTE 6 SB:YOUNG CIRCLE		
1	4	206	30	T	6	RTE 6 NB:YOUNG CIRCLE		
1	4	7	30	F	7	RTE 7:YOUNG CIRCLE		
1	4	9	40	F	9	RTE 9:BROWARD CENTRAL		
1	4	10	30	F	10	RTE 10: BROWARD CENTRAL		
1	4	11	30	F	11	RTE 11:POMPANO SQUARE		
1	4	12	45	F	12	RTE 12:WEST BROWARD		
1	4	14	30	F	14	RTE 14:BROWARD CENTRAL		
1	4	15	45	T	15	RTE 15 SB:		
1	4	215	45	T	15	RTE 15 NB:		
1	4	17	40	T	17	RTE 17 WB:HOLLYWOOD BLVD		
1	4	217	40	T	17	RTE 17 EB:HOLLYWOOD BLVD		
1	4	18	15	F	18	RTE 18:MARGATE TERMINAL		
1	4	20	40	F	20	RTE 20:POMPANO SQUARE		
1	4	22	30	F	22	RTE 22:SAWGRASS MILLS		
1	4	28	30	F	28	RTE 28:YOUNG CIRCLE		
1	4	30	30	F	30	RTE 30:BROWARD CENTRAL		
1	4	31	30	F	31	RTE 31:BROWARD CENTRAL		
1	4	36	20	F	36	RTE 36:SAWGRASS MILLS		
1	4	40	30	F	40	RTE 40:BROWARD CENTRAL		
1	4	50	30	F	50	RTE 50:BROWARD CENTRAL		
1	4	55	40	F	55	RTE 55:BROWARD CENTRAL		
1	4	56	30	F	56	RTE 56:SUNSHINE PLAZA		
1	4	57	70	T	57	RTE 57 WB:SUNSHINE PLAZA		
1	4	58	70	T	57	RTE 57 EB:SUNSHINE PLAZA		
1	4	60	30	F	60	RTE 60:		
1	4	62	60	F	62	RTE 62:CORAL SQUARE MALL		
1	4	72	30	F	72	RTE 72:SAWGRASS MILLS		
1	4	75	60	T	75	RTE 75:WEST BROWARD		
1	4	81	30	T	81	RTE 81 EB:BROWARD CENTRAL		
1	4	82	30	T	81	RTE 81 WB:BROWARD CENTRAL		
1	4	83	30	F	83	RTE 83:POMPANO SQUARE		
1	4	92	45	F	92	RTE 92:CENT VILL92		
1	4	93	90	F	93	RTE 93:CENT VILL93		MD Only
1	4	94	45	F	94	RTE 94:CENT VILL94		MD Only
1	4	95	90	F	95	RTE 95:CENT VILL95		MD Only
2	12	106	60	F	106	RTE=53:DT-LO		
2	12	108	60	T	108	RTE=43		
2	12	110	60	T	108	RTE=41		
2	12	114	60	T	108	RTE=42		
2	12	118	60	T	118	RTE=33 WB		
2	12	119	60	T	118	RTE=33 EB		
2	12	122	60	T	122	RTE=23		
2	12	124	60	F	122	RTE=24		
2	12	126	60	T	126	RTE=63		
2	12	128	60	T	128	RTE=74		
1	4	130	60	F	130	RTE=MA-A:MARGATE A		
1	4	131	120	F	130	RTE=MA-B:PEPPERTREE		
1	4	141	120	F	130	RTE=MA-B:TURTLE RUN		
1	4	142	120	T	130	RTE=MA-B:PALM LAKES		
1	4	132	60	F	130	RTE=MA-C:MARGATE C		
1	4	133	60	F	130	RTE=MA-D:OAKLAND HILLS		
1	4	143	120	F	130	RTE=MA-D:PALM LAKES		
1	4	144	120	F	130	RTE=MA-D:COC. CREEK		
1	4	134	90	T	134	RTE=CO:COOPER CITY		
1	4	135	60	T	135	RTE=HI:HILLSBORO BEACH		
1	4	136	90	F	136	RTE=PP:PEMBROKE PINES		
1	4	137	90	F	137	RTE=CC:COCONUT CREEK		
1	4	138	60	F	138	RTE=MI:MIRAMAR		
1	4	140	60	T	140	RTE=BUS:BRO URB SHUTTLE	No Data	
1	6	152	30	T	152	RTE=DAVIE/SFEC EXPRESS		
4	8	200	60	F	200	TRI-RAIL		
1	4	210	10	F	210	COURTHOUSE LOOP	No Data	
1	4	211	10	F	210	TMAX LUNCH	No Data	MD Only
1	4	212	10	F	210	COURTHOUSE TROLLEY	No Data	MD Only

(*) The following Routes do have ridership data without route-card records: Routes 34, 84, 97 and an Unknown.

Table 4.2 Transit network of Miami Dade County

Mode	System	Service hours	Notes
Metrobus (express and local)	Bus	4:00 am to 2:30 am of the following day	73 routes
Metrorail	Train	4:30 am to 12:45 am	21.1 mile line
Metro mover	Train	5:30 am to 12:45 am	6.9 mile lines
Tri-Rail (Tri-County Commuter Rail Authority)	Train		

On Feb 2001, we received the final report of the Southeast Florida Travel Characteristics Travel Study. The consultant developed a sampling frame for each system. The survey focus was weekday travel 24 hours per day. The routes and trips to survey were randomly selected from each system's weekday service schedule. In the random selection process each system was examined individually. Table 4.3 summarizes the transit daily ridership and number of completed surveys for all transit systems available in the three counties.

Table 4.3 Transit ridership and number of completed surveys

System	Daily ridership	Completed surveys
1. Miami-Dade Metrobus	200,000 (59.4%)	4,870 (43.5%)
2. Miami-Dade Metrorail	50,000 (14.8%)	477 (4.3%)
3. Broward County Transit	66,000 (19.6%)	3,719 (33.3%)
4. Palm Transit	13,000 (3.9%)	1,492 (13.4%)
5. Tri-Rail	8,000 (2.3%)	615 (5.5%)
Total	337,000 (100%)	11,173 (100%)

Apparently there was no specific approach to sample certain number or percentage of each transit service patrons. This gives rise to the issue of choice based sampling, which is discussed in the following chapter and adjusted for in the models. In addition, Table 4.4 summarizes the express bus routes included in the survey.

Table 4.4 Miami-Dade Express bus routes

Route	Service	Sample
95ex	Express	Included
27max	Express	Included
Biscayne(93,41)	Express	Included
51	Express and local	Included
240	Express	Not included
K104	Express	Not included
Kat-Kendall	Express	Included but there is no any trips associated with this mode
Kat-sunset	Express	Included
38ex	Express	Included

Also, we made contacts with the Miami-Dade Transit Authority. They sent to us some maps and bus routes by time of day, which we used to determine the express bus (EB) service schedules, which we matched with the survey to determine the EB trips. For example, Figures 4.1 and 4.2 show the map and service schedule for route 27MAX express bus service.

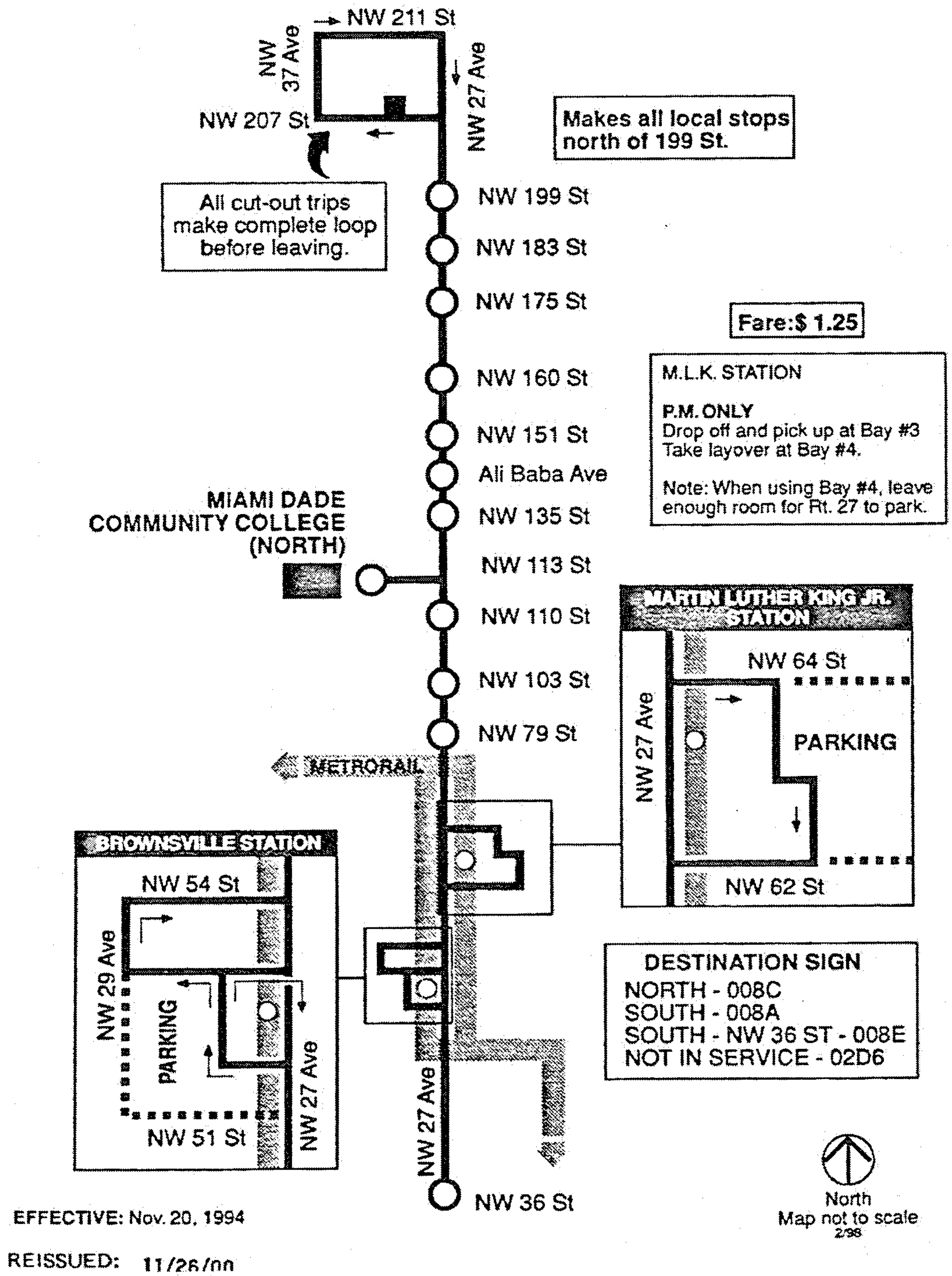

Figure 4.1 Route of 27MAX express bus service

*****PREPARED BY MDTA SCHEDULING*****

MIAMI-DADE TRANSIT AGENCY
METROBUS

97 -- ROUTE: 97 M.D.T.A. ROTARY PAGE: 1
SOUTHBOUND WEEKDAY DATE: 26NOV00

27 AVE MAX: CALDER-ML KING STA TIME: 5:30 AM

RUN NO.	BLOCK NO.	NOTE	D-H	GAR-OUT FR-LINE	27AV 207S	27AV 211S	199S 27AV	27AV 183S	27AV 175S	27AV 151S	27AV 135S	N.D. C.C.	27AV 79ST	MRTN KING	BRWN SVIL	27AV 36ST	GAR-IN FR-LINE	D-H	TRIP TIME	L-O TIME
1135	1		SET	CE-4:57	5:30	5:35	5:38	5:41	5:42	5:46	5:49	5:53	5:59	6:02					32	4
1136	2		SET	CE-5:27	6:00	6:05	6:08	6:11	6:12	6:16	6:19	6:23	6:29	6:32					32	4
1137	3		SET	CE-5:42	6:15	6:20	6:23	6:26	6:27	6:31	6:34	6:38	6:44	6:47					32	4
1138	4		SET	CE-5:57	6:30	6:35	6:38	6:41	6:42	6:46	6:49	6:53	6:59	7:02					32	4
1135	1				6:45	6:50	6:52	6:55	6:56	7:00	7:04	7:09	7:16	7:19					34	3
1139	5				7:00	7:06	7:09	7:12	7:13	7:17	7:21	7:26	7:33	7:36					36	2
1136	2				7:15	7:21	7:24	7:27	7:28	7:32	7:36	7:41	7:48	7:51					36	2
1137	3				7:30	7:36	7:39	7:42	7:43	7:47	7:51	7:56	8:03	8:06	8:10	8:16*	CE-8:18	#	46	
1138	4				7:45	7:51	7:54	7:57	7:58	8:02	8:06	8:11	8:18	8:21	8:25	8:31*	CE-8:33	#	46	
1135	1				8:00	8:06	8:09	8:12	8:13	8:17	8:21	8:26	8:33	8:36	8:40	8:46*	CE-8:48	#	46	
1139	5				8:15	8:21	8:24	8:27	8:28	8:32	8:35	8:39	8:45	8:48	8:52	8:58*	CE-9:00	#	43	
1136	2				8:30	8:36	8:38	8:41	8:42	8:45	8:48	8:52	8:58	9:01	9:05	9:11*	CE-9:13	#	41	
1140	6				4:43	4:49	4:51	4:54	4:55	4:58	5:01	5:05	5:11	5:14					31	6
1141	7				4:58	5:04	5:06	5:09	5:10	5:13	5:16	5:20	5:26	5:29					31	6
1142	8				5:13	5:19	5:21	5:24	5:25	5:28	5:31	5:35	5:41	5:44					31	6
1143	9				5:28	5:34	5:36	5:39	5:40	5:43	5:46	5:50	5:56	5:59					31	6
1144	10				5:48	5:54	5:56	5:59	6:00	6:03	6:06	6:10	6:16	6:19					31	6
1140	6				6:02	6:08	6:10	6:13	6:14	6:17	6:20	6:24	6:30	6:33					31	7
1141	7				6:16	6:22	6:24	6:27	6:28	6:31	6:34	6:38	6:44	6:47*			CE-6:55	#	31	
1142	8				6:31	6:37	6:39	6:42	6:43	6:46	6:49	6:53	6:59	7:02					31	8
1143	9				6:44	6:50*											CE-7:17	#	6	
1144	10				6:59	7:05*											CE-7:32	#	6	
1140	6				7:14	7:20*											CE-7:47	#	6	
1142	8				7:44	7:50*											CE-8:17	#	6	

