FINAL REPORT

to

THE FLORIDA DEPARTMENT OF TRANSPORTATION
RESEARCH OFFICE

on Project

"Development of Time-of-Day Modeling Procedures Using FSUTMS Powered by Cube Voyager"

FDOT Contract BD-545, RPWO #65 (UF Project 00059616)

August 30, 2007

Transportation Research Center
The University of Florida

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METRIC CONVERSION CHART

U.S. UNITS TO METRIC (SI) UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

METRIC (SI) UNITS TO U.S. UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
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km	kilometers	0.621	miles	mi

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16. Abstract

The Florida Standard Urban Transportation Modeling Structure (FSUTMS) currently models daily travel demand and then produces estimates of peak volumes through a simple post-processing routine. However, there are pressing needs to address planning issues and answer questions that are time-of-day related. In recognition of the importance of modeling travel demand by time of day, this research project has (1) developed time-of-day factors using travel survey data from the different parts of the state, (2) evaluated the existing transit time-of-day modeling procedures and suggested enhancements to conform to the FTA New Starts analysis requirements, (3) investigated modeling high-occupancy/toll lane operations within the FSUTMS framework, and (4) assessed the ability to model the peak-spreading phenomenon within the FSUTMS framework.

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EXECUTIVE SUMMARY

The Florida Standard Urban Transportation Modeling Structure (FSUTMS) is a computerized model package developed by the Florida Department of Transportation (FDOT) for planning and analysis of transportation systems. It has been used by all 26 Metropolitan Planning Organizations, FDOT Districts and other planning agencies in Florida. Currently FSUTMS models daily travel demand and then produces estimates of peak volumes through a simple post-processing routine. However, there are pressing needs to address planning issues and answer questions that are time-of-day (TOD) related. The daily-basis modeling framework is not competent for those tasks.

In recognition of the importance of modeling travel demand by time of day, FDOT has investigated the options for TOD modeling and recommended a post-distribution TOD factoring approach within the FSUTMS framework. As a continuation of previous efforts, the objectives of this research project are the following:

- Develop TOD factors using travel survey data from the different parts of the state;
- Evaluate the existing transit TOD modeling procedures and suggest enhancements to conform to the FTA New Starts analysis requirements;
- Examine the evaluation of demand-management strategies like high-occupancy/toll (HOT) lanes within the FSUTMS framework and
- Assess the ability to model the peak-spreading phenomenon within the FSUTMS framework.

TOD Factors

TOD factors are defined as the ratio of trips made in a time period to those made in one day. In this study TOD factors were developed for the different regions in Florida for five discrete time periods: midnight – 7 AM, 7-9 AM, 9 AM – 3 PM, 3 – 6 PM, and 6 PM – midnight. These time-of-periods were determined based on the observed temporal profiles of the total travel volumes over the day. Factors were developed separately for rural and urban areas and for each of the trip purposes included in the FSUTMS framework (except truck/taxi, IE, EI, and EE trips) and for each direction (i.e., production to attraction and attraction to production). In addition to the TOD factors, peak hour factors were also developed for each time-period to facilitate the creation of peak one-hour OD matrices for network assignment. The TOD factors are found to vary considerably across different regions. Hence it is recommended that factors developed from local surveys be used as opposed to statewide generic factors.

TOD Transit Modeling and New Starts Analysis

FDOT and the Florida Model Task Force are in the process of developing a new transit modeling system for FSUTMS/Voyager. The use of the best-path option of the public transportation (PT) module offered by Cube Voyager has been recommended as a short-term solution. Considering that the Tranplan procedure is still being used in Florida for transit modeling and the PT best-path option will maintain the same modeling structure, we have proposed TOD transit modeling procedures for a simplified and complete analysis respectively. These procedures may improve the calculation of project justification criteria, e.g., cost effectiveness, the most important measure for the New Starts analysis.

Modeling HOT Operations

Two approaches are generally applicable in FSUTMS to model HOT lanes: the modal-split and trip-assignment approaches. Both approaches have pros and cons, but the trip-assignment approach may be more preferable. For the trip-assignment approach, a multiclass stochastic user equilibrium assignment model is recommended where different values of time may be used for classes with different trip purposes and income. To address the issue of overlapping paths, more advanced models or techniques can be adopted, such as the C-Logit model and the subnetwork technique. Determination of time-dependent tolls is another important practice for modeling HOT lanes. We recommend treating traffic in each individual time period as static and determine fixed optimal toll rates accordingly for the time of day. Those time-of-day optimal tolls may serve as the base toll schedule and may be further adjusted in response to the changing traffic conditions.

Peak Spreading

Rigorous analysis of peak spreading requires that the underlying travel demand models be sensitive to system capacity constraints (to capture passive spreading) as well as behavioral responses of travelers to congestion and policy actions (i.e. active spreading). The TOD modeling approach (compared to the TOD factoring approach) is conceptually capable of more realistically capturing both active and passive peak spreading within the four-step travel forecasting framework. However, we identified practical issues that make the robust estimations of TOD choice models difficult. We also note that it is not always possible to completely capture the temporal dimension of travel demand and the related effects of peak spreading by simply introducing an additional time-of-day apportioning component without any changes to the rest of the demand-forecasting framework.

The above results may help improve the modeling practice in the state and enable analysts to develop effective travel demand management and transit oriented strategies. The research provides analysts a better understanding on the phenomenon of peak-spreading and how to capture both active and passive peak spreading. It may also benefit intermodal and multimodal planning in the state with providing estimates of travel demand by time of day. Consequently, transit agencies will be able to better plan and optimize their resources and services in response to the demand. The research will also help planning, evaluation and design of highway tolling for congestion mitigation.

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CHAPTER 1. INTRODUCTION

The Florida Standard Urban Transportation Modeling Structure (FSUTMS) is a computerized model package developed by the Florida Department of Transportation (FDOT) for planning and analysis of transportation systems. It has been used by all 26 Metropolitan Planning Organizations, FDOT Districts and other planning agencies in Florida. Currently FSUTMS models daily travel demand and then produces estimates of peak volumes through a simple post-processing routine. However, there are pressing needs to address planning issues and answer questions that are time-of-day (TOD) related. For example, transit agencies need the ridership forecasts by time of day to better plan their services and determine their operational strategies. As another example, many travel-demand management strategies intend to even the temporal distribution of travel over the entire day. The daily-basis modeling framework is not able to evaluate the impacts of such strategies.

In recognition of the importance of modeling travel demand by time of day, FDOT has investigated the options for TOD modeling (Pendyala *et al.*, 2002). The daily-basis four-step procedure is revised by applying TOD factors, defined as the ratio of trips made in a time period to those made in one day, to capture the time-varying characteristics of travel demand. Depending on when or where TOD factors are applied, four standard TOD factoring procedures can be distinguished as post-generation, post-distribution, post-split and post-assignment. Below are brief descriptions and discussions of these four procedures:

Post-generation TOD modeling obtains separate trip generations for different time periods by factoring the initial daily trip generation estimates. This method allows different travel characteristics by time of day to be considered in the trip distribution and mode choice processes, which may lead to better estimate results. However, this method is computationally demanding because of a large number of distribution and mode choice models for different trip-purpose/time-period combinations.

Post-distribution TOD modeling divides the daily trip tables by purpose into trip tables by purpose by time of day. Only one distribution model is required in this process but the differences in level of service among different time periods are ignored in the distribution process.

Post-split TOD modeling allows different TOD factors for different modes.

However, since mode choice must be modeled based on the daily trip distribution, there is an inconsistency in the path building between mode choice and transit assignment. This approach is probably the most widely-used approach in the U.S. (Rossi, 2002).

Post-assignment TOD modeling is the simplest one. TOD factors used in this process may be calculated from the observed traffic data and do not take account for different trip purposes and chosen modes. Instead of using fixed TOD factors, the relationships between TOD factors and facility congestion levels can be calibrated and applied in the assignment. However, the improvement in assignment accuracy may not be empirically evident (Gan et al, 2003). This procedure does not address the fundamental issue that TOD models are designed to address, and thus can only be applied in small urban areas with limited congestion during the peak period (Rossi, 2002).

The post-distribution approach has been recommended by FDOT. As a continuation of this previous effort, it is necessary to examine the implementation of the TOD modeling procedure into the FSUTMS now powered by Cube Voyager and to refine the procedure if necessary. This would enable modelers across Florida to conduct TOD modeling in their respective jurisdictional areas to provide both short and long term solutions.