( ) -- OPERATOR CHANGES * -- TRIP ENDS

SET-- FARE = $1.25 - PRESET METER TO 1

*****PREPARED BY MDTA SCHEDULING*****

MIAMI-DADE TRANSIT AGENCY
METROBUS

97 -- ROUTE: 97 M.D.T.A. ROTARY PAGE: 2
NORTHBOUND WEEKDAY DATE: 26NOV00

27 AVE MAX: CALDER-ML KING STA TIME: 6:06 AM

RUN NO.	BLOCK NO.	NOTE	D-H	GAR-OUT FR-LINE	27AV 36ST	BRWN SVIL	MRTN KING	27AV 79ST	N.D. C.C.	27AV 135S	27AV 151S	27AV 175S	27AV 183S	199S 27AV	27AV 207S	GAR-IN FR-LINE	D-H	TRIP TIME	L-O TIME
1135	1						6:06	6:10	6:16	6:20	6:23	6:26	6:28	6:31	6:34			28	11
1139	5		SET	CE-6:12			6:21	6:25	6:31	6:35	6:38	6:41	6:43	6:46	6:49			28	11
1136	2						6:36	6:40	6:46	6:50	6:53	6:56	6:58	7:01	7:04			28	11
1137	3						6:51	6:55	7:02	7:06	7:10	7:13	7:15	7:18	7:21			30	9
1138	4						7:06	7:11	7:18	7:22	7:26	7:29	7:31	7:34	7:37			31	8
1135	1						7:22	7:27	7:34	7:38	7:42	7:45	7:47	7:50	7:53			31	7
1139	5						7:38	7:43	7:50	7:54	7:58	8:01	8:03	8:06	8:09			31	6
1136	2						7:53	7:58	8:05	8:09	8:13	8:16	8:18	8:21	8:24			31	6
1140	6		SET	CE-3:51	3:55	3:59	4:05	4:10	4:17	4:22	4:28	4:33	4:35	4:38	4:41			46	2
1141	7		SET	CE-4:06	4:10	4:14	4:20	4:25	4:32	4:37	4:43	4:48	4:50	4:53	4:56			46	2
1142	8		SET	CE-4:21	4:25	4:29	4:35	4:40	4:47	4:52	4:58	5:03	5:05	5:08	5:11			46	2
1143	9		SET	CE-4:36	4:40	4:44	4:50	4:55	5:02	5:07	5:13	5:18	5:20	5:23	5:26			46	2
1144	10		SET	CE-4:51	4:55	4:59	5:05	5:10	5:17	5:22	5:28	5:33	5:35	5:38	5:41			46	7
1140	6						5:20	5:25	5:32	5:37	5:42	5:47	5:49	5:52	5:55			35	7
1141	7						5:35	5:40	5:46	5:51	5:56	6:01	6:03	6:06	6:09			34	7
1142	8						5:50	5:55	6:01	6:06	6:11	6:16	6:18	6:21	6:24			34	7
1143	9						6:05	6:10	6:16	6:21	6:26	6:31	6:33	6:36	6:39			34	5
1144	10						6:25	6:30	6:36	6:41	6:46	6:51	6:53	6:56	6:59			34	
1140	6						6:40	6:45	6:51	6:56	7:01	7:06	7:08	7:11	7:14			34	
1142	8						7:10	7:15	7:21	7:26	7:31	7:36	7:38	7:41	7:44			34	

( ) -- OPERATOR CHANGES * -- TRIP ENDS

SET-- FARE = $1.25 - PRESET METER TO 1

Figure 4.2 Schedule of route 27MAX express bus service

4.2 FSTUMS Skim Tables

The main objective of this step was to extract the skim values from the FSTUMS tables. Table 4.5 shows the needed attributes for estimating a full mode-choice model. The research team made a lot of effort to open these skims. However, we discovered that these skim files were written in a special FSTUMS format. We eventually obtained a computer program that reads the FSTUMS skim files and write them into a text file format. Also we used another program that uses the origin-destination fields (reported in the travel survey) to obtain all information about the skims (both programs were provided by Mr. Jim Fennessey).

Table 4.5 Skim Values needed for calibrating a mode-choice model

Transit Walk Time (minutes)
Transit Auto Access Time (minutes)
Transit Run Time (minutes)
Transit First Wait (minutes)
Transit Transfer Time (minutes)
Transit Number of Transfers
Transit fare (cents)
Highway terminal time (minutes)
Highway Run Time (minutes)
Highway Auto Operating Costs (cents)
Highway Parking Costs (cents)

4.2.1 Transit skims

The FSTUMS transit skim files include travel times and costs of all of the available modes. According to the SERPM mode, nine modes of travel are available.

1. Auto Driver
2. Auto Passenger
3. Walk to Local Bus (LB)
4. Walk to Express Bus (EB)
5. Walk to Metro-Rail (MR)
6. Walk to Tri-Rail (TR)
7. Drive to Express Bus (EB)
8. Drive to Metro-Rail (MR)
9. Drive to Tri-Rail (TR)

Each of the above nine modes has FSTUMS skim files. Table 4.6 and Table 4.7 describe the fields of the FSTUMS skim files. There are 13 skims for the transit models. Twelve transit skim variables (Walk time, Drive Time, Sidewalk time, Local bus IVT (Palm Beach. Broward), Local bus IVT (Dade), Express Bus IVT, Metro Rail IVT, Tri Rail IVT, Number of transfers, First Wait time, Transfer Wait time, Total time) are located in "tskimam1.xxx" file for AM peak and "tskimmd.xxx" for the midday (MD) period. The AM and MD fare values are located in "tfaream1.xxx" and "tfaremd1.xxx", respectively.

Table 4.6 Transit AM-Peak FSTUMS Skim File Description

Mode	FSTUMS Files	no. of skims	Skims
Transit modes			
• Walk to LB	TSKIMAM1	12	Walk time, Drive Time, Sidewalk time, Local bus IVT (Palm Beach. Broward), Local bus IVT (Dade), Express Bus IVT, Metro Rail IVT, Tri Rail IVT, No. of transfers, First Wait time, Transfer Wait time, Total time
• Walk to EB	TSKIMAM2	12	
• Walk to MR	TSKIMAM3	12	
• Walk to TR	TSKIMAM4	12	
• Drive to EB	TSKIMAM5	12	
• Drive to MR	TSKIMAM6	12	
• Drive to TR	TSKIMAM7	12	
• Walk to LB	TFAREAM1	1	Fare
• Walk to EB	TFAREAM2	1	
• Walk to MR	TFAREAM3	1	
• Walk to TR	TFAREAM4	1	
• Drive to EB	TFAREAM5	1	
• Drive to MR	TFAREAM6	1	
• Drive to TR	TFAREAM7	1	

Table 4.7 Transit Midday-Period FSTUMS Skim File Description

Mode	FSTUMS Files	no. of skims	Skims
Transit modes			
• Walk to LB	TSKIMMD1	12	Walk time, Drive Time, Sidewalk time, Local bus IVT (Palm Beach. Broward), Local bus IVT (Dade), Express Bus IVT, Metro Rail IVT, Tri Rail IVT, No. of transfers, First Wait time, Transfer Wait time, Total time
• Walk to EB	TSKIMMD2	12	
• Walk to MR	TSKIMMD3	12	
• Walk to TR	TSKIMMD4	12	
• Drive to EB	TSKIMMD5	12	
• Drive to MR	TSKIMMD6	12	
• Drive to TR	TSKIMMD7	12	
• Walk to LB	TFAREMD1	1	Fare
• Walk to EB	TFAREMD2	1	
• Walk to MR	TFAREMD3	1	
• Walk to TR	TFAREMD4	1	
• Drive to EB	TFAREMD5	1	
• Drive to MR	TFAREMD6	1	
• Drive to TR	TFAREMD7	1	

To extract the skim values for a specific mode, a customized executable program "getod.exe" (created by Mr. Jim Fennessy) was used. The program inputs files for a specific mode are the skim files of that mode and a text file with two columns for origin and destination pairs. Each O-D pair represents a trip. This text O-D file has to be written in a specific format (5 spaces for each column with right alignment and arranged in an ascending order for origin and destination). The output of the program is a text file that contains the skim values for each trip. A batch file was created to facilitate the use of getod.exe file and make it faster to extract the skim values from the skim files.

After extracting the transit skim values for each trip, we posted a new set of questions to Mr. Kaltenbach (The Corradino Group) and Mr. Li:

1. What are the ranges of TAZ numbering for each county (Miami, Palm Beach, Broward)?
2. Each transit skim has a "total time" field. What does this variable represent?
3. Some transit skims are all zeros, what does a value of zero mean? We logically assume that a value of zero (for a specific trip) means that this transit mode is not available for that trip.
4. In Table 2-2, page 22 in the Users Manual (PC-X32) Version, what are the definitions of the AM and PM peak periods?

On November 10th, Mr. Kaltenbach responded with the following answers:

1. An ArcView shape file with the zones was provided. County is one of the fields. Please note that these zones are not the same as used in SERPM4 or the individual MPO models.
2. Total transit travel time for the path. Zero in table 12 means that the "path mode" was not available. However, zero in the other tables, like table (auto access) means that component of

the skim was not used, eventhough there is a path. For example, for TSKIMAM1, which is walk to local bus, table 2 always will be zero because this path requires walk access.

3. Zero in the TTIME variable means that the "path mode" was not available. However, zero in the other tables, like table (auto access) means that component of the skim was not used, even though there is a path. For example, for TSKIMAM1, which is walk to local bus, table 2 always will be zero because this path requires walk access.
4. AM peak is 6 – 9 AM; PM peak is 4 - 7 PM.

Reviewing the skim values for the transit trips, we discovered that the TAZs of the survey are not compatible with the FSTUMS skim files. To make the two databases compatible, we started looking at the relationship between the old TAZ numbering and the new TAZ number. We made a look-up table that coverts any old TAZ to the corresponding new TAZ. Then, all transit skims were extracted again.

4.2.2 Highway skims

There are 3 skim values for the highway models. These skims represent impedance, distance and toll. The AM and MD for drive-alone and share-drive modes are located in the two files “hskims.a96” and “hvskims.a96” respectively. Travel time and total cost variables for the highway modes (drive-alone, share-drive) are not included in the skim tables. Instead, the skim files contain impedance, distance, and toll. The impedance variable is a combination of travel time and cost.

Table 4.8 Highway AM-Peak FSTUMS Skim File Description

Mode	FSTUMS Files	no. of skims	Skims
AM-Peak			
• Auto driver	HSKIMS.A96	6	Impedance, Distance, and Toll (AM peak) Impedance, Distance, and Toll (PM peak)
• Auto Passenger	HVSKIMS.A96	6	Impedance, Distance, and Toll (AM peak) Impedance, Distance, and Toll (PM peak)
Midday-Period			
• Auto driver	HSKIMS.A96	6	Impedance, Distance, and Toll (AM peak) Impedance, Distance, and Toll (PM peak)
• Auto Passenger	HVSKIMS.A96	6	Impedance, Distance, and Toll (AM peak) Impedance, Distance, and Toll (PM peak)

The following equations for travel time and cost were extracted from the "nlogit.for" and "nlogit.loc" files:

$$\text{Travel Time (minutes)} = (\text{Impedance} - \text{Toll} * \text{Ctoll})*0.01$$

$$\text{Highway Operating Cost (cents)} = \text{AOC} * \text{Distance} + \text{toll}$$

where: impedance, toll, and distance are obtained from the highway skims files, Ctoll is the toll coefficient (Ctoll = 0.10 from profile.mas file), and AOC is the auto operating cost coefficient (AOC = 9.5 cents per mile from profile.mas file).

In addition to the travel time and cost, there are two other zone-level variables. These zone-level variables are parking cost and highway terminal time. The highway parking costs are included in the ZDATA2 file (Figure 4.3). There are two types: short-term and long-term. Short-term is used for non-work trip purpose and long-term is used for home-based work trips. The zone in the ZDATA2 file is the destination (attraction) zone. The unit of parking cost is in cents.

A "2" indicates the type of zonal data

Sector number (optional)

Employment

School Enrollment

Parking Costs

2	1	1	500	5571	542	6613	594	10	150
2	1	2	221	293	221	735	0	10	150
2	2	3	21	47	22	90	81	5	50
2	2	4	19	141	20	180	29	5	50
2	2	5	14	188	15	217	63	5	50
2	2	6	377	564	377	1318	58	5	50
2	3	7	979	242	979	2200	95	0	0
2	3	8	124	66	124	314	151	0	0
2	3	9	248	132	248	628	133	0	0
2	4	10	481	86	482	1049	302	0	0
2	4	11	1158	130	1159	2447	201	0	0
2	5	12	88	0	89	177	70	0	0
2	5	13	48	0	49	97	123	0	0
2	5	14	16	0	16	32	6	0	0
2	5	15	8	0	8	16	0	0	0

Long term parking costs (0¢)

Short term parking costs (0¢)

School Enrollment (school totals by location by TAZ)

Total Employment by Place of Work (SIC 01-99)

Service Employment by Place of Work (SIC 40-49 and 60-69)

Commercial Employment by Place of Work (SIC 50-59)

Industrial Employment by Place of Work (SIC 01-39)

Zone

Figure 4.3 ZDATA2 file format (source : FSTUMS manual)

Terminal times were determined based on the area type. The new FSTUMS area type code consists of two digits. The first digit can be {1, 2, 3, 4, or 5} for areas using old codes. The new two-digit code has a total of 14 codes (Categories). These categories are shown in Table 4.9. The area type of a TAZ can be determined from the LINKS file (Figure 4.4) of the SERPM model. There is only one file for the three counties. Then, the values of terminal time are retrieved from PROFILE.MAS using the area types. Table 4.10 summarizes the terminal time values for different area types of TAZs.

Table 4.9 FSTUMS Area Type Two-digit Codes (source: FSTUMS manual)

Area Type	Code
1x CBD areas	
▪ Urbanized area (over 500,000) primary city Central Business District	11
▪ Urbanized area (under 500,000) primary city Central Business District	12
▪ Other urbanized area central business districts and small city downtown	13
▪ Non-urbanized area small city downtown	14
2x CBD fringe areas (mix use of commercial and warehouses)	
▪ All Central Business District (CBD) fringe areas	21
3x Residential areas	
▪ Residual area of urbanized areas	31
▪ Undeveloped portions of urbanized areas	32
▪ Transitioning areas / urban areas over 5,00 population	33
▪ Beach residential	34
4x Outlying Business District (OBO) areas (not adjacent to CBD)	
▪ High density outlying business district	41
▪ Other outlying business district	42
▪ Beach outlying business district	43
5x Rural areas	
▪ Developed rural areas / small cities under 5,000 population	51
▪ Undeveloped rural areas	52

A to B Directional Link Values

B to A Link Values Same Format as A to B

	1	1280	51	1	S	0199S	01995010
	1	1350	51	1	S	0199S	01995010
	2	1280	52	1	S	0199S	01995020
	3	1220	52	1	S	0199S	01995020
	3	1265	52	1	S	0199S	01995020
	4	1205	53	1	S	0199S	01995030
	4	1255	53	1	S	0199S	01995030
	5	1255	53	1	S	0199S	01995030
	5	1325	53	1	S	0199S	01995030
	6	1265	52	1	S	0199S	01995020
	6	1285	52	1	S	0199S	01995020
	6	1290	52	1	S	0199S	01995020
	6	1335	52	1	S	0199S	01995020
	7	1335	52	1	S	0199S	01995020
	7	1355	52	1	S	0199S	01995020
	7	1360	52	1	S	0199S	01995020
	7	1395	52	1	S	0199S	01995020
	8	1325	54	1	S	0199S	01995040
	8	1360	54	1	S	0199S	01995040
	8	1385	54	1	S	0199S	01995040
	9	1310	54	1	S	0199S	01995040
	9	1365	54	1	S	0199S	01995040
	10	1240	53	1	S	0199S	01995030
	10	1295	53	1	S	0199S	01995030
	10	1300	53	1	S	0199S	01995030
	10	1310	53	1	S	0199S	01995030
	11	1190	54	1	S	0199S	01995040
	11	1225	54	1	S	0199S	01995040
	11	1230	54	1	S	0199S	01995040
	11	1240	54	1	S	0199S	01995040
	12	1120	54	1	S	0199S	01995040
	12	1170	54	1	S	0199S	01995040
	12	1180	54	1	S	0199S	01995040
	12	1190	54	1	S	0199S	01995040
	13	1100	54	1	S	0199S	01995040
	13	1130	54	1	S	0199S	01995040
	14	1140	54	1	S	0199S	01995040
	14	1160	54	1	S	0199S	01995040
	15	1155	55	1	S	0199S	01995050
	16	2038	55	1	S	0199S	01995050
	17	2069	55	1	S	0199S	01995050
1	18	2068	55	1	S	0199S	01995050

A Node

B Node

One-Digit Facility Type

One-Digit Area Type

Geographic Location Code

S = Speed
May also be
T = Time
U = Uniform Time

Link Group (Screenline)

Two-Digit Facility Type

Two-Digit Area Type

One-Way Indicator (1 = One-Way)

Vehicle Count

# of lanes

Figure 4.4 LINKS file format (source: FSTUMS manual)

Table 4.10 Highway Terminal Times (source: profile.mas)

FSTUMS *Old* Area Code	FSTUMS *New* Area Code	Terminal time (minutes)
1	10	5
1	11	5
1	12	5
1	19	5
2	20	3
2	21	3
2	29	3
3	30	1
3	31	1
3	32	1
3	33	1
3	34	1
3	39	1
4	40	2
4	41	2
4	42	2
4	49	2
5	50	1
5	51	1
5	52	1
5	59	1

CHAPTER 5

MODEL ESTIMATION

5.1 Modeling Framework

As discussed before, the household survey data set had very limited cases of transit trips, therefore we needed to use the transit on-board surveys to estimate the transit section of the mode choice model. The sampling methodology followed in the household travel survey is different from the one used for the ob-board transit survey. In the household travel survey, sequence of decision makers were drawn and their choice behaviors were observed. This kind of sampling scheme is called exogenous sampling process. In contrast, in the on-board transit survey, sequence of chosen alternatives were drawn, and the characteristics of the decision makers selecting those alternatives were observed. This kind of sampling scheme is called choice-based sampling. This type of sampling is appropriate when some alternatives of particular interest are infrequently chosen.

Manski and Lerman (1977) considered the maximum likelihood estimation of discrete choice models when the sample of observations is choice-based. Unlike a random sample in which the probability of being included is the same for all individuals, a choice-based sample is designed so that the probability of being included depends on which choice the individual made; that is, the sample is stratified on an endogenous variable. The method modifies the familiar exogenous sampling maximum likelihood estimator by weighting each observation's contribution to the log-likelihood. If i is the chosen alternative associated with observation n, then the weight imposed is

$Q(i)$/H(i), where $Q(i)$ is the fraction of the decision making population selecting i and $H(i)$ is the analogous fraction for the choice based-sample.

Consider a continuum of decision makers T each facing the same abstract finite choice set C. In choice based sampling, the analyst draws an alternative i from C with probability H(i), next draws a decision maker at random from that subset of T selecting i and then observes the attribute matrix z associated with that decision maker. The likelihood of an observation is thus

$$\frac{P(i,z,\theta)g(z)}{\int_Z P(i,z,\theta)g(z)dz}.H(i)$$

where P(i,z,θ) is the probability that a trip maker with attribute matrix z will select alternative i, θ is a parameter vector, and g(z) is the probability density of z. The choice-based sampling likelihood function can be written as follows:

$$L(\theta) = \prod_1^N \frac{P(i,z,\theta)g(z)}{\int_Z P(i,z,\theta)g(z)dz}.H(i)$$

$$\text{Log } L(\theta) = \sum_1^N \log P(i,z,\theta) - \sum_1^N \log \int_Z P(i,z,\theta)g(z)dz + \sum_1^N \log[g(z).H(i)]$$

The above equation forms the basis for two informational distinct maximum likelihood estimators for θ. In particular, given knowledge of the population shares Q(i), $i \in C$, and of the attribute distribution g(z), z ∈ Z, we may maximize subject to the set of constraints Q(i) = $\int_Z P(i,z,\theta)g(z)dz$, all $i \in C$. With the g(z) known but not the Q(i), an unconstrained maximization of the above equation may be performed. However, these various versions of choice-based sampling maximum likelihood (CBSML) all suffer severe computational drawbacks because of the set of constraints Q(i) = $\int_Z P(i,z,\theta)g(z)dz$, all $i \in C$.

Another method that is available for choice-based sampling process is the weighted exogenous maximum likelihood. Consider the log-likelihood appropriate to exogenous sampling as follows:

$$L(\theta) = \prod_{1}^{N} P(i, z, \theta) g(z)$$

$$\text{Log } L(\theta) = \sum_{1}^{N} \log P(i, z, \theta) + \sum_{1}^{N} \log g(z)$$

Given its simplicity relative to the CBSML estimators, one might inquire whether unconstrained maximization of the above equation provides a suitable estimation procedure in the context of choice-based sampling. Unfortunately, this is not the case. On the other hand, there exists a straightforward modification of the unconstrained exogenous sampling maximum likelihood (ESML) criterion that does have desirable computational and statistical properties under choice based sampling. Given the assumed knowledge of the population shares Q(i) and sample shares $H(i)$ directly from the data, the weights $w(i) = Q(i)/H(i)$ are known non-negative constants. Then the weighted exogenous sampling maximum likelihood (WESML) estimator is:

$$\text{Log } L(\theta) = \sum_{n=1}^{N} w(i_n) \log P(i, z, \theta^*) + \sum_{n=1}^{N} w(i_n) \log g(z)$$

From the above discussion, the WESML is more appropriate than the CBSML. Therefore, the WESML approach was utilized in this project to account for the choice-based sampling in the transit on-board surveys. The market shares Q(i) were calculated based on the market share percentages presented before in Table 4.3. The sample shares $H(i)$ were directly from the data.

The modeling estimation approach was based on the estimation of two nested-logit models. One of which is based on the on-board transit survey and the other for the household travel survey. The two models were linked through the use of the inclusive value of the transit. The inclusive value of the transit system was defined as a representative of the aggregate utility of using the transit system. The transit model was calibrated using full information weighted exogenous sampling maximum likelihood (FI-WESML) approach. The FI-WESML estimation is the most efficient statistical approach, because different nesting levels are estimated simultaneously as opposed to sequentially in the limited information case.

5.1.1 Choice set limitations

A traveler's choice set consists of every mode whose probability of being chosen exceeds zero. According to the available skim files, nine modes are available. Seven of which are transit modes and the remaining two are highway modes. The nine modes are :

1. Walk-access to local bus
2. Walk-access to express bus
3. Walk-access to metro rail
4. Walk-access to tri rail
5. Auto-access to express bus
6. Auto-access to metro rail
7. Auto-access Walk to tri rail
8. Share riding
9. Drive alone

In practice, the choice set contains every mode whose probability of being chosen is large enough to be practically significant. For example, should drive alone be included in the choice set of a traveler whose household does not own an automobile? The answer is no, if there is no significant likelihood that such a traveler has access to an automobile. However, it may be yes, if substantial numbers of non-automobile-owning travelers borrow or lease cars or drive cars provided by their employers.

The difficulty of deciding whether drive alone should be included in the choice set is greatly reduced if the data include information on the number of cars available to a household, including cars not owned. Drive alone usually can be safely excluded from the choice set of a traveler whose household has no car available. There are no rigorous analytic methods for assigning choice sets to travelers. The assignment must be based mainly on the experience and judgment of the analyst. The model assumed that all persons could drive with the exception of the zero car household trips, which was excluded from the drive alone and auto-access to transit modes. The following guide rules were used to assign the choice set for every trip-maker.

1. *Transit modes.*

   Generally, if the sums of skim values for a specific case is equal zero (actually the in-vehicle travel time), then this transit mode for that case is not available. Also, for car availability equals to zero the auto-access modes (drive to transit) are not available.

2. *Highway modes.*

   Household survey: the field "RVEH" indicates the vehicle availability in the household. If the RVEH field for a given person is equal zero then the drive-alone mode in not included in the choice set available for that person.

3. *Transit survey.*

   The field "QD" indicates the vehicle availability in the household. If QD for a given person is equal zero then the drive-alone mode in not included in the choice set available for that person. However, if the field QH is equal 2 then the drive-alone mode is available.