In light of the above discussions, the objectives of this research project are: (1) develop TOD factors using travel survey data from the different parts of the state, (2) evaluate the existing transit TOD modeling procedures and suggest enhancements to conform to the FTA New Starts analysis requirements, (3) examine the evaluation of demand-management strategies like High-Occupancy/Toll (HOT) lanes within the FSUTMS framework, and (4) assess the ability to model the peak-spreading phenomenon within the FSUTMS framework.

The rest of this report is organized as follows. Chapter 2 presents the TOD factors developed using travel-survey data from different parts of the state. Specifically, factors are developed to apportion the 24-hour production-attraction (PA) matrix obtained after the trip distribution step into three to five discrete time periods. The factors are developed separately for each of the trip purposes included in the FSUTMS framework (except truck/taxi, IE, EI, and EE trips) and for each direction (i.e., P to A and A to P). Further, factors are developed separately for urban and rural regions.

Chapter 3 investigates TOD transit modeling procedures for incorporation within the current FSUTMS framework and discusses the resulting improvements in Federal Transit

Administration (FTA)'s New Starts analyses. This chapter begins with a brief review on current FSUTMS transit modeling procedures, and subsequently proposes an enhanced TOD transit modeling procedure. FTA's New Starts requirements are discussed followed by a discussion about the potential improvements resulted by the TOD modeling procedure in meeting these requirements.

Chapter 4 examines methods to incorporate analysis of HOV and HOT lanes within the FSUTMS framework. A background on toll roads and HOT lanes in the US is first presented. Subsequently, the modeling of toll lanes is discussed. Finally, methods to incorporate modeling of toll lanes within FSUTM and procedures to determine optimum tolls are described.

Chapter 5 describes the application of TOD modeling procedures for peak spreading analysis. This chapter begins by defining peak-spreading and subsequently evaluates the ability of adding a TOD component to effectively model peak-spreading within the FSUTMS structure.

Chapter 6 discusses our pilot implementation results. Specifically, the Olympus model was enhanced to include a post distribution TOD factoring and TOD specific assignments for both highway and transit modes. The conceptual structure of the enhanced model is detailed and some empirical results are presented comparing the results from the original and enhanced models.

Chapter 7 presents a summary of all work done and identifies the major results.

CHAPTER 2. DEVELOPMENT OF GENERIC TOD FACTORS FOR INCORPORATION WITHIN FSUTMS

2.1 Introduction

This chapter describes the development of TOD factors for incorporation within FSUTMS. Specifically, this task involves the development of factors to apportion the 24-hour PA matrix obtained after the trip distribution step into three to five discrete time periods. In addition, peak-hour factors are also developed to identify the volume of travel during the peak one hour within each of the five discrete time periods. The factors are developed separately for each of the trip purposes included in the FSUTMS framework (except truck/taxi, IE, EI, and EE trips) and for each direction (*i.e.*, P to A and A to P). All factors are developed for both urban and rural regions.

The rest of this chapter is organized as follows. Section 2.2 describes the analysis methods, data, and the results for *urban* areas. In addition, the factors determined are also compared with those obtained from surveys elsewhere in the country to ensure the reasonableness of the results. Section 2.3 presents the procedures, data, and results for *rural* areas. Finally, Section 2.4 presents a summary of major findings. In addition to these major sections, detailed temporal profiles (at a one-hour resolution) of urban and rural trips are presented in Appendix A. Appendix B presents the TOD profiles and factors for rural regions obtained from continuous-count stations in rural regions in Florida.

2.2 TOD Factors for Urban Areas

This section of the report is focused on the development of TOD factors for urban areas and is organized into four main sub-sections. First, Section 2.2.1 briefly outlines the analysis procedure adopted. Section 2.2.2 presents the data used. Next, Section 2.2.3 presents the analysis results, *i.e.*, the TOD periods and the corresponding factors. Finally, Section 2.2.4 presents a comparative assessment of our analysis results with TOD factors developed using data from other parts of the country.

2.2.1 Analysis Procedure

As already indicated, the focus of research in the case of urban areas is on the development of TOD factors for internal-internal person trips. Hence, travel survey data are appropriate for use. The first step of this analysis involves the creation of a person-trips file from the overall travel-survey data file. This person-trips file does not include trips made purely by non-motorized modes (*i.e.,* walk and bike) and is restricted to weekday travel records. Each trip is characterized by the activity type at the origin and the destination using the following classification scheme: home, work, school, shopping, social/recreation, and other. Hence, it is possible to classify each trip into one of the following six disaggregate trip purposes: home-based work, home-based school, home-based shopping, home-based social/recreation, home-based other, and non-home-based. Further, since the activity purposes are known at the origin and destination ends of the trip, it is possible to determine the directionality of the trip (*i.e.,* P to A and A to P). The start and end times of each trip are also included in a continuous time scale. The discrete TOD within which a trip falls is then defined using the *mid point time* of the trip.

With the above-described structure, the trips (overall or by purpose) can be suitably aggregated over any time-period of the day to determine the appropriate factors. In our analysis, we first aggregated the trips into 24 one-hour periods (*i.e.*, midnight to 1:00 AM, 1:00 – 2:00 AM, and so on). The temporal profiles at this level of aggregation were plotted to determine the suitable TOD periods. Then, the trips were aggregated within each of the chosen TOD periods to determine the factors.

2.2.2 Data

The data were drawn from five household travel surveys conducted in Florida (Table 2.1). The data sets were downloaded from the website www.floridatravelsurveys.org. Note that "NHTS-Fl/Urb" represents a sub sample of the National Household Travel Survey (NHTS) data from urban regions in Florida. The clean data used for the analysis were obtained by retaining only those persons for whom the start and end times are available for all trips made. The reason to remove *all* the records of a person even when trip timing information was only partially missing was motivated by the observation that trips with missing TOD information appeared to be systematically made during the later part of the day (and often the last trip of the person). If only the trips with missing TOD information were removed, this would lead to disproportionately more trips during the earlier parts of the day in the sample. Further, during the cleaning process, it was also ensured that, for each person, the number of trips originating at home equals the number of trips destined to home. However, it should be mentioned that the missing timing information was the primary reason for the reduction in the sample size.

Table 2.1 Travel surveys used and sample characteristics

Survey	Raw File			Motorized trips			Cleaned Analysis Sample		
	Trips	Persons	Households	Trips	Persons	Households	Trips	Persons	Households
NHTS-Fl/Urb	8050	1725	866	7357	1669	851	6271	1439	771
Northeast Florida	28390	8036	3921	27057	7915	3895	22625	5671	3057
Southeast Florida	33082	8873	4603	31948	8735	4578	20534	5759	3313
Tampa-bay	31277	8997	5304	31041	8965	5303	24088	6653	4206
Volusia	13402	1833	1107	13248	1829	1106	13059	1808	1097

2.2.3 Results

This section presents the analysis results. First, in Section 2.2.3.1 the choice of TOD periods is presented. Next, in Section 2.2.3.2, the TOD factors and peak-hour factors are provided. Detailed temporal profiles by purpose and direction for the different regions are presented in Appendix A.

Prior to the discussion of results, it is useful to make the following note about the use of "weights" in developing the TOD factors. If the temporal distribution of travel in the *cleaned analysis sample* is representative of the corresponding distribution in the population, then the TOD factors may be obtained by simple aggregation. However, this might not be true because of several reasons. For example, surveys may have used a stratified sampling approach. A second reason is the non-response bias; that is, the non-respondents might have different temporal patterns of travel compared to the respondents. The cleaning of the dataset (to retain only those persons for whom the start and end times are available for all trips made; see discussion in Section 2.2.2) could also introduce biases.

Therefore, it becomes necessary to weight the samples to make it reflective of the population. However, we do not have weights that comprehensively control for all these biases and for all the surveys used in our analysis. For three of the surveys (NHTS, Tampa Bay, and Volusia), sampling weights (at the household/person level) are available which scale the *raw* samples to the population to account for the stratified sampling procedures. The reader will note that the analysis sample in our case was obtained by removing an entire person even if the trip timing information was only partially missing. As it is not necessary that all persons are equally likely to have missing trip-timing information, the sampling weights may not necessarily be scaling the cleaned analysis sample to population accurately. In the light of the above discussions, we present both weighted (wherever sampling weights are available) and unweighted analysis results for all the surveys. Validations (such as against hourly counts) of specific model applications using TOD specific factors determined with and without sampling weights is one way of determining which approach is more "accurate".

2.2.3.1 Choice of TOD periods

The choice of TOD periods are determined based the temporal profile of local travel patterns. In general, the 24-hour day is divided into two peak periods (the AM peak and the PM peak) and one or more off-peak periods. The peak periods are typically between 2 to 3 hours in length. The AM peak is more likely (than the PM peak) to be a two hour period, given the rather sharp peaking of travel volumes around the work start time of about 8 AM.