Figure 5.1 presents the format of the calibration data file. The file consists of 24 fields that cover trip purpose, trip time, mode attributes, car ownership, and selected mode travel. In order to construct this calibration data file, many customized Visual Basic code and Structure Query Language (SQL) statements were developed to control the merging of the two different survey data sets (household travel survey and on-board transit survey).

5.2 Home Based Work trips (HBW)

The adopted structure consists of a three level-nested structure as illustrated in Figure 5.2. In the primary nest, total person trips are divided into auto and transit trips. In the secondary nest, the auto trips are split into drive-alone and shared-ride trips, and the transit trips are split into walk-access and auto-access trips. In the third nest, the transit walk-access trips are split into local-bus (LB), express bus (EP), metro rail (MR), and tri rail (TR). The transit auto-access trips are divided into express bus (EP), metro rail (MR) and tri rail (TR).

We used the transit data to calibrate the transit part of the structure because transit cases in the household travel survey were insufficient. Then, to avoid adjusting the model for enriching the data with transit cases, we estimated two separate nesting structures based on two different data sets, and then linked both structures with the inclusive value calculated based on the transit section, and entered into the highway transit model. The nests encompassed in the doted box in

Figure 5.2 were estimated using the on-board survey data. The results of the transit part are shown in Table 5.1, Table 5.2, and Figure 5.3. Results of the highway-transit part are shown in Table 5.3, Table 5.5, and Figure 5.4. The system of probability equations of the HBW trips is listed in Figure 5.5.

Figure 5.1 Format of the calibration file

Mode code

1. local bus
2. express bus / walk access
3. metro rail / walk access
4. tri rail / walk access
5. express bus / auto access
6. metro rail / auto access
7. tri rail / auto access
8. share riding
9. drive alone

Mode availability

- Number of available modes
- Codes of available modes

Socioeconomic characteristics

- Zero car ownership dummy variable (1 or 0)
- One car ownership dummy variable (1 or 0)
- Two+ car ownership dummy variable (1 or 0)

Zone characteristics

- Origin
- Destination
- Area type

Attributes of the transportation modes

- Highway parking cost (cent)
- Highway terminal time (minutes)
- Highway running time (minutes)
- Vehicle operating cost (cent)
- Highway trip distance (miles)
- Transit in-vehicle travel (minutes)
- Transit first waiting time (minutes)
- Transit transfer time (minutes)
- Transit walk time (minutes)
- Transit number of transfers
- Transit fare (cent)
- Transit auto-access time (minutes)

Trip characteristics

- Trip mode of travel
- Trip purpose
- Trip time

Table 5.1 presents the estimation results of the nested logit model for the transit trips. The significant variables include; transit access time, transit wait time, number of transfers, in-vehicle travel time, fare, and household car ownership. The inclusive value coefficient is significantly different from zero and one. This provides a statistical validation of using the nested logit structure. All variables included in the model are statistically significant. The overall fit of the model is excellent, with a log likelihood ratio index of 0.864.

Figure 5.3 summarizes the transit equations for calculating the market shares of the transit system. The equations use the estimated coefficients and inclusive value parameters to calculate the utilities. Then, the probability equations are then used to convert the utilities to probabilities. The definitions of all terms included in these calculations are presented in Table 5.2.

The remaining part of the model includes the estimation of probabilities of drive alone, share driving, and transit. The household travel survey data and the inclusive value calculated based on the transit section shown in Table 5.1 were used to calibrate this model. Using this model, we can calculate market shares of the highway modes and transit systems. Table 5.3 presents the estimation results of the nested logit model for the highway/transit trips. All the variables that entered into the model are statistically significant. The transit inclusive value was also significant indicating the validity of the nesting structure used. The overall fit of the model is excellent, with a log likelihood ratio index of 0.893. The system of probability equations is listed in Figure 5.5.

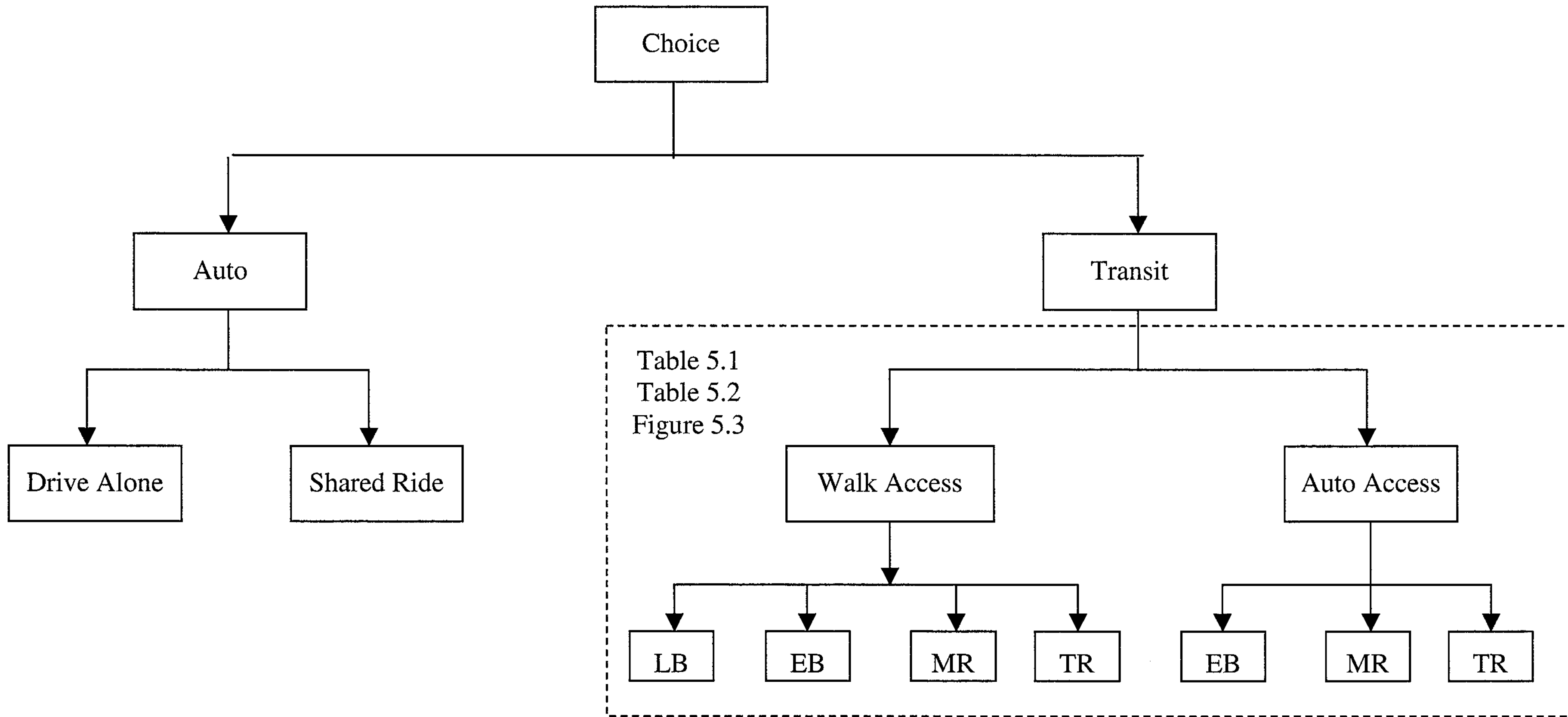

Figure 5.2 Structure of the mode-choice model of HBW trips

Table 5.1 Transit nested logit mode-choice model for HBW trips

Variable	Notation	Coef.	t-stat
Mode choice model coefficients			
Walk time to transit (minutes)	WT	-0.143	-3.245
Drive time to transit (minutes)	DT	-0.063	-3.668
Transit in-vehicle travel time (min.)	RT	-0.048	-12.225
Transit first wait time (minutes)	FWT	-0.031	-3.209
Transit transfer (2^{nd} wait) time (minutes)	TT	-0.024	-2.235
Number of transfers	NT	-0.478	-4.407
Transit Fare indicator 1 (fare is greater than $1.00 and less than or equal $2.00)	F1	-1.446	-6.696
Transit Fare indicator 2 (fare is greater than $2.00)	F2	-1.823	-6.463
Mode specific constants			
Walk to local bus (LB)			
Zero car household	LBWV0	4.583	2.846
One car household	LBWV1	1.057	1.827
Two+ car household	LBWV2	0.266	1.743
Walk to express bus (EP,WK)			
Zero car household	EBWV0	0.510	1.840
One car household	EBWV1	-2.199	-3.349
Two+ car household	EBWV2	-3.472	-4.667
Walk to metro rail (MR,WK)			
Zero car household	MRWV0	1.747	1.637
One car household	MRWV1	-0.471	-1.760
Two+ car household	MRWV2	-0.627	-1.915
Walk to tri rail (TR,WK)			
Zero car household	TRWV0	1.105	1.488
One car household	TRWV1	-1.211	1.673
Two+ car household	TRWV2	-1.638	2.602
Drive to express bus (EP,DV)			
Zero car household	EBAV0	-4.173	-1.743
One car household	EBAV1	0.250	1.645
Two+ car household	EBAV2	0.370	1.630
Drive to metro rail (MR,DV)			
Zero car household	MRAV0	-3.425	-1.706
One car household	MRAV1	1.042	3.165
Two+ car household	MRAV2	1.050	3.125
Inclusive value parameters			
Walk to transit	τ_{WK}	0.862	5.713
Drive to transit	τ_{DV}	0.673	6.389
Number of observations		2693	
LL (β)		-702.52	
LL (0)		-5162.49	
$\rho = 1 - LL(\beta) / LL(0)$		0.864	

Figure 5.3 Mathematical specification of the transit HBW nested logit model

1. Utility equations

U_{LB} = -0.143 WT – 0.063 DT – 0.048 RT – 0.031 FWT – 0.024 TT – 0.478 NT – 1.446 F1 – 1.823 F2 + 4.583 LBWV0 + 1.057 LBWV1 + 0.266 LBWV2

$U_{EB,WK}$ = -0.143 WT – 0.063 DT – 0.048 RT – 0.031 FWT – 0.024 TT – 0.478 NT – 1.446 F1 – 1.823 F2 + 0.510 EBWV0 – 2.199 EBWV1 –3.472 EBWV2

$U_{MR,WK}$ = -0.143 WT – 0.063 DT – 0.048 RT – 0.031 FWT – 0.024 TT – 0.478 NT – 1.446 F1 – 1.823 F2 + 1.747 MRWV0 – 0.471 MRWV1 –0.627 MRWV2

$U_{TR,WK}$ = -0.143 WT – 0.063 DT – 0.048 RT – 0.031 FWT – 0.024 TT – 0.478 NT – 1.446 F1 – 1.823 F2 + 1.105 TRWV0 – 1.211 TRWV1 –1.638 TRWV2

$U_{EB,DV}$ = -0.143 WT – 0.063 DT – 0.048 RT – 0.031 FWT – 0.024 TT – 0.478 NT – 1.446 F1 – 1.823 F2 – 4.173 EBAV0 + 0.250 EBAV1 + 0.370 EBAV2

$U_{MR,DV}$ = -0.143 WT – 0.063 DT – 0.048 RT – 0.031 FWT – 0.024 TT – 0.478 NT – 1.446 F1 – 1.823 F2 – 3.425 MRAV0 + 1.042 MRAV1 + 1.050 MRAV2

$U_{TR,DV}$ = -0.143 WT – 0.063 DT – 0.048 RT – 0.031 FWT – 0.024 TT – 0.478 NT – 1.446 F1 – 1.823 F2

2. Conditional probabilities

$$P_{LB|WK|Tr} = \frac{\exp(U_{LB})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{EB|WK|Tr} = \frac{\exp(U_{EB,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{MR|WK|Tr} = \frac{\exp(U_{MR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{TR|WK|Tr} = \frac{\exp(U_{TR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{EB|DV|Tr} = \frac{\exp(U_{EB,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}$$

$$P_{MR|DV|Tr} = \frac{\exp(U_{MR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}$$

$$P_{TR|DV|Tr} = \frac{\exp(U_{TR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}$$

3. Inclusive values

$$I_{WK} = \ln\left[\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})\right]$$

$$I_{DV} = \ln\left[\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})\right]$$

4. Access mode shares

$$P_{WK} = \frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}$$

$$P_{DV} = \frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}$$

5. Alternative Probabilities (market shares)

$$P_{LB,WK|Tr} = \left(\frac{\exp(U_{LB})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{EB,WK|Tr} = \left(\frac{\exp(U_{EB,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{MR,WK|Tr} = \left(\frac{\exp(U_{MR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{TR,WK|Tr} = \left(\frac{\exp(U_{TR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{EB,DV|Tr} = \left(\frac{\exp(U_{EB,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}\right)\left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{MR,DV|Tr} = \left(\frac{\exp(U_{MR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}\right)\left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{TR,DV|Tr} = \left(\frac{\exp(U_{TR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}\right)\left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