To determine the discrete TOD periods, we first obtained the *total* travel volumes for each one-hour period (midnight to 1 AM, 1 – 2 AM, and so on) of the day. Figure 2.1 presents this temporal profile of travel graphically for each survey (the unweighted numbers are presented). The labels on the X-axis indicate end-time of the discrete TOD periods (on a 24-hour clock). For example, "1" represents the period from midnight to 1 AM, "13" represents the time from mid-day to 1 PM, and so on. This figure indicates a sharper peaking profile during the AM than the PM as discussed above. Subsequently, we define a "peak period" as a continuous two or three hour period during the day with the highest total travel volumes. The Tables 2.2 and 2.3 below identify these continuous two and three hour periods during the AM and PM portions of the day from each of the surveys (and determined with and without weights wherever applicable).

From the tables and the figure, the following may be inferred: First, the TOD of the peaking of travel demand appear largely similar across the different urban regions of the state and hence the choice of a single set of discrete TOD periods may be appropriate. Second, the concentration of travel during the AM period is confined to a smaller time period than the PM period (the per-hour concentration over the peak three hours is less than the corresponding number for the peak two hours in the case of AM peak; In the case of the PM periods the difference is much smaller– see the last columns under each of “2 hour peak” and “3 hour peak” in Tables 2.2 and 2.3). This result is also indicated by the graphs in Figure 2.1.

Based on the above discussions, we choose 7-9 AM as the AM peak period and 3-6 PM as the PM peak period. This divides the day into the following five periods: Morning (midnight – 7 AM), AM Peak (7-9 AM), Midday (9 AM – 3 PM), PM Peak (3 – 6 PM), and Evening (6 PM – midnight).

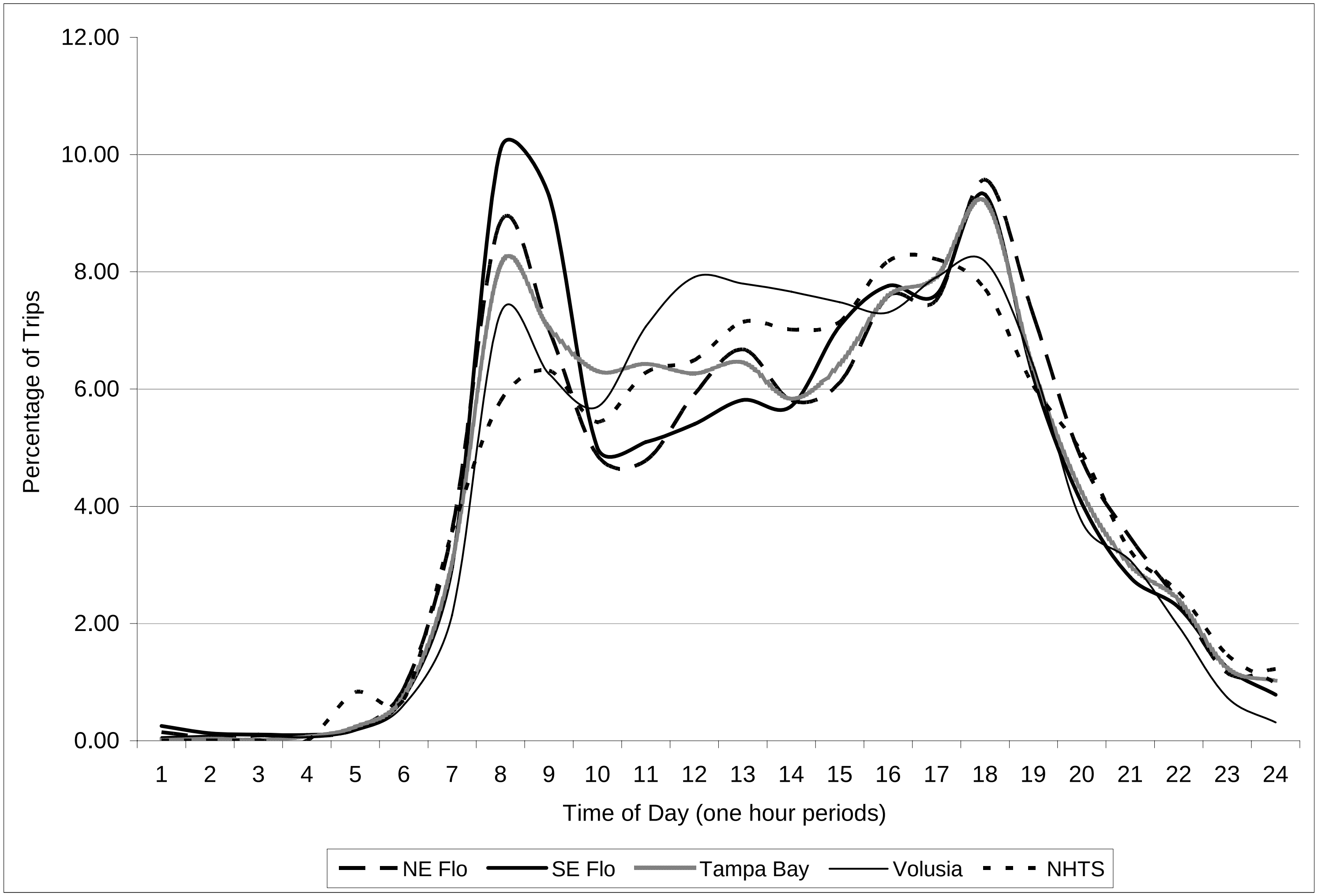

Figure 2.1 Temporal profiles of unweighted total travel volumes

Table 2.2 The peak periods during the AM

Survey	2-hour period	% of daily trips	Avg. % of daily trips per hour of the period	3-hour period	% of daily trips	Avg. % of daily trips per hour of the period
NHTS-Fl/Urb (unweighted)	8 am – 10am	11.75	5.88	8 am – 11am	18.04	6.01
NHTS-Fl/Urb (weighted)	7 am – 9 am	14.54	7.27	7 am – 10am	18.95	6.32
Northeast Florida (unweighted)	7 am – 9 am	15.85	7.92	7 am – 10am	20.72	6.91
Southeast Florida (unweighted)	7 am – 9 am	19.39	9.69	7 am – 10am	24.38	8.13
Tampa Bay (unweighted)	7 am – 9 am	15.15	7.57	7 am – 10am	21.45	7.15
Tampa Bay (weighted)	7 am – 9 am	17.20	8.60	7 am – 10am	22.88	7.63
Volusia County (unweighted)	7 am – 9 am	13.55	6.77	7 am – 10am	19.24	6.41
Volusia County (weighted)	7 am – 9 am	15.78	7.89	7 am – 10am	20.58	6.86

Table 2.3 The peak periods during the PM

Survey	2-hour period	% of daily trips	Avg. % of daily trips per hour of the period	3-hour period	% of daily trips	Avg. % of daily trips per hour of the period
NHTS-Fl/Urb (unweighted)	3 pm – 5 pm	16.39	8.2	3 pm – 6 pm	24.1	8.03
NHTS-Fl/Urb (weighted)	3 pm – 5 pm	18.02	9.01	3 pm – 6 pm	26.24	7.80
Northeast Florida (unweighted)	4 pm – 6 pm	17.09	8.55	3 pm – 6 pm	24.68	8.23
Southeast Florida (unweighted)	4 pm – 6 pm	16.93	8.47	3 pm – 6 pm	24.69	8.23
Tampa Bay (unweighted)	4 pm – 6 pm	17.12	8.56	3 pm – 6 pm	24.71	8.24
Tampa Bay (weighted)	4 pm – 6 pm	17.76	8.88	3 pm – 6 pm	25.38	8.46
Volusia County (unweighted)	4 pm – 6 pm	16.09	8.04	3 pm – 6 pm	23.39	7.8
Volusia County (weighted)	4 pm – 6 pm	17.15	8.57	3 pm – 6 pm	24.07	8.02

2.2.3.2 TOD factors

The TOD factors by trip purpose and by direction (P to A and A to P) for each of the survey regions are presented in this section. There are seven tables (2.4 – 2.10), one for each trip purpose. Each table includes the factors obtained from each of the surveys and developed both with and without the weights (wherever available). Note that, for each trip purpose, the factors sum to 100% across all time periods and directions. Further, factors (for any purpose) for total bi-directional volumes can be obtained by simply adding the appropriate P to A and A to P values. Similarly, the factors (for any purpose) for more aggregate time-periods (such as say a single off-peak period) can be obtained by summing the factors over the appropriate TOD periods.