Table 5.2 Definition of terms included in the equations of the transit HBW model

Term	Definition
Utility equations	
U_{LB}	Utility index of local bus
$U_{EB,WK}$	Utility index of express bus/walk access
$U_{MR,WK}$	Utility index of metro rail/walk access
$U_{TR,WK}$	Utility index of tri rail/walk access
$U_{EB,DV}$	Utility index of express bus/auto access
$U_{MR,DV}$	Utility index of metro rail/auto access
$U_{TR,DV}$	Utility index of tri rail/auto access
Conditional probabilities	
$P_{LB\mid WK\mid Tr}$	Probability of using local bus given that the trip-maker walks to the transit system
$P_{EB\mid WK\mid Tr}$	Probability of using express bus given that the trip-maker walks to the transit system
$P_{MR\mid WK\mid Tr}$	Probability of using metro rail given that the trip-maker walks to the transit system
$P_{TR\mid WK\mid Tr}$	Probability of using tri rail given that the trip-maker walks to the transit system
$P_{EB\mid DV\mid Tr}$	Probability of using express bus given that the trip-maker drives to the transit system
$P_{MR\mid DV\mid Tr}$	Probability of using metro rail given that the trip-maker drives to the transit system
$P_{TR\mid DV\mid Tr}$	Probability of using tri rail given that the trip-maker drives to the transit system
Inclusive values	
I_{WK}	Inclusive value of transit walk-access mode
I_{DV}	Inclusive value of transit auto-access mode
Access mode shares	
$P_{WK\mid Tr}$	Probability that the transit user will walk to transit
$P_{DV\mid Tr}$	Probability that the transit user will drive to transit
$P_{LB\mid Tr}$	Probability of local bus (market share of local bus with respect to the transit service)
$P_{EB,WK\mid Tr}$	Probability of express bus/walk access (market share with respect to the transit service)
$P_{MR,WK\mid Tr}$	Probability of metro rail/walk access (market share with respect to the transit service)
$P_{TR,WK\mid Tr}$	Probability of tri rail/walk access (market share with respect to the transit service)
$P_{EB,DV\mid Tr}$	Probability of express bus/auto access (market share with respect to the transit service)
$P_{MR,DV\mid Tr}$	Probability of metro rail/auto access (market share with respect to the transit service)
$P_{TR,DV\mid Tr}$	Probability of tri rail/auto access (market share with respect to the transit service)

Table 5.3 Highway/transit nested logit mode-choice model for HBW trips

Variable	Notation	Coef.	t-stat.
Mode choice model coefficients			
Transit In-vehicle travel time (min.)	$INVEH_{Tr}$	-0.171	-2.424
Share-driving in-vehicle travel time (min.)	$INVEH_{SD}$	-0.182	-2.294
Drive-alone in-vehicle travel time (min.)	$INVEH_{DA}$	-0.127	-2.123
Transit cost (cents)	OC_{Tr}	-0.036	-8.116
Share-driving cost (toll, parking, and gas)	OC_{SD}	-0.003	-4.182
Drive-alone cost (toll, parking, and gas)	OC_{DA}	-0.003	-5.552
Walk time to transit (minutes)	TRWT	-0.531	-8.225
CBD dummy variable (1 if Highway terminal time equals to 5 minutes, 0 otherwise)	HYT	-0.743	-2.135
Transit inclusive-link value	IL_{Tr}	0.676	5.202
Mode specific constants			
Transit			
Zero car household	TRV0	2.079	3.816
One car household	TRV1	-1.005	-3.579
Two+ car household	TRV2	-2.566	-8.309
Share driving			
Zero car household	SDV0	0.916	2.229
One car household	SDV1	-0.557	-4.263
Two+ car household	SDV2	-1.254	-10.215
Inclusive value parameters			
Transit	τ_{Tr}	0.178	2.873
Highway	τ_{Hy}	0.810	2.714
Number of observations	6275		
LL (β)	-919.04		
LL (0)	-8628.98		
$\rho = 1 - LL(\beta) / LL(0)$	0.893		

Figure 5.4 Highway / Transit mathematical specification of the HBW model

1. Transit inclusive-link value

$$IL_{Tr} = \ln\left[\exp(\tau_{wk}\, I_{wk}) + \exp(\tau_{DV}\, I_{Dv})\right]$$

2. Utility equations

$U_{Tr} =$ -0.171 $INVEH_{Tr}$ – 0.036 OC_{Tr}

$U_{DA} =$ -0.127 $INVEH_{DA}$ – 0.003 OC_{DA}

$U_{SD} =$ -0.182 $INVEH_{SD}$ – 0.003 OC_{SD} + 0.916 SDV0 – 0.557 SDV1 – 1.254 SDV2

3. Conditional probabilities

$$P_{DA|HY} = \frac{\exp(U_{DA})}{\exp(U_{DA}) + \exp(U_{SD})}$$

$$P_{SD|HY} = \frac{\exp(U_{SD})}{\exp(U_{DA}) + \exp(U_{SD})}$$

4. Inclusive values

$$I_{HY} = \ln\left[\exp(U_{DA}) + \exp(U_{SD})\right]$$

$$I_{Tr} = \ln\left[\exp(U_{Tr})\right]$$

5. Highway/transit shares

$$P_{Tr} = \frac{exp(2.079TRV0 - 1.005TRV1 - 2.566TRV2 - 0.531TRWT + 0.676IL_{TR} + 0.178\,I_{Tr})}{exp(2.079TRV0 - 1.005TRV1 - 2.566TRV2 - 0.531TRWT + 0.676IL_{TR} + 0.178\,I_{Tr}) + exp(-0.743HYT + 0.810I_{HY})}$$

$$P_{HY} = \frac{exp(-0.743HYT + 0.810I_{HY})}{exp(2.079TRV0 - 1.005TRV1 - 2.566TRV2 - 0.531TRWT + 0.676IL_{TR} + 0.178\,I_{Tr}) + exp(-0.743HYT + 0.810I_{HY})}$$

6. Alternative Probabilities (market shares)

$$P_{DA} = P_{DA|HY}\, P_{HY}$$

$$P_{SD} = P_{SD|HY}\, P_{HY}$$

$$P_{Tr} = \frac{exp(2.079TRV0 - 1.005TRV1 - 2.566TRV2 - 0.531TRWT + 0.676IL_{TR} + 0.178\,I_{Tr})}{exp(2.079TRV0 - 1.005TRV1 - 2.566TRV2 - 0.531TRWT + 0.676IL_{TR} + 0.178\,I_{Tr}) + exp(-0.743HYT + 0.810I_{HY})}$$

Table 5.4 Definition of terms included in the equations of the highway/transit HBW model

Term	Definition
<u>Utility equations</u>	
U_{Tr}	Utility index of transit system
U_{DA}	Utility index of drive alone
U_{SD}	Utility index of share driving
<u>Conditional probabilities</u>	
$P_{DA\|HY}$	Probability of drive alone given that the trip-maker uses the highway network
$P_{SD\|HY}$	Probability of share driving given that the trip-maker uses the highway network
<u>Inclusive values</u>	
I_{HY}	Inclusive value of highway modes
I_{Tr}	Inclusive value of transit modes
<u>Mode shares</u>	
P_{DA}	Probability of drive-alone mode
P_{SD}	Probability of share driving
P_{Tr}	Probability of using the transit system

Figure 5.5 summarizes the system of probability equations of the HBW trips. The definitions of the probabilities are as follow:

P_{LB}	Probability of local bus
$P_{EB,WK}$	Probability of express bus/walk access
$P_{MR,WK}$	Probability of metro rail/walk access
$P_{TR,WK}$	Probability of tri rail/walk access
$P_{EB,DV}$	Probability of express bus/auto access
$P_{MR,DV}$	Probability of metro rail/auto access
$P_{TR,DV}$	Probability of tri rail/auto access
P_{DA}	Probability of drive alone
P_{SD}	Probability of shared driving

Figure 5.5 Probability equations for the HBW trips

$$P_{LB} = \left(\frac{\exp(U_{LB})}{\exp(U_{LB}) + \exp(U_{EB-WK}) + \exp(U_{MR-WK}) + \exp(U_{TR-WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{EB,WK} = \left(\frac{\exp(U_{EB,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{MR,WK} = \left(\frac{\exp(U_{MR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{TR,WK} = \left(\frac{\exp(U_{TR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{EB,DV} = \left(\frac{\exp(U_{EB,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})} \right) \left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{MR,DV} = \left(\frac{\exp(U_{MR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})} \right) \left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{TR,DV} = \left(\frac{\exp(U_{TR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})} \right) \left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{DA} = \left(\frac{\exp(U_{DA})}{\exp(U_{DA}) + \exp(U_{SD})} \right) \left(\frac{exp(-0.743\,HYT + 0.810\,I_{HY})}{exp(2.079TRV0 - 1.005TRV1 - 2.566TRV2 - 0.531TRWT + 0.676IL_{TR} + 0.178\,I_{Tr}) + exp(-0.743\,HYT + 0.810\,I_{HY})} \right)$$

$$P_{SD} = \left(\frac{\exp(U_{SD})}{\exp(U_{DA}) + \exp(U_{SD})} \right) \left(\frac{exp(-0.743\,HYT + 0.810\,I_{HY})}{exp(2.079TRV0 - 1.005TRV1 - 2.566TRV2 - 0.531TRWT + 0.676IL_{TR} + 0.178\,I_{Tr}) + exp(-0.743\,HYT + 0.810\,I_{HY})} \right)$$

5.3 Home Based Non-Work Trips (HBNW)

The adopted structure consists of a three level-nested structure as illustrated in Figure 5.6. In the primary nest, total person trips are divided into auto and transit trips. In the secondary nest, the auto trips are split into drive-alone and shared-ride trips, and the transit trips are split into walk-access and auto-access trips. In the third nest, the transit walk-access trips are split into local-bus (LB), express bus (EP), metro rail (MR), and tri rail (TR). The transit auto-access trips are divided into express bus (EP), metro rail (MR) and tri rail (TR). The structure and modeling procedure is similar to the HBW model. The results of the transit part are shown in Table 5.5, Table 5.6, and Figure 5.7. Results of the highway-transit part are shown in Table 5.7, Table 5.8, and Figure 5.8. The probability equations are listed in Figure 5.9.