Table 2.4 TOD factors (in percentages) for home-based work trips

Survey	# Trips	Direction	Morning midnight - 7 AM	AM Peak 7-9 AM	Mid-day 9 AM - 3 PM	PM Peak 3-6 PM	Evening 6 PM - midnight
NHTS-Fl/Urb (unweighted)	915	P to A	14.64	23.61	12.35	2.84	0.44
		A to P	1.42	0.87	7.76	23.28	12.79
NHTS-Fl/Urb (weighted)	915	P to A	15.40	22.29	11.96	3.14	0.87
		A to P	1.72	0.95	7.89	23.33	12.45
Northeast Florida (unweighted)	4665	P to A	14.36	27.27	10.35	2.14	1.39
		A to P	0.77	1.11	6.54	23.37	12.69
Southeast Florida (unweighted)	4937	P to A	10.05	28.68	10.63	2.07	1.38
		A to P	1.46	0.75	6.02	25.68	13.29
Tampa Bay (unweighted)	5373	P to A	13.29	27.10	9.49	2.42	1.40
		A to P	0.30	0.91	6.05	26.09	12.95
Tampa Bay (weighted)	5373	P to A	12.51	27.99	8.05	2.77	1.54
		A to P	0.87	0.61	5.73	24.27	15.65
Volusia (unweighted)	1881	P to A	12.55	29.61	8.88	2.50	1.28
		A to P	1.01	0.32	6.06	26.16	11.64
Volusia (weighted)	1881	P to A	11.89	29.76	8.38	3.45	1.14
		A to P	0.96	0.23	5.64	26.02	12.51

Table 2.5 TOD factors (in percentages) for home-based school trips

Survey	# Trips	Direction	Morning midnight - 7 AM	AM Peak 7-9 AM	Mid-day 9 AM - 3 PM	PM Peak 3-6 PM	Evening 6 PM - midnight
NHTS-Fl/Urb (unweighted)	452	P to A	8.19	31.19	7.96	3.54	3.98
		A to P	0.00	0.44	15.49	22.12	7.08
NHTS-Fl/Urb (weighted)	452	P to A	8.42	30.73	9.37	1.83	4.59
		A to P	0.00	0.30	15.49	23.27	6.01
Northeast Florida (unweighted)	2371	P to A	3.96	33.36	10.50	4.72	2.28
		A to P	0.34	3.12	13.79	19.19	8.73
Southeast Florida (unweighted)	1928	P to A	4.36	42.63	5.71	1.92	0.73
		A to P	0.10	1.04	17.17	22.41	3.94
Tampa Bay (unweighted)	1841	P to A	2.39	35.31	8.96	4.67	2.61
		A to P	0.16	4.02	16.08	18.09	7.71
Tampa Bay (weighted)	1841	P to A	1.23	29.99	8.72	7.71	3.41
		A to P	0.04	5.01	17.99	16.32	9.59
Volusia (unweighted)	170	P to A	2.35	37.06	7.06	4.71	1.76
		A to P	0.00	0.59	17.65	18.82	10.00
Volusia (weighted)	170	P to A	1.84	34.61	7.97	8.15	0.00
		A to P	0.00	0.29	18.75	15.46	12.93

Table 2.6 TOD factors (in percentages) for home-based shopping trips

Survey	# Trips	Direction	Morning	AM Peak	Mid-day	PM Peak	Evening
			midnight - 7 AM	7-9 AM	9 AM - 3 PM	3-6 PM	6 PM - midnight
NHTS-Fl/Urb (unweighted)	1235	P to A	1.21	3.81	24.62	7.37	6.72
		A to P	0.16	0.89	23.32	17.33	14.57
NHTS-Fl/Urb (weighted)	1235	P to A	0.97	2.79	9.29	9.02	9.17
		A to P	0.15	1.01	26.14	19.84	21.62
Northeast Florida (unweighted)	3062	P to A	0.23	3.40	21.23	7.58	7.67
		A to P	0.23	0.85	21.03	19.04	18.75
Southeast Florida (unweighted)	1580	P to A	1.08	6.08	32.78	11.33	11.20
		A to P	0.25	1.01	16.58	9.18	10.51
Tampa Bay (unweighted)	4543	P to A	0.37	3.98	25.58	7.55	6.27
		A to P	0.07	0.86	25.07	16.93	13.32
Tampa Bay (weighted)	4543	P to A	1.47	7.91	18.64	6.55	7.13
		A to P	0.03	2.29	23.48	16.00	16.50
Volusia (unweighted)	1571	P to A	0.32	2.93	27.43	5.92	4.71
		A to P	0.32	1.02	29.73	16.55	11.08
Volusia (weighted)	1571	P to A	0.47	2.50	24.07	6.75	6.04
		A to P	0.40	1.11	27.53	16.33	14.81

Table 2.7 TOD factors (in percentages) for home-based social/recreational trips

Survey	# Trips	Direction	Morning	AM Peak	Mid-day	PM Peak	Evening
			midnight - 7 AM	7-9 AM	9 AM - 3 PM	3-6 PM	6 PM - midnight
NHTS-Fl/Urb (unweighted)	580	P to A	1.55	4.83	17.07	13.10	13.28
		A to P	1.55	0.34	10.00	9.48	28.79
NHTS-Fl/Urb (weighted)	580	P to A	1.56	4.48	14.94	14.51	14.74
		A to P	2.02	0.84	8.58	7.20	31.14
Northeast Florida (unweighted)	2055	P to A	1.95	7.15	11.00	11.92	14.06
		A to P	1.46	0.73	10.07	10.36	31.29
Southeast Florida (unweighted)	1194	P to A	1.84	8.46	18.01	13.07	16.92
		A to P	1.84	1.01	9.63	9.55	19.68
Tampa Bay (unweighted)	3012	P to A	1.83	6.54	17.13	10.13	12.08
		A to P	0.23	0.56	11.52	12.88	27.09
Tampa Bay (weighted)	3012	P to A	2.69	3.50	15.87	8.95	13.42
		A to P	0.14	0.24	12.34	9.53	33.33
Volusia (unweighted)	1026	P to A	2.14	6.73	19.79	9.94	9.65
		A to P	0.29	1.66	13.06	13.45	23.29
Volusia (weighted)	1026	P to A	1.89	5.81	17.72	9.98	12.05
		A to P	0.43	1.27	11.30	12.07	27.47

Table 2.8 TOD factors (in percentages) for home-based other trips

Survey	# Trips	Direction	Morning	AM Peak	Mid-day	PM Peak	Evening
			midnight - 7 AM	7-9 AM	9 AM - 3 PM	3-6 PM	6 PM - midnight
NHTS-Fl/Urb (unweighted)	1196	P to A	3.51	10.12	19.73	9.45	8.95
		A to P	0.59	3.01	17.14	11.62	15.89
NHTS-Fl/Urb (weighted)	1196	P to A	4.26	11.36	18.14	8.94	8.55
		A to P	0.88	3.02	16.32	13.07	15.47
Northeast Florida (unweighted)	3297	P to A	3.67	12.83	16.71	8.04	9.10
		A to P	0.73	1.94	13.50	12.89	20.59
Southeast Florida (unweighted)	5768	P to A	1.51	12.10	14.94	6.26	5.88
		A to P	0.62	2.77	19.85	18.20	17.86
Tampa Bay (unweighted)	3531	P to A	2.58	12.46	22.57	7.59	7.11
		A to P	0.14	1.76	17.11	13.40	15.29
Tampa Bay (weighted)	3531	P to A	2.26	9.74	18.60	12.42	6.86
		A to P	0.04	0.99	11.96	19.42	17.70
Volusia (unweighted)	3710	P to A	1.94	12.40	22.64	8.84	5.77
		A to P	0.46	2.96	16.77	13.37	14.85
Volusia (weighted)	3710	P to A	2.11	14.32	19.48	8.53	6.43
		A to P	0.64	3.25	15.14	14.04	16.06

Table 2.9 TOD factors (in percentages) for home-based non-work trips

Survey	# Trips	Direction	Morning	AM Peak	Mid-day	PM Peak	Evening
			midnight - 7 AM	7-9 AM	9 AM - 3 PM	3-6 PM	6 PM - midnight
NHTS-Fl/Urb (unweighted)	3643	P to A	2.97	9.73	19.49	8.55	8.23
		A to P	0.52	1.47	17.93	14.67	16.43
NHTS-Fl/Urb (weighted)	3643	P to A	3.51	10.84	13.55	8.79	9.19
		A to P	0.73	1.60	17.63	15.66	18.51
Northeast Florida (unweighted)	10785	P to A	2.43	13.58	15.54	7.92	8.14
		A to P	0.64	1.66	15.05	15.54	19.50
Southeast Florida (unweighted)	10470	P to A	2.01	16.40	16.28	7.00	6.99
		A to P	0.61	1.99	17.70	16.63	14.39
Tampa Bay (unweighted)	12927	P to A	1.60	11.36	20.42	7.75	7.33
		A to P	0.14	1.49	18.46	15.19	16.27
Tampa Bay (weighted)	12927	P to A	1.89	11.95	15.97	8.82	7.69
		A to P	0.06	2.07	16.94	15.50	19.12
Volusia (unweighted)	6477	P to A	1.59	9.85	22.94	8.20	6.02
		A to P	0.39	2.22	19.35	14.30	15.15
Volusia (weighted)	6477	P to A	1.72	11.60	19.57	8.36	6.88
		A to P	0.53	2.35	17.32	14.29	17.38

NOTE: Home-based non-work is an aggregate category of all home-based purposes except work

Table 2.10 TOD factors (in percentages) for non home-based trips

Survey	# Trips	Direction	Morning	AM Peak	Mid-day	PM Peak	Evening
			midnight - 7 AM	7-9 AM	9 AM - 3 PM	3-6 PM	6 PM - midnight
NHTS-Fl/Urb (unweighted)	1893	P to A	2.69	7.77	52.72	24.72	12.10
NHTS-Fl/Urb (weighted)	1893	P to A	3.28	9.63	48.04	24.82	14.23
Northeast Florida (unweighted)	7175	P to A	1.49	8.61	50.72	25.97	13.21
Southeast Florida (unweighted)	5124	P to A	1.50	11.75	51.11	23.91	11.73
Tampa Bay (unweighted)	5788	P to A	0.97	8.36	55.67	25.14	9.87
Tampa Bay (weighted)	5788	P to A	1.42	10.44	48.80	25.62	13.72
Volusia (unweighted)	4056	P to A	0.44	8.31	59.02	22.39	9.84
Volusia (weighted)	4056	P to A	0.56	10.28	55.45	23.00	10.72

2.2.3.3 Peak-hour factors

Tables 2.11 – 2.17 present the peak-hour factors (by direction, trip purpose, and survey region). These factors will be useful if a one-hour demand (OD matrix) is required for each time period for performing network assignment. Each table is for a specific trip purpose. Note that the peak-hour factors represent the ratio of the travel volume (of a given purpose and direction) during the "peak" one hour of a TOD period to the total travel (of the same purpose and direction) during the corresponding period (expressed as a percentage). For example, the entry "71.57" in row "South East Florida, P-A" and under the column "Morning" in Table 2.11 means that 71.57% of all home-based work trips from P to A during the morning period (midnight – 7 AM) are concentrated within a one-hour period. The peak-hour within any TOD period was identified as the one hour within the TOD period which had the maximum total (all trip purposes) travel. These peak hours were found to be largely the same across all surveys and are indicated in the tables (6-7 AM is the peak hour of the morning period, 5-6 PM is the peak hour of the PM peak period, and so on).

Table 2.11 Peak-hour factors (in percentages) for home-based work trips

Survey	# Trips	Direction	Morning 6-7 AM	AM Peak 7 - 8 AM	Mid-day Noon-1 PM	PM Peak 5 - 6 PM	Evening 6 - 7 PM
NHTS-Fl/Urb (unweighted)	915	P to A	75.37	56.94	11.50	61.54	25.00
		A to P	0.00	37.50	23.94	19.25	41.03
NHTS-Fl/Urb (weighted)	915	P to A	73.49	56.64	15.13	28.22	8.76
		A to P	0.00	46.71	40.31	31.75	42.47
Northeast Florida (unweighted)	4665	P to A	72.39	65.88	16.36	17.00	29.23
		A to P	19.44	51.92	33.44	50.55	44.09
Southeast Florida (unweighted)	4937	P to A	71.57	54.94	13.71	27.45	35.29
		A to P	22.22	48.65	30.98	51.97	46.95
Tampa Bay (unweighted)	5373	P to A	69.05	64.22	12.55	27.69	46.67
		A to P	37.50	46.94	29.85	49.86	39.80
Tampa Bay (weighted)	5373	P to A	67.97	65.91	22.66	13.77	19.35
		A to P	7.20	45.23	31.37	46.46	51.50
Volusia (unweighted)	1881	P to A	66.53	65.71	14.37	21.28	29.17
		A to P	15.79	83.33	28.95	50.20	42.92
Volusia (weighted)	1881	P to A	68.07	63.96	14.65	17.49	28.10
		A to P	9.27	83.28	29.98	49.12	42.12

Table 2.12 Peak-hour factors (in percentages) for home-based school trips

Survey	# Trips	Direction	Morning 6-7 AM	AM Peak 7 - 8 AM	Mid-day Noon-1 PM	PM Peak 5 - 6 PM	Evening 6 - 7 PM
NHTS-Fl/Urb (unweighted)	452	P to A	91.89	51.77	5.56	50.00	55.56
		A to P	0.00	0.00	8.57	44.00	21.88
NHTS-Fl/Urb (weighted)	452	P to A	90.97	56.14	34.78	9.59	58.84
		A to P	0.00	0.00	51.88	43.05	24.36
Northeast Florida (unweighted)	2371	P to A	97.87	63.72	9.24	33.93	50.00
		A to P	25.00	29.73	13.46	23.74	31.88
Southeast Florida (unweighted)	1928	P to A	96.43	64.48	9.09	54.05	50.00
		A to P	100.00	30.00	70.39	19.91	53.95
Tampa Bay (unweighted)	1841	P to A	93.18	64.00	22.42	32.56	64.58
		A to P	66.67	44.59	62.50	15.02	19.01
Tampa Bay (weighted)	1841	P to A	95.18	48.13	9.06	59.95	30.18
		A to P	89.29	60.61	50.12	31.81	8.75
Volusia (unweighted)	170	P to A	75.00	68.25	25.00	50.00	100.00
		A to P	0.00	0.00	16.67	12.50	17.65
Volusia (weighted)	170	P to A	61.05	77.95	7.63	51.23	0.00
		A to P	0.00	0.00	18.92	17.83	16.03

Table 2.13 Peak-hour factors (in percentages) for home-based shopping trips

Survey	# Trips	Direction	Morning 6-7 AM	AM Peak 7 - 8 AM	Mid-day Noon-1 PM	PM Peak 5 - 6 PM	Evening 6 - 7 PM
NHTS-Fl/Urb (unweighted)	1235	P to A	93.33	23.40	15.13	46.15	33.73
		A to P	100.00	45.45	14.58	35.05	37.22
NHTS-Fl/Urb (weighted)	1235	P to A	75.41	37.39	11.92	35.43	41.09
		A to P	100.00	36.59	15.96	37.07	34.41
Northeast Florida (unweighted)	3062	P to A	71.43	26.92	8.31	31.47	37.45
		A to P	42.86	19.23	18.32	37.39	35.89
Southeast Florida (unweighted)	1580	P to A	64.71	40.63	11.39	29.61	34.46
		A to P	75.00	25.00	14.89	39.31	20.48
Tampa Bay (unweighted)	4543	P to A	70.59	36.46	12.48	31.49	43.86
		A to P	33.33	35.90	18.61	27.83	31.57
Tampa Bay (weighted)	4543	P to A	9.11	70.28	18.22	47.61	46.87
		A to P	4.00	68.27	26.16	28.71	32.38
Volusia (unweighted)	1571	P to A	80.00	30.43	11.60	30.11	50.00
		A to P	40.00	18.75	19.70	27.31	38.51
Volusia (weighted)	1571	P to A	76.57	37.60	10.51	34.31	48.09
		A to P	44.38	31.53	21.50	33.16	38.67

Table 2.14 Peak-hour factors (in percentages) for home-based social/recreational trips