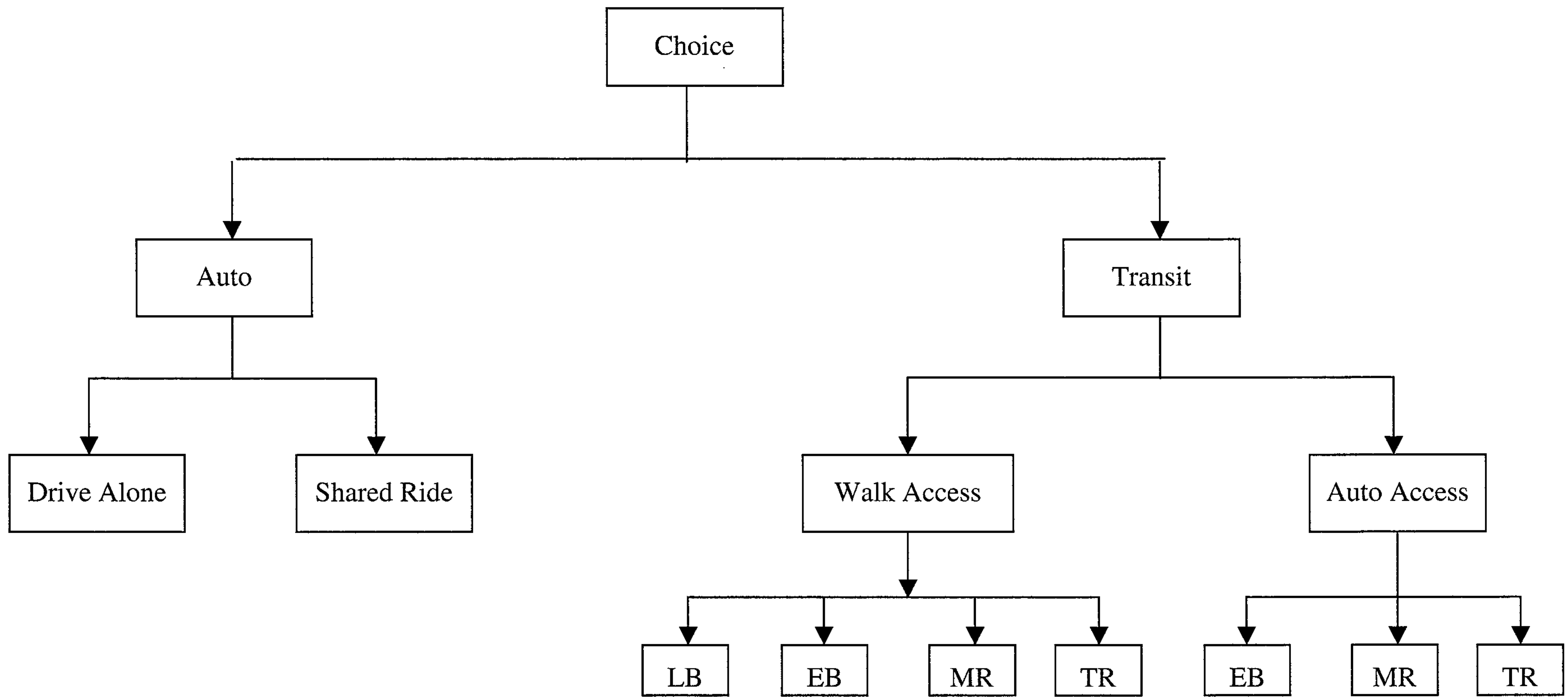

Figure 5.6 Structure of the mode-choice model of HBNW trips

Table 5.5 Transit nested logit mode-choice model for HBNW trips

Variable	Notation	Coef.	t-stat
Mode choice model coefficients			
Walk time to transit (minutes)	WT	-0.124	-3.658
Drive time to transit (minutes)	DT	-0.051	-2.332
Transit in-vehicle travel time (min.)	RT	-0.041	-15.387
Transit first wait time (minutes)	FWT	-0.058	-4.899
Transit wait time (minutes)	TT	-0.017	-1.676
Number of transfers	NT	-0.361	-7.078
Transit Fare indicator 1 (fare is greater than \$1.00 and less than or equal \$2.00)	F1	-1.305	-6.721
Transit Fare indicator 2 (fare is greater than \$2.00)	F2	-1.987	-6.675
Mode specific constants			
Walk to local bus			
Zero car household	LBWV0	3.752	2.508
One car household	LBWV1	1.136	2.836
Two+ car household	LBWV2	0.508	1.615
Walk to express bus			
Zero car household	EBWV0	1.381	3.049
One car household	EBWV1	0.447	1.989
Two+ car household	EBWV2	-0.489	-2.020
Walk to metro rail			
Zero car household	MRWV0	1.533	2.054
One car household	MRWV1	-0.094	-1.520
Two+ car household	MRWV2	-0.614	1.717
Walk to tri rail			
Zero car household	TRWV0	1.145	1.639
One car household	TRWV1	-1.531	-2.022
Two+ car household	TRWV2	-1.783	-2.325
Drive to express bus			
Zero car household	EBAV0	-1.788	-3.940
One car household	EBAV1	0.279	1.713
Two+ car household	EBAV2	1.706	2.020
Drive to metro rail			
Zero car household	MRAV0	-1.647	-1.717
One car household	MRAV1	1.373	3.481
Two+ car household	MRAV2	1.608	3.686
Inclusive value parameters			
Walk to transit	τ_{WK}	0.734	4.973
Drive to transit	τ_{DV}	0.591	6.094
Number of observations		2714	
LL (β)		-1774.35	
LL (0)		-5076.12	
$\rho = 1 - LL(\beta) / LL(0)$		0.650	

Figure 5.7 Mathematical specification of the transit HBNW nested logit model

1. Utility equations

$U_{LB} =$ -0.124 WT – 0.051 DT – 0.041 RT – 0.058 FWT – 0.017 TT – 0.361 NT – 1.305 F1 – 1.987 F2 + 3.752 LBWV0 + 1.136 LBWV1 + 0.508 LBWV2

$U_{EB,WK} =$ -0.124 WT – 0.051 DT – 0.041 RT – 0.058 FWT – 0.017 TT – 0.361 NT – 1.305 F1 – 1.987 F2 + 1.381 EBWV0 + 0.447 EBWV1 – 0.489 EBWV2

$U_{MR,WK} =$ -0.124 WT – 0.051 DT – 0.041 RT – 0.058 FWT – 0.017 TT – 0.361 NT – 1.305 F1 – 1.987 F2 + 1.533 MRWV0 – 0.094 MRWV1 – 0.614 MRWV2

$U_{TR,WK} =$ -0.124 WT – 0.051 DT – 0.041 RT – 0.058 FWT – 0.017 TT – 0.361 NT – 1.305 F1 – 1.987 F2 + 1.145 TRWV0 – 1.531 TRWV1 – 1.783 TRWV2

$U_{EB,DV} =$ -0.124 WT – 0.051 DT – 0.041 RT – 0.058 FWT – 0.017 TT – 0.361 NT – 1.305 F1 – 1.987 F2 – 1.788 EBAV0 + 0.279 EBAV1 + 1.706 EBAV2

$U_{MR,DV} =$ -0.124 WT – 0.051 DT – 0.041 RT – 0.058 FWT – 0.017 TT – 0.361 NT – 1.305 F1 – 1.987 F2 – 1.647 MRAV0 + 1.373 MRAV1 + 1.608 MRAV2

$U_{TR,DV} =$ -0.124 WT – 0.051 DT – 0.041 RT – 0.058 FWT – 0.017 TT – 0.361 NT – 1.305 F1 – 1.987 F2

2. Conditional probabilities

$$P_{LB|WK|Tr} = \frac{\exp(U_{LB})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{EB|WK|Tr} = \frac{\exp(U_{EB,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{MR|WK|Tr} = \frac{\exp(U_{MR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{TR|WK|Tr} = \frac{\exp(U_{TR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{EB|DV|Tr} = \frac{\exp(U_{EB,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}$$

$$P_{MR|DV|Tr} = \frac{\exp(U_{MR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}$$

$$P_{TR|DV|Tr} = \frac{\exp(U_{TR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}$$

3. Inclusive values

$$I_{WK} = \ln\left[\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})\right]$$

$$I_{DV} = \ln\left[\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})\right]$$

4. Access mode shares

$$P_{WK} = \frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}$$

$$P_{DV} = \frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}$$

5. Alternative Probabilities (market shares)

$$P_{LB,WK|Tr} = \left(\frac{\exp(U_{LB})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{EB,WK|Tr} = \left(\frac{\exp(U_{EB,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{MR,WK|Tr} = \left(\frac{\exp(U_{MR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{TR,WK|Tr} = \left(\frac{\exp(U_{TR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{EB,DV|Tr} = \left(\frac{\exp(U_{EB,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}\right)\left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{MR,DV|Tr} = \left(\frac{\exp(U_{MR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}\right)\left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{TR,DV|Tr} = \left(\frac{\exp(U_{TR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}\right)\left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

Table 5.6 Definition of terms included in the equations of the transit HBNW model

Term	definition
Utility equations	
U_{LB}	Utility index of local bus
$U_{EB,WK}$	Utility index of express bus/walk access
$U_{MR,WK}$	Utility index of metro rail/walk access
$U_{TR,WK}$	Utility index of tri rail/walk access
$U_{EB,DV}$	Utility index of express bus/auto access
$U_{MR,DV}$	Utility index of metro rail/auto access
$U_{TR,DV}$	Utility index of tri rail/auto access
Conditional probabilities	
$P_{LB\|WK\|Tr}$	Probability of using local bus given that the trip-maker walks to the transit system
$P_{EB\|WK\|Tr}$	Probability of using express bus given that the trip-maker walks to the transit system
$P_{MR\|WK\|Tr}$	Probability of using metro rail given that the trip-maker walks to the transit system
$P_{TR\|WK\|Tr}$	Probability of using tri rail given that the trip-maker walks to the transit system
$P_{EB\|DV\|Tr}$	Probability of using express bus given that the trip-maker drives to the transit system
$P_{MR\|DV\|Tr}$	Probability of using metro rail given that the trip-maker drives to the transit system
$P_{TR\|DV\|Tr}$	Probability of using tri rail given that the trip-maker drives to the transit system
Inclusive values	
I_{WK}	Inclusive value of transit walk-access mode
I_{DV}	Inclusive value of transit auto-access mode
Access mode shares	
$P_{WK\|Tr}$	Probability that the transit user will walk to transit
$P_{DV\|Tr}$	Probability that the transit user will drive to transit
$P_{LB\|Tr}$	Probability of local bus (market share of local bus with respect to the transit service)
$P_{EB,WK\|Tr}$	Probability of express bus/walk access (market share with respect to the transit service)
$P_{MR,WK\|Tr}$	Probability of metro rail/walk access (market share with respect to the transit service)
$P_{TR,WK\|Tr}$	Probability of tri rail/walk access (market share with respect to the transit service)
$P_{EB,DV\|Tr}$	Probability of express bus/auto access (market share with respect to the transit service)
$P_{MR,DV\|Tr}$	Probability of metro rail/auto access (market share with respect to the transit service)
$P_{TR,DV\|Tr}$	Probability of tri rail/auto access (market share with respect to the transit service)

Table 5.7 Highway/Transit nested logit mode-choice model for HBNW trips

Variable	Notation	Coef.	t-stat.
Mode choice model coefficients			
Transit In-vehicle travel time (min.)	$INVEH_{Tr}$	-0.183	-2.351
Share-driving in-vehicle travel time (min.)	$INVEH_{SD}$	-0.218	-3.277
Drive-alone in-vehicle travel time (min.)	$INVEH_{DA}$	-0.183	-3.502
Transit cost (cents)	OC_{Tr}	-0.041	-7.634
Share-driving cost (toll, parking, and gas)	OC_{SD}	-0.005	-6.229
Drive-alone cost (toll, parking, and gas)	OC_{DA}	-0.003	-5.095
Walk time to transit (minutes)	TRWT	-0.350	-7.764
CBD dummy variable (1 if Highway terminal time equals to 5 minutes, 0 otherwise)	HYT	-0.226	-5.566
Transit inclusive-link value	IL_{Tr}	1.266	2.433
Mode specific constants			
Transit			
Zero car household	TRV0	0.352	2.436
One car household	TRV1	-2.588	-2.634
Two+ car household	TRV2	-3.864	-5.753
Share driving			
Zero car household	SDV0	1.608	2.718
One car household	SDV1	-0.124	-2.192
Two+ car household	SDV2	-0.420	-5.458
Inclusive value parameters			
Transit	τ_{Tr}	0.164	2.396
Highway	τ_{Hy}	0.832	2.904
Number of observations	13411		
LL (β)	-2128.65		
LL (0)	-11387.02		
$\rho = 1 - LL(\beta) / LL(0)$	0.812		

Figure 5.8 Highway / Transit mathematical specification of the HBNW model

1. Transit inclusive-link value

$$IL_{Tr} = \ln\left[\exp\left(\tau_{wk} I_{wk}\right) + \exp\left(\tau_{DV} I_{Dv}\right)\right]$$

2. Utility equations

$$U_{Tr} = -0.183\ INVEH_{Tr} - 0.041\ OC_{Tr}$$

$$U_{DA} = -0.183\ INVEH_{DA} - 0.003\ OC_{DA}$$

$$U_{SD} = -0.218\ INVEH_{SD} - 0.005\ OC_{SD} + 1.608\ SDV0 - 0.124\ SDV1 - 0.420\ SDV2$$

3. Conditional probabilities

$$P_{DA|HY} = \frac{\exp(U_{DA})}{\exp(U_{DA}) + \exp(U_{SD})}$$

$$P_{SD|HY} = \frac{\exp(U_{SD})}{\exp(U_{DA}) + \exp(U_{SD})}$$

4. Inclusive values

$$I_{HY} = \ln\left[\exp(U_{DA}) + \exp(U_{SD})\right]$$

$$I_{Tr} = \ln\left[\exp(U_{Tr})\right]$$

5. Highway/transit shares

$$P_{Tr} = \frac{exp(0.352TRV0 - 2.588TRV1 - 3.864TRV2 - 0.350TRWT + 1.266\,IL_{Tr} + 0.164\,I_{Tr})}{exp(0.352TRV0 - 2.588TRV1 - 3.864TRV2 - 0.350TRWT + 1.266\,IL_{Tr} + 0.164\,I_{Tr}) + exp(-0.226HYT + 0.832I_{HY})}$$

$$P_{HY} = \frac{exp(-0.226HYT + 0.832I_{HY})}{exp(0.352TRV0 - 2.588TRV1 - 3.864TRV2 - 0.350TRWT + 1.266\,IL_{Tr} + 0.164\,I_{Tr}) + exp(-0.226HYT + 0.832I_{HY})}$$

6. Alternative Probabilities (market shares)

$$P_{DA} = P_{DA|HY}\,P_{HY}$$

$$P_{SD} = P_{SD|HY}\,P_{HY}$$

$$P_{Tr} = \frac{exp(0.352TRV0 - 2.588TRV1 - 3.864TRV2 - 0.350TRWT + 1.266\,IL_{Tr} + 0.164\,I_{Tr})}{exp(0.352TRV0 - 2.588TRV1 - 3.864TRV2 - 0.350TRWT + 1.266\,IL_{Tr} + 0.164\,I_{Tr}) + exp(-0.226HYT + 0.832I_{HY})}$$

Table 5.8 Definition of terms included in the equations of the highway/transit HBNW model

Term	Definition
Utility equations	
U_{Tr}	Utility index of transit system
U_{DA}	Utility index of drive alone
U_{SD}	Utility index of share driving
Conditional probabilities	
$P_{DA\|HY}$	Probability of drive alone given that the trip-maker uses the highway network
$P_{SD\|HY}$	Probability of share driving given that the trip-maker uses the highway network
Inclusive values	
I_{HY}	Inclusive value of highway modes
I_{Tr}	Inclusive value of transit modes
Mode shares	
P_{DA}	Probability of drive-alone mode
P_{SD}	Probability of share driving
P_{Tr}	Probability of using the transit system