Survey	# Trips	Direction	Morning 6-7 AM	AM Peak 7 - 8 AM	Mid-day Noon-1 PM	PM Peak 5 - 6 PM	Evening 6 - 7 PM
NHTS-Fl/Urb (unweighted)	580	P to A	55.56	32.14	24.24	14.47	48.05
		A to P	22.22	0.00	22.41	34.55	18.56
NHTS-Fl/Urb (weighted)	580	P to A	75.41	37.39	11.92	35.43	41.09
		A to P	4.12	0.00	25.66	26.41	17.60
Northeast Florida (unweighted)	2055	P to A	55.00	43.54	7.96	51.02	46.37
		A to P	20.00	26.67	19.81	40.38	19.44
Southeast Florida (unweighted)	1194	P to A	59.09	39.60	18.14	38.46	37.62
		A to P	13.64	16.67	22.61	30.70	17.02
Tampa Bay (unweighted)	3012	P to A	78.18	42.13	11.24	54.75	45.33
		A to P	42.86	29.41	23.05	35.57	18.87
Tampa Bay (weighted)	3012	P to A	93.14	39.48	5.34	53.67	30.47
		A to P	46.37	25.08	34.15	40.32	16.70
Volusia (unweighted)	1026	P to A	72.73	39.13	15.27	37.25	56.57
		A to P	0.00	23.53	17.16	30.43	23.85
Volusia (weighted)	1026	P to A	65.24	41.07	12.75	38.88	52.60
		A to P	0.00	27.13	19.22	29.02	24.81

Table 2.15 Peak-hour factors (in percentages) for home-based other trips

Survey	# Trips	Direction	Morning 6-7 AM	AM Peak 7 - 8 AM	Mid-day Noon-1 PM	PM Peak 5 - 6 PM	Evening 6 - 7 PM
NHTS-Fl/Urb (unweighted)	1196	P to A	76.19	49.59	17.37	24.78	41.12
		A to P	14.29	47.22	23.90	34.53	20.53
NHTS-Fl/Urb (weighted)	1196	P to A	69.33	54.32	16.40	44.41	38.37
		A to P	20.21	47.49	28.44	33.69	17.10
Northeast Florida (unweighted)	3297	P to A	84.30	52.01	9.07	55.47	54.67
		A to P	37.50	35.94	24.04	45.65	22.83
Southeast Florida (unweighted)	5768	P to A	77.01	52.15	16.36	30.75	43.07
		A to P	19.44	33.75	24.28	39.14	29.22
Tampa Bay (unweighted)	3531	P to A	87.91	40.68	8.91	39.93	62.95
		A to P	80.00	27.42	16.23	43.34	26.11
Tampa Bay (weighted)	3531	P to A	96.23	40.64	6.18	33.87	62.71
		A to P	85.75	49.92	13.80	32.80	29.89
Volusia (unweighted)	3710	P to A	80.56	57.83	12.14	38.41	60.28
		A to P	52.94	40.00	15.92	35.28	26.68
Volusia (weighted)	3710	P to A	84.70	65.04	13.16	39.41	58.48
		A to P	43.77	43.79	16.01	39.70	26.04

Table 2.16 Peak-hour factors (in percentages) for home-based non-work trips

Survey	# Trips	Direction	Morning 6-7 AM	AM Peak 7 - 8 AM	Mid-day Noon-1 PM	PM Peak 5 - 6 PM	Evening 6 - 7 PM
NHTS-Fl/Urb (unweighted)	3643	P to A	82.52	45.40	16.74	30.07	41.75
		A to P	27.78	43.14	17.71	36.61	25.31
NHTS-Fl/Urb (weighted)	3643	P to A	78.89	52.66	16.72	37.88	41.63
		A to P	16.97	39.54	26.24	36.63	23.49
Northeast Florida (unweighted)	10785	P to A	84.35	55.70	8.65	44.85	47.04
		A to P	28.99	30.17	19.10	36.16	26.25
Southeast Florida (unweighted)	10470	P to A	81.90	56.67	14.60	33.29	39.62
		A to P	23.44	31.73	31.08	33.83	27.60
Tampa Bay (unweighted)	12927	P to A	85.02	50.68	11.78	40.92	50.53
		A to P	55.56	35.94	24.10	30.92	24.39
Tampa Bay (weighted)	12927	P to A	73.71	50.66	10.77	46.28	42.58
		A to P	51.63	61.10	30.48	32.28	23.27
Volusia (unweighted)	6477	P to A	78.64	54.86	12.52	36.91	57.69
		A to P	44.00	35.42	17.48	31.53	27.93
Volusia (weighted)	6477	P to A	79.67	63.95	12.31	39.05	55.00
		A to P	38.39	40.92	18.31	35.54	27.60

NOTE: Home-based non-work is an aggregate category of all home-based purposes except work

Table 2.17 Peak-hour factors (in percentages) for non home-based trips

Survey	# Trips	Direction	Morning	AM Peak	Mid-day	PM Peak	Evening
			6-7 AM	7 - 8 AM	Noon-1 PM	5 - 6 PM	6 - 7 PM
NHTS-Fl/Urb (unweighted)	1893	P to A	62.75	42.18	19.54	38.68	29.69
NHTS-Fl/Urb (weighted)	1893	P to A	52.10	40.60	15.36	36.03	28.53
Northeast Florida (unweighted)	7175	P to A	72.90	43.04	24.05	32.64	41.77
Southeast Florida (unweighted)	5124	P to A	64.94	39.04	17.68	32.08	39.43
Tampa Bay (unweighted)	5788	P to A	82.14	37.81	15.52	32.03	39.40
Tampa Bay (weighted)	5788	P to A	36.37	34.09	12.73	27.72	25.95
Volusia (unweighted)	4056	P to A	77.78	39.47	21.14	29.74	48.62
Volusia (weighted)	4056	P to A	80.80	42.58	22.33	34.15	48.45

2.2.4 Reasonableness Checks

In this section, we compare the TOD factors developed for Florida in this study with those developed using data from other parts of the country. For data on the latter, we draw from Rossi (2002) and NCHRP synthesis report 365 (TRB, 1998).

Table 2.18 compares the TOD factors for the AM peak period (7-9 AM) by direction for the three trip purposes (home-based work, home-based non work, and non home-based). Table 2.19 compares the TOD factors for the PM peak period (3-6 PM) by direction for the three trip purposes (home-based work, home-based non work, and non home-based). In either case, we observe that the factors developed for Florida fall within the typical range of values obtained elsewhere in the country.

Table 2.18 Comparison of TOD factors for AM peak (7-9 AM) period

Region	Home-based work		Home-based non-work		Non home-based
	P to A	A to P	P to A	A to P	P to A
NHTS-Fl/Urb (unweighted)	23.61	0.87	9.73	1.47	7.77
NHTS-Fl/Urb (weighted)	22.29	0.95	10.84	1.60	9.63
Northeast Florida (unweighted)	27.27	1.11	13.58	1.66	8.61
Southeast Florida (unweighted)	28.68	0.75	16.40	1.99	11.75
Tampa Bay (unweighted)	27.10	0.91	11.36	1.49	8.36
Tampa Bay (weighted)	27.99	0.61	11.95	2.07	10.44
Volusia (unweighted)	29.61	0.32	9.85	2.22	8.31
Volusia (weighted)	29.76	0.23	11.60	2.35	10.28
NPTS[1]	21.20	1.00	9.80	1.20	4.10
Denver[2]	33.80	0.30	7.70	0.70	2.70
Jacksonville[2]	28.90	1.00	8.60	1.80	8.20
Miami[2]	23.30	1.10	8.50	1.40	5.60
Philadelphia[2]	33.00	0.90	14.80	1.00	8.50
Portland[2]	25.10	0.60	5.10	1.80	4.20
Sacremento[2]	27.00	1.00	8.20	1.60	6.40
Salt Lake[2]	24.50	0.70	10.20	1.50	5.10
Tampa[2]	26.60	1.10	11.90	1.70	9.10

[1] from NHCRP synthesis report 365
[2] from Rossi (2002)

Table 2.19 Comparison of TOD factors for PM peak (3-6 PM) period

Region	Home-based work		Home-based non-work		Non home-based
	P to A	A to P	P to A	A to P	P to A
NHTS-Fl/Urb (unweighted)	2.84	23.28	8.55	14.67	24.72
NHTS-Fl/Urb (weighted)	3.14	23.33	8.79	15.66	24.82
Northeast Florida (unweighted)	2.14	23.37	7.92	15.54	25.97
Southeast Florida (unweighted)	2.07	25.68	7.00	16.63	23.91
Tampa Bay (unweighted)	2.42	26.09	7.75	15.19	25.14
Tampa Bay (weighted)	2.77	24.27	8.82	15.50	25.62
Volusia (unweighted)	2.50	26.16	8.20	14.30	22.39
Volusia (weighted)	3.45	26.02	8.36	14.29	23.00
NPTS[1]	3.20	26.80	9.20	13.90	28.40
Denver[2]	3.00	27.30	10.60	12.90	24.20
Jacksonville[2]	1.40	27.00	8.50	12.80	22.60
Miami[2]	1.60	24.90	10.80	10.80	16.00
Philadelphia[2]	2.40	30.20	8.80	15.40	20.00
Portland[2]	3.10	32.30	9.10	14.50	22.50
Sacremento[2]	3.20	26.30	8.90	13.00	23.70
Salt Lake[2]	2.00	28.00	9.70	15.80	26.00
Tampa[2]	2.80	25.40	9.00	13.60	24.90

[1] from NHCRP synthesis report 365
[2] from Rossi (2002)

2.3 TOD Factors for Rural Areas

In the development of TOD factors for rural areas, we follow a procedure similar to the one outlined in the previous section in the context of urban areas. However, in this case, we use national-level travel-survey data obtained from the NHTS, as adequate data are not available specific to rural regions in Florida. From Table 2.20, the reader will note that there are only about 1000 trips from 105 households from rural regions in Florida represented in the NHTS sample. As this is too small, we use the rural sample from the entire nation in our analysis. The temporal profiles of the total travel volume are plotted (Figure 2.2) and this is used to determine the TOD periods. Detailed temporal profiles of travel volumes by purpose and direction are presented in Appendix A.

Table 2.20 Travel survey used and sample characteristics

Survey	Raw File			Motorized trips			Cleaned Analysis Sample		
	Trips	Persons	Households	Trips	Persons	Households	Trips	Persons	Households
NHTS Rural	44233	9626	4242	41566	9394	4180	34984	8028	3865
NHTS Rural- FL	1128	248	115	1046	243	112	919	215	105

An alternate approach which relies on local information is to use the continuous-count data from stations located in rural locations. However, such counts are more likely to represent long-distance vehicle-trips and further, do not allow us to distinguish the trip purposes. Nonetheless, Appendix B presents our analysis of the temporal profile of travel from continuous count stations in rural Florida locations.

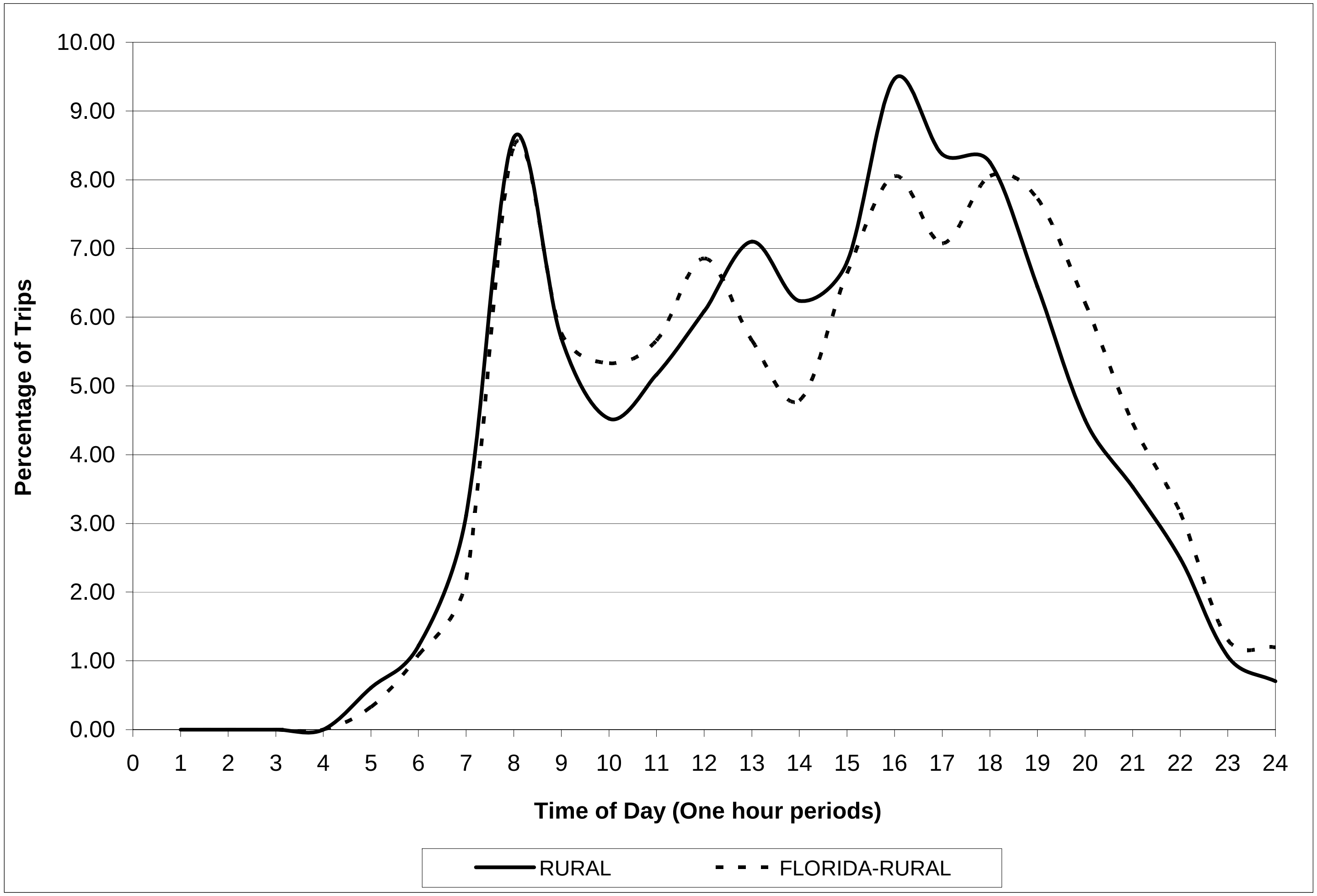

Figure 2.2 Temporal profiles of total travel volumes

Again, adopting a similar procedure as in the case of the urban analysis (see Tables 2.21 and 2.22), we choose 7-9 AM as the AM peak period and 3-6 PM as the PM peak period. This divides the day into the following five periods: Morning (midnight – 7 AM), AM Peak (7-9 AM), Midday (9 AM – 3 PM), PM Peak (3 – 6 PM), and Evening (6 PM – midnight).

Table 2.21 The peak periods during the AM

Survey	2-hour period	% of daily trips	Avg. % of daily trips per hour of the period	3-hour period	% of daily trips	Avg. % of daily trips per hour of the period
NHTS- Rural (unweighted)	7 am – 9am	14.31	7.16	7 am – 10am	18.83	6.28
NHTS- Rural (weighted)	7 am – 9am	14.54	7.27	7 am – 10am	18.95	6.32

Table 2.22 The peak periods during the PM

Survey	2-hour period	% of daily trips	Avg. % of daily trips per hour of the period	3-hour period	% of daily trips	Avg. % of daily trips per hour of the period
NHTS- Rural (unweighted)	3 pm - 5 pm	17.84	8.92	3 pm - 6 pm	26.09	8.7
NHTS- Rural (weighted)	3 pm - 5 pm	18.02	9.01	3 pm - 6 pm	26.24	8.75

The TOD factors by trip purpose and by direction (P to A and A to P) are presented in Tables 2.23 (unweighted) and 2.24 (weighted). Tables 2.25 and 2.26 present the unweighted and weighted peak-hour factors (by direction and by trip purpose) respectively. These represent the ratio of the travel volume during the peak one hour of a TOD period to the total travel during the corresponding period (expressed as a percentage).