Figure 5.5 summarizes the system of probability equations of the HBW trips. The definitions of the probabilities are as follow:

P_{LB}	Probability of local bus
$P_{EB,WK}$	Probability of express bus/walk access
$P_{MR,WK}$	Probability of metro rail/walk access
$P_{TR,WK}$	Probability of tri rail/walk access
$P_{EB,DV}$	Probability of express bus/auto access
$P_{MR,DV}$	Probability of metro rail/auto access
$P_{TR,DV}$	Probability of tri rail/auto access
P_{DA}	Probability of drive alone
P_{SD}	Probability of share driving

Figure 5.9 Probability equations for the HBNW trips

$$P_{LB} = \left(\frac{\exp(U_{LB})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{EB,WK} = \left(\frac{\exp(U_{EB,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{MR,WK} = \left(\frac{\exp(U_{MR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{TR,WK} = \left(\frac{\exp(U_{TR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{EB,DV} = \left(\frac{\exp(U_{EB,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})} \right) \left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{MR,DV} = \left(\frac{\exp(U_{MR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})} \right) \left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{TR,DV} = \left(\frac{\exp(U_{TR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})} \right) \left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{DA} = \left(\frac{\exp(U_{DA})}{\exp(U_{DA}) + \exp(U_{SD})} \right) \frac{exp(-0.226HYT+0.832I_{HY})}{exp(0.352TRV0-2.588TRV1-3.864TRV2-0.350TRWT+1.266\,IL_{Tr}+0.164\,I_{Tr})+exp(-0.226HYT+0.832I_{HY})}$$

$$P_{SD} = \left(\frac{\exp(U_{SD})}{\exp(U_{DA}) + \exp(U_{SD})} \right) \frac{exp(-0.226HYT+0.832I_{HY})}{exp(0.352TRV0-2.588TRV1-3.864TRV2-0.350TRWT+1.266\,IL_{Tr}+0.164\,I_{Tr})+exp(-0.226HYT+0.832I_{HY})}$$

5.4 Non-Home Based Trips (NHB)

The adopted structure consists of a three level-nested structure as illustrated in Figure 5.10. In the primary nest, total person trips are divided into auto and transit trips. In the secondary nest, the auto trips are split into drive-alone and shared-ride trips, and the transit trips are split into walk-access and auto-access trips. In the third nest, the transit walk-access trips are split into local-bus (LB), express bus (EP), metro rail (MR), and tri rail (TR). The transit auto-access trips are divided into express bus (EP), metro rail (MR) and tri rail (TR). The results of the transit part are shown in Table 5.9, Table 5.10, and Figure 5.11. Results of the highway-transit part are shown in Table 5.11, Table 5.12, and Figure 5.12. The system of probability equations is listed in Figure 5.13.

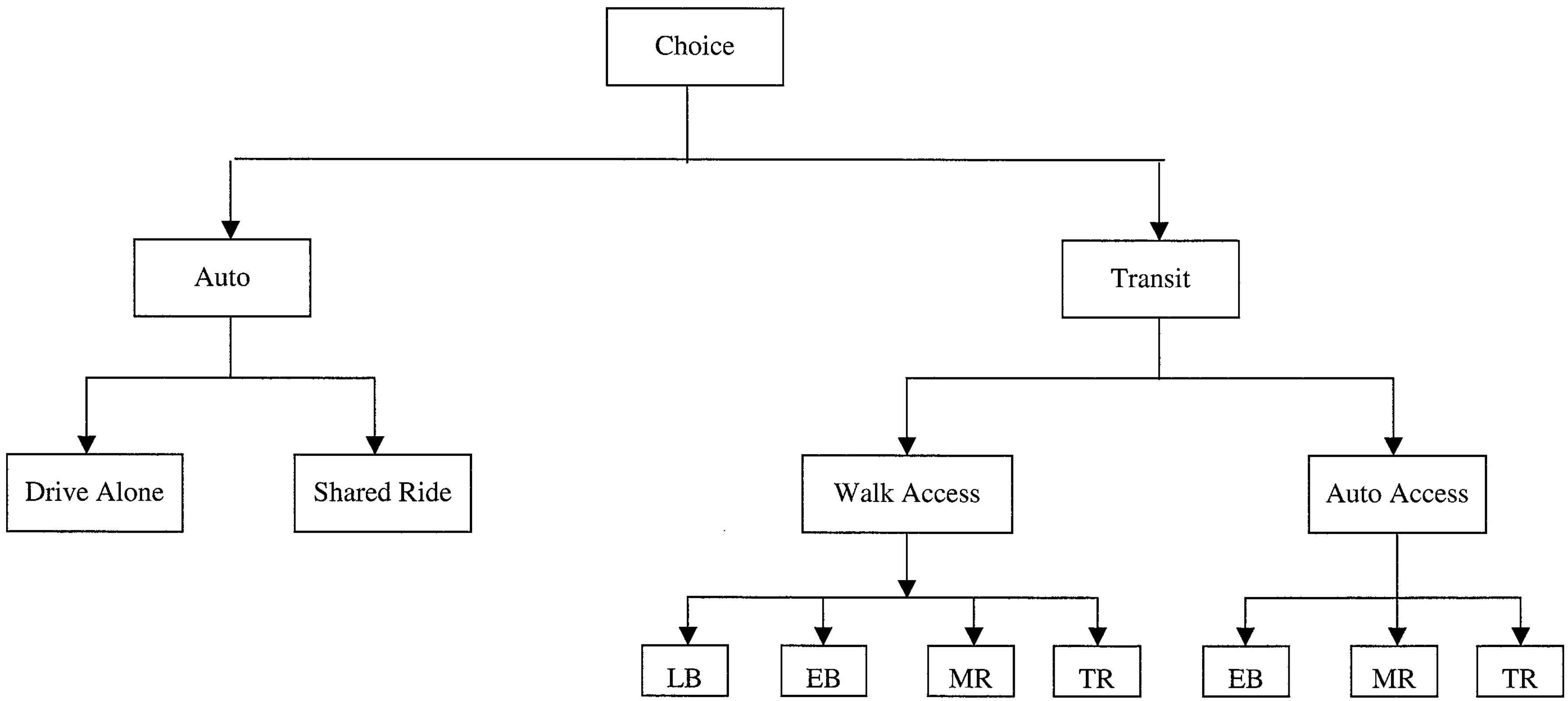

Figure 5.10 Structure of the mode-choice model of NHB trips

Table 5.9 Transit nested logit mode-choice model for NHB trips

Variable	Notation	Coef.	t-stat.
Mode choice model coefficients			
Walk time to transit (minutes)	WT	-0.346	-4.527
Drive time to transit (minutes)	DT	-0.027	-1.680
Transit in-vehicle travel time (min.)	RT	-0.040	-9.087
Transit first wait time (minutes)	FWT	-0.069	-2.724
Transit wait time (minutes)	TT	-0.014	-1.793
Number of transfers	NT	-0.667	-3.812
Transit Fare indicator 1 (fare is greater than $1.00 and less than or equal $2.00)	F1	-1.438	-4.626
Transit Fare indicator 2 (fare is greater than $2.00)	F2	-1.689	-3.073
Mode specific constants			
Walk to local bus			
Zero car household	LBWV0	2.662	1.608
One car household	LBWV1	0.632	1.703
Two+ car household	LBWV2	0.343	1.576
Walk to express bus			
Zero car household	EBWV0	1.189	1.541
One car household	EBWV1	-3.839	-2.742
Two+ car household	EBWV2	-4.174	-3.551
Walk to metro rail			
Zero car household	MRWV0	0.860	1.608
One car household	MRWV1	-1.250	-1.439
Two+ car household	MRWV2	-1.476	-1.538
Walk to tri rail			
Zero car household	TRWV0	1.052	1.819
One car household	TRWV1	-1.830	-2.448
Two+ car household	TRWV2	-2.258	-1.965
Drive to express bus			
Zero car household	EBAV0	-2.788	-2.357
One car household	EBAV1	1.582	1.848
Two+ car household	EBAV2	1.837	1.996
Drive to metro rail			
Zero car household	MRAV0	-1.185	-1.532
One car household	MRAV1	1.312	1.650
Two+ car household	MRAV2	1.416	1.792
Inclusive value parameters			
Walk to transit	τ_{WK}	0.785	6.817
Drive to transit	τ_{DV}	0.623	5.487
Number of observations		1935	
LL (β)		-1037.84	
LL (0)		-3659.59	
$\rho = 1 - LL(\beta) / LL(0)$		0.716	

Figure 5.11 Mathematical specification of the transit NHB nested logit model

1. Utility equations

U_{LB} = -0.346 WT – 0.027 DT – 0.040 RT – 0.069 FWT – 0.014 TT – 0.667 NT – 1.438 F1 – 1.689 F2 + 2.662 LBWV0 + 0.632 LBWV1 + 0.343 LBWV2

$U_{EB,WK}$ = -0.346 WT – 0.027 DT – 0.040 RT – 0.069 FWT – 0.014 TT – 0.667 NT – 1.438 F1 – 1.689 F2 + 1.189 EBWV0 – 3.839 EBWV1 – 4.174 EBWV2

$U_{MR,WK}$ = -0.346 WT – 0.027 DT – 0.040 RT – 0.069 FWT – 0.014 TT – 0.667 NT – 1.438 F1 – 1.689 F2 + 0.860 MRWV0 – 1.250 MRWV1 – 1.476 MRWV2

$U_{TR,WK}$ = -0.346 WT – 0.027 DT – 0.040 RT – 0.069 FWT – 0.014 TT – 0.667 NT – 1.438 F1 – 1.689 F2 + 1.052 TRWV0 – 1.830 TRWV1 – 2.258 TRWV2

$U_{EB,DV}$ = -0.346 WT – 0.027 DT – 0.040 RT – 0.069 FWT – 0.014 TT – 0.667 NT – 1.438 F1 – 1.689 F2 – 2.788 EBAV0 + 1.582 EBAV1 + 1.837 EBAV2

$U_{MR,DV}$ = -0.346 WT – 0.027 DT – 0.040 RT – 0.069 FWT – 0.014 TT – 0.667 NT – 1.438 F1 – 1.689 F2 – 1.185 MRAV0 + 1.312 MRAV1 + 1.416 MRAV2

$U_{TR,DV}$ = -0.346 WT – 0.027 DT – 0.040 RT – 0.069 FWT – 0.014 TT – 0.667 NT – 1.438 F1 – 1.689 F2

2. Conditional probabilities

$$P_{LB|WK|Tr} = \frac{\exp(U_{LB})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{EB|WK|Tr} = \frac{\exp(U_{EB,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{MR|WK|Tr} = \frac{\exp(U_{MR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{TR|WK|Tr} = \frac{\exp(U_{TR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}$$

$$P_{EB|DV|Tr} = \frac{\exp(U_{EB,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}$$

$$P_{MR|DV|Tr} = \frac{\exp(U_{MR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}$$

$$P_{TR|DV|Tr} = \frac{\exp(U_{TR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}$$

3. Inclusive values

$$I_{WK} = \ln\left[\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})\right]$$

$$I_{DV} = \ln\left[\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})\right]$$

4. Access mode shares

$$P_{WK} = \frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}$$

$$P_{DV} = \frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}$$

5. Alternative Probabilities (market shares)

$$P_{LB,WK|Tr} = \left(\frac{\exp(U_{LB})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{EB,WK|Tr} = \left(\frac{\exp(U_{EB,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{MR,WK|Tr} = \left(\frac{\exp(U_{MR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{TR,WK|Tr} = \left(\frac{\exp(U_{TR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})}\right)\left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{EB,DV|Tr} = \left(\frac{\exp(U_{EB,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}\right)\left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{MR,DV|Tr} = \left(\frac{\exp(U_{MR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}\right)\left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

$$P_{TR,DV|Tr} = \left(\frac{\exp(U_{TR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})}\right)\left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})}\right)$$

Table 5.10 Definition of terms included in the equations of the transit NHB model

Term	Definition
<u>Utility equations</u>	
U_{LB}	Utility index of local bus
$U_{EB,WK}$	Utility index of express bus/walk access
$U_{MR,WK}$	Utility index of metro rail/walk access
$U_{TR,WK}$	Utility index of tri rail/walk access
$U_{EB,DV}$	Utility index of express bus/auto access
$U_{MR,DV}$	Utility index of metro rail/auto access
$U_{TR,DV}$	Utility index of tri rail/auto access
<u>Conditional probabilities</u>	
$P_{LB\|WK\|Tr}$	Probability of using local bus given that the trip-maker walks to the transit system
$P_{EB\|WK\|Tr}$	Probability of using express bus given that the trip-maker walks to the transit system
$P_{MR\|WK\|Tr}$	Probability of using metro rail given that the trip-maker walks to the transit system
$P_{TR\|WK\|Tr}$	Probability of using tri rail given that the trip-maker walks to the transit system
$P_{EB\|DV\|Tr}$	Probability of using express bus given that the trip-maker drives to the transit system
$P_{MR\|DV\|Tr}$	Probability of using metro rail given that the trip-maker drives to the transit system
$P_{TR\|DV\|Tr}$	Probability of using tri rail given that the trip-maker drives to the transit system
<u>Inclusive values</u>	
I_{WK}	Inclusive value of transit walk-access mode
I_{DV}	Inclusive value of transit auto-access mode
<u>Access mode shares</u>	
$P_{WK\|Tr}$	Probability that the transit user will walk to transit
$P_{DV\|Tr}$	Probability that the transit user will drive to transit
$P_{LB\|Tr}$	Probability of local bus (market share of local bus with respect to the transit service)
$P_{EB,WK\|Tr}$	Probability of express bus/walk access (market share with respect to the transit service)
$P_{MR,WK\|Tr}$	Probability of metro rail/walk access (market share with respect to the transit service)
$P_{TR,WK\|Tr}$	Probability of tri rail/walk access (market share with respect to the transit service)
$P_{EB,DV\|Tr}$	Probability of express bus/auto access (market share with respect to the transit service)
$P_{MR,DV\|Tr}$	Probability of metro rail/auto access (market share with respect to the transit service)
$P_{TR,DV\|Tr}$	Probability of tri rail/auto access (market share with respect to the transit service)

Table 5.11 Highway/Transit nested logit mode-choice model for NHB trips

Variable	Notation	Coef.	t-stat.
Mode choice model coefficients			
Transit In-vehicle travel time (min.)	$INVEH_{Tr}$	-0.156	-2.312
Share-driving in-vehicle travel time (min.)	$INVEH_{SD}$	-0.203	-2.244
Drive-alone in-vehicle travel time (min.)	$INVEH_{DA}$	-0.169	-2.246
Transit cost (cents)	OC_{Tr}	-0.058	-9.653
Share-driving cost (toll, parking, and gas)	OC_{SD}	-0.006	-5.923
Drive-alone cost (toll, parking, and gas)	OC_{DA}	-0.004	-5.094
Walk time to transit (minutes)	TRWT	-0.427	-6.670
CBD dummy variable (1 if Highway terminal time equals to 5 minutes, 0 otherwise)	HYT	-0.835	-1.985
Transit inclusive-link value	IL_{Tr}	0.899	7.664
Mode specific constants			
Transit			
Zero car household	TRV0	0.613	2.629
One car household	TRV1	-3.008	-6.039
Two car household	TRV2	-4.437	-10.200
Share driving			
Zero car household	SDV0	1.180	2.561
One car household	SDV1	-0.610	-6.286
Two car household	SDV2	-0.637	-8.218
Inclusive value parameters			
Transit	τ_{Tr}	0.191	2.934
Highway	τ_{Hy}	0.807	2.613
Number of observations	5461		
LL (β)	-1232.88		
LL (0)	-7517.87		
$\rho = 1 - LL(\beta) / LL(0)$	0.836		

Figure 5.12 Highway / Transit mathematical specification of the NHB model

1. Transit inclusive-link value

$$IL_{Tr} = \ln\left[\exp(\tau_{wk} I_{wk}) + \exp(\tau_{DV} I_{Dv})\right]$$

2. Utility equations

U_{Tr} = -0.156 $INVEH_{Tr}$ – 0.058 OC_{Tr}

U_{DA} = -0.169$INVEH_{DA}$ – 0.004 OC_{DA}

U_{SD} = -0.203 $INVEH_{SD}$ – 0.006 OC_{SD} + 1.180 SDV0 – 0.610 SDV1 – 0.637 SDV2

3. Conditional probabilities

$$P_{DA|HY} = \frac{\exp(U_{DA})}{\exp(U_{DA}) + \exp(U_{SD})}$$

$$P_{SD|HY} = \frac{\exp(U_{SD})}{\exp(U_{DA}) + \exp(U_{SD})}$$

4. Inclusive values

$$I_{HY} = \ln\left[\exp(U_{DA}) + \exp(U_{SD})\right]$$

$$I_{Tr} = \ln\left[\exp(U_{Tr})\right]$$

5. Highway/transit shares

$$P_{Tr} = \frac{exp(0.613TRV0 - 3.008TRV1 - 4.437TRV2 - 0.427TRWT + 0.899\ IL_{TR} + 0.191\ I_{Tr})}{exp(0.613TRV0 - 3.008TRV1 - 4.437TRV2 - 0.427TRWT + 0.899\ IL_{TR} + 0.191\ I_{Tr}) + exp(-0.835HYT + 0.807I_{HY})}$$

$$P_{HY} = \frac{exp(-0.835HYT + 0.807I_{HY})}{exp(0.613TRV0 - 3.008TRV1 - 4.437TRV2 - 0.427TRWT + 0.899\ IL_{TR} + 0.191\ I_{Tr}) + exp(-0.835HYT + 0.807I_{HY})}$$

6. Alternative Probabilities (market shares)

$$P_{DA} = P_{DA|HY}\, P_{HY}$$

$$P_{SD} = P_{SD|HY}\, P_{HY}$$

$$P_{Tr} = \frac{exp(0.613TRV0 - 3.008TRV1 - 4.437TRV2 - 0.427TRWT + 0.899\ IL_{TR} + 0.191\ I_{Tr})}{exp(0.613TRV0 - 3.008TRV1 - 4.437TRV2 - 0.427TRWT + 0.899\ IL_{TR} + 0.191\ I_{Tr}) + exp(-0.835HYT + 0.807I_{HY})}$$

Table 5.12 Definition of terms included in the equations of the highway/transit NHB model

Term	Definition
Utility equations	
U_{Tr}	Utility index of transit system
U_{DA}	Utility index of drive alone
U_{SD}	Utility index of share driving
Conditional probabilities	
$P_{DA\|HY}$	Probability of drive alone given that the trip-maker uses the highway network
$P_{SD\|HY}$	Probability of share driving given that the trip-maker uses the highway network
Inclusive values	
I_{HY}	Inclusive value of highway modes
I_{Tr}	Inclusive value of transit modes
Mode shares	
P_{DA}	Probability of drive-alone mode
P_{SD}	Probability of share driving
P_{Tr}	Probability of using the transit system

Figure 5.5 summarizes the system of probability equations of the HBW trips. The definitions of the probabilities are as follow:

P_{LB}	Probability of local bus
$P_{EB,WK}$	Probability of express bus/walk access
$P_{MR,WK}$	Probability of metro rail/walk access
$P_{TR,WK}$	Probability of tri rail/walk access
$P_{EB,DV}$	Probability of express bus/auto access
$P_{MR,DV}$	Probability of metro rail/auto access
$P_{TR,DV}$	Probability of tri rail/auto access
P_{DA}	Probability of drive alone
P_{SD}	Probability of share driving

Figure 5.13 Probability equations for the NHB trips

$$P_{LB} = \left(\frac{\exp(U_{LB})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{EB,WK} = \left(\frac{\exp(U_{EB,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{MR,WK} = \left(\frac{\exp(U_{MR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{TR,WK} = \left(\frac{\exp(U_{TR,WK})}{\exp(U_{LB}) + \exp(U_{EB,WK}) + \exp(U_{MR,WK}) + \exp(U_{TR,WK})} \right) \left(\frac{\exp(\tau_{WK} I_{WK})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{EB,DV} = \left(\frac{\exp(U_{EB,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})} \right) \left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{MR,DV} = \left(\frac{\exp(U_{MR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})} \right) \left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{TR,DV} = \left(\frac{\exp(U_{TR,DV})}{\exp(U_{EB,DV}) + \exp(U_{MR,DV}) + \exp(U_{TR,DV})} \right) \left(\frac{\exp(\tau_{DV} I_{DV})}{\exp(\tau_{WK} I_{WK}) + \exp(\tau_{DV} I_{DV})} \right) P_{Tr}$$

$$P_{DA} = \left(\frac{\exp(U_{DA})}{\exp(U_{DA}) + \exp(U_{SD})} \right) \frac{exp(-0.835\,HYT + 0.807\,I_{HY})}{exp(0.613TRV0 - 3.008TRV1 - 4.437TRV2 - 0.427TRWT + 0.899\,IL_{TR} + 0.191\,I_{Tr}) + exp(-0.835\,HYT + 0.807\,I_{HY})}$$

$$P_{SD} = \left(\frac{\exp(U_{SD})}{\exp(U_{DA}) + \exp(U_{SD})} \right) \frac{exp(-0.835\,HYT + 0.807\,I_{HY})}{exp(0.613TRV0 - 3.008TRV1 - 4.437TRV2 - 0.427TRWT + 0.899\,IL_{TR} + 0.191\,I_{Tr}) + exp(-0.835\,HYT + 0.807\,I_{HY})}$$

CHAPTER 6

SUMMARY AND CONCLUSIONS

Generally, the mode choice nested logit model is applied by a set of three model parameters. These model parameters include nesting coefficients, mode-specific constants, and level-of-service coefficients. So far, the common practice in developing a mode choice model in Florida is borrowing coefficients from other cities (e.g., Minneapolis / St. Paul). Then, the model is implemented in the following manner. Adjusting the modal bias coefficients (constants of the utility equation) to replicate the transit ridership data. Then, examining the validation results to identify any additional adjustments to coefficients or other parameters that were appropriate. The research team has questioned the validity of such approach, especially that the basis for mode choice nested logit models in the state was the Miami model, which was originally borrowed from Minneapolis, which in turn was borrowed from Shirley Highway. This stressed the need to develop, for the first time, a Florida model, based on Florida travel data.

This report describes the development of mode choice nested logit models for Florida. Data from the 1999 travel survey conducted in Southeast Florida were used in the calibration of the models. The calibration also involved the travel time and cost of the highway and transit systems obtained from the skim files of the southeast model. The selection of the proper universal nesting structure is critical to the development of a nested logit mode choice model. The nesting structure must address the existing transit service while at the same time provide suitable flexibility to permit the addition of future modes that might be considered. The selection of a nesting structure must also consider the data that are available for estimating the model.

Several alternative nesting structures were investigated. Finally, the mode choice model was estimated as a three-level nested logit structure. All models included seven transit mode/access combinations and two highway modes. The transit mode/access combinations were local bus, walk to express bus, walk to metro rail, walk access to tri rail, auto-access to express bus, auto-access to metro rail, auto-access to tri rail. The highway modes were drive-alone and shared riding. Also, different models were calibrated for three different trip purposes (home based work trips (HBW), home based non-work trips (HBNW), and non home-based trips (NHB).

Two separate surveys were used in the estimation process. The first is the on-board transit survey, and the second is the household survey. In conducting the 1999 Southeast Florida surveys, the sampling methodology followed in the household travel survey was different from the one used for the on-board transit survey. In the household travel survey, sequence of decision makers were drawn and their choice behaviors were observed. In contrast, in the on-board transit survey, sequence of chosen alternatives were drawn and the characteristics of the decision makers selecting those alternatives were observed. This kind of sampling scheme is called choice-based sampling. Therefore, we adopted a weighted exogenous sampling maximum likelihood (WESML) methodology to estimate the models. The weights are the ratio of population market shares to the sample (survey data) market shares. The modeling estimation approach was based on estimation of two nested-logit models. One of which is based on the on-board transit survey and the other for the household travel survey. The two models were linked through the use of inclusive value of transit.

The transit section of the model was calibrated using full information weighted exogenous sampling maximum likelihood (FI-WESML) approach. The FI-WESML estimation is the most efficient statistical approach, because different nesting levels are estimated simultaneously as opposed to sequentially in the limited information case. The overall model was also calibrated using Full Information Maximum Likelihood (FIML). The results of the final models are shown in the model estimation chapter of this report. Also, probability equations were provided to help practitioners implement the calibrated models.

CHAPTER 7

RECOMMENDATIONS AND FUTURE DIRECTION

The initial objective of this research effort was to develop a universal nested logit mode choice model for the state of Florida. After intensive investigation of the mode choice modeling in the state, the research team discovered that the foundation for the models is flawed, and that basing a universal model on flawed models would be of questionable benefit. Therefore, after consulting with the project manager, it was decided to modify the focus of the project. New models based on actual Florida travel data were warranted, and was possible because of the recently completed major survey in Southeast Florida. The research team calibrated for the first time nested logit mode choice models for different trip purposes based on Florida travel data to replace the models that are currently used in the state, which are based on the Miami model, which in turn borrowed model coefficients from Minneapolis, which again borrowed from Virginia's Shirley Highway model.

This effort leads to immediate action and also recommends future actions. The immediate action is to adopt these models to replace the current southeast (SERPM) model. Also, all models used in Miami, Orlando, Tampa, Jacksonville, and Volusia, should be re-validated based on the new model coefficients. As for the future action, the concept of a universal model should be re-visited, and defined clearly, and if warranted a new research project would be initiated. Again the models developed within the framework of this effort would be the basis for such universal model.

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