Table 2.23 Unweighted TOD factors (in percentages)

Trip purpose	# Trips	Direction	Morning midnight - 7 AM	AM Peak 7-9 AM	Mid-day 9 AM - 3 PM	PM Peak 3-6 PM	Evening 6 PM - midnight
Home-based work	5494	P to A	17.35	22.21	9.32	2.82	1.26
		A to P	1.09	0.29	8.12	25.79	11.76
Home-based school	3531	P to A	3.34	37.13	4.87	2.75	5.24
		A to P	0.06	0.48	10.79	25.38	9.97
Home-based shopping	5640	P to A	1.10	4.57	24.56	8.51	5.83
		A to P	0.07	1.12	23.24	17.96	13.03
Home-based social/recreational	2920	P to A	1.23	4.38	14.14	13.73	14.62
		A to P	1.23	0.89	9.01	11.95	28.80
Home-based other	5743	P to A	3.64	12.87	16.33	9.96	8.62
		A to P	0.57	2.99	12.68	14.23	18.11
Home-based non-work[1]	17824	P to A	2.38	13.66	16.31	8.69	8.05
		A to P	0.42	1.56	15.04	17.24	16.64
Non home-based	11656	P to A	1.85	9.05	51.60	25.15	12.35

[1] this is an aggregate category of all home-based purposes except work

Table 2.24 Weighted TOD factors (in percentages)

Trip purpose	# Trips	Direction	Morning midnight - 7 AM	AM Peak 7-9 AM	Mid-day 9 AM - 3 PM	PM Peak 3-6 PM	Evening 6 PM - midnight
Home-based work	5494	P to A	17.82	21.41	9.22	3.08	1.25
		A to P	1.36	0.31	8.24	25.51	11.79
Home-based school	3531	P to A	3.47	36.60	4.99	2.89	4.74
		A to P	0.03	0.57	11.36	25.36	9.98
Home-based shopping	5640	P to A	1.24	4.79	23.44	8.81	6.62
		A to P	0.07	1.11	21.75	18.13	14.03
Home-based social/recreational	2920	P to A	1.23	4.49	14.37	12.70	15.52
		A to P	1.29	0.90	9.14	10.73	29.63
Home-based other	5743	P to A	3.41	13.00	15.13	9.50	9.81
		A to P	0.66	3.10	12.14	14.38	18.88
Home-based non-work[1]	17824	P to A	2.39	13.96	15.44	8.45	8.74
		A to P	0.46	1.59	14.42	17.20	17.36
Non home-based	11656	P to A	1.99	9.48	49.75	26.02	12.75

[1] this is an aggregate category of all home-based purposes except work

Table 2.25 Unweighted peak hour factors (in percentages)

Trip purpose	# Trips	Direction	Morning 6-7 AM	AM Peak 7 -8 AM	Mid-day Noon - 1 PM	PM Peak 3-4 PM	Evening 6-7 PM
Home-based work	5494	P to A	63.69	70.00	17.97	46.45	52.17
		A to P	8.33	37.50	24.22	24.35	33.59
Home-based school	3531	P to A	92.37	70.71	12.21	12.37	73.51
		A to P	0.00	23.53	12.60	68.97	15.63
Home-based shopping	5640	P to A	66.13	37.21	13.29	36.25	42.25
		A to P	0.00	31.75	18.38	33.96	29.80
Home-based social/recreational	2920	P to A	44.44	43.75	15.50	20.95	56.44
		A to P	8.33	42.31	14.07	22.92	16.88
Home-based other	5743	P to A	69.86	59.95	14.07	31.12	54.55
		A to P	54.55	43.60	19.51	32.44	24.81
Home-based non-work[1]	17824	P to A	73.41	62.48	13.79	28.90	54.74
		A to P	28.00	39.57	17.44	42.50	22.71
Non home-based	11656	P to A	66.20	49.38	23.52	38.93	37.67

[1] this is an aggregate category of all home-based purposes except work

Table 2.26 Weighted peak hour factors (in percentages)

Trip purpose	# Trips	Direction	Morning 6-7 AM	AM Peak 7 -8 AM	Mid-day Noon - 1 PM	PM Peak 3-4 PM	Evening 6-7 PM
Home-based work	5494	P to A	61.15	71.86	18.07	49.91	44.82
		A to P	6.54	38.73	24.89	23.62	31.52
Home-based school	3531	P to A	93.41	72.92	13.40	12.39	72.40
		A to P	0.00	33.53	10.80	66.92	18.86
Home-based shopping	5640	P to A	54.73	35.14	14.36	36.76	41.07
		A to P	0.00	31.23	18.45	33.57	28.60
Home-based social/recreational	2920	P to A	36.68	42.37	14.51	20.37	54.56
		A to P	3.83	57.65	15.58	21.11	16.67
Home-based other	5743	P to A	69.76	59.62	14.88	31.58	53.54
		A to P	37.08	39.45	17.51	31.30	22.52
Home-based non-work[1]	17824	P to A	71.64	63.36	14.48	29.03	53.08
		A to P	18.78	38.98	16.64	41.89	21.90
Non home-based	11656	P to A	65.45	48.37	23.66	38.10	35.95

[1] this is an aggregate category of all home-based purposes except work

2.4 Summary

This chapter described the development of factors to apportion the 24-hour PA matrix obtained after the trip distribution step into five discrete time periods: midnight – 7 AM, 7-9 AM, 9 AM – 3 PM, 3 – 6 PM, and 6 PM – midnight. These time-of-periods were determined based on the observed temporal profiles of the total travel volumes over the day. Factors are developed separately for rural and urban areas and for each of the trip purposes included in the FSUTMS framework (except truck/taxi, IE, EI, and EE trips) and for each direction (*i.e.*, P to A and A to P). In addition to the TOD factors, peak hour factors were also developed for each time-period to facilitate the creation of peak one-hour OD matrices for network assignment.

In the case of urban areas, factors were developed from travel survey data from different parts of Florida. Preliminary "reasonableness" assessment of the developed factors indicates that they fall within the typical values obtained from elsewhere in the country. However, it is also found that the TOD factors depend on whether or not sampling weights are used in the calculations. At the same time, it is not readily apparent that one of the approaches is necessarily better. Therefore, case-specific validation exercises are recommended for the determination of the appropriate factors to be used. Further, although the shape of the temporal profile of travel demand appears reasonably the same across the different regions in Florida (allowing us to use the same TOD periods for all regions in the state), the actual concentrations of travel during the different TOD periods appear to be significantly different. For example, the overall concentration of travel during the AM peak is significantly higher in the SE Florida region compared to the rest of the state and significantly lower in the Volusia County (again, compared to the rest of the state). Therefore, it is recommended that factors developed from local surveys be used. In the absence of such surveys, one may try to borrow the factors from another "similar" geographic area rather than relying on statewide generic factors.

In the context of rural regions, national-level survey data were used to develop the TOD factors due to lack of sufficient data at the state level.

CHAPTER 3. TOD TRANSIT MODELING WITH FSUTMS AND ITS IMPACTS ON NEW STARTS ANALYSIS

3.1 Introduction

This chapter is an attempt to investigate and recommend a TOD transit modeling procedure for the current FSUTMS framework and discuss the resulting improvements in FTA's New Starts analyses.

For the remainder, Section 3.2 gives a brief review on current transit modeling in FSUTMS, and Section 3.3 discusses the relevant issues of transit TOD modeling with FSUTMS. Section 3.4 proposes two TOD transit modeling procedures. Section 3.5 details FTA's New Starts requirements, followed by a discussion in Section 3.6 about the potential improvements resulted by the TOD modeling procedure in meeting these requirements.

3.2 Transit Modeling with FSUTMS

FSUTMS was initiated in 1978 upon the mainframe programs of Urban Transportation Planning System distributed by Federal Highway Administration (FHWA) and the Urban Mass Transit Administration (now FTA), and then was updated thoroughly around 1990s upon Tranplan. Currently, FSUTMS is under another major conversion to Cube Voyager distributed by Citilabs.

Below we provide an overview to the transit modeling in FSUTMS. Section 3.2.1 reviews and discusses the transit modeling procedure with Tranplan since at this point the majority of models in Florida are still based on Cube Tranplan. Certainly some discussions in Section 3.2.1 may not be relevant when the conversion to Cube Voyager is complete. Section 3.2.2 briefly describes the proposed FSUTMS/Voyager transit model based on the information available at the time when we drafted this report.

3.2.1 Transit Modeling with FSUTMS/Tranplan

FSUTMS/Tranplan consists of 15 modules shown in Table 3.1, among which TNET, TPATH, MODE, TASSIGN, TEVAL and TPLOT are transit related. The transit modeling process is illustrated in Figure 3.1 as well as the highway process (FDOT, 1997a).

FSUTMS/Tranplan offers three transit modeling processes: single-path, multi-path/single-period and multi-path/multi-period. The single-path process is appropriate for modeling local bus services with no variation in service for all day; the multi-path/single-period is applicable to the areas where multiple modes of transit exist during the peak period only; the last process is designed for multiple modes existing all day.

Table 3.1 FSUTMS modules

EXT	Develops external-external trips
GEN	Generates trips
HNET	Prepares highway networks
HPATH	Builds zone-to-zone highway paths
DISTRIB	Distributes trips
TNET	Prepares transit networks
TPATH	Builds zone-to-zone transit skim, path and fare matrices
MODE	Performs modal split, auto occupancy and combines trip purposes
HASSIGN	Assigns highway trips
TASSIGN	Assigns transit trips
HEVAL	Prepares highway evaluation reports
TEVAL	Prepares transit evaluation reports
EMIS	Estimates mobile source emissions
HPLOT	Prepares standard highway plots
TPLOT	Prepares standard transit plots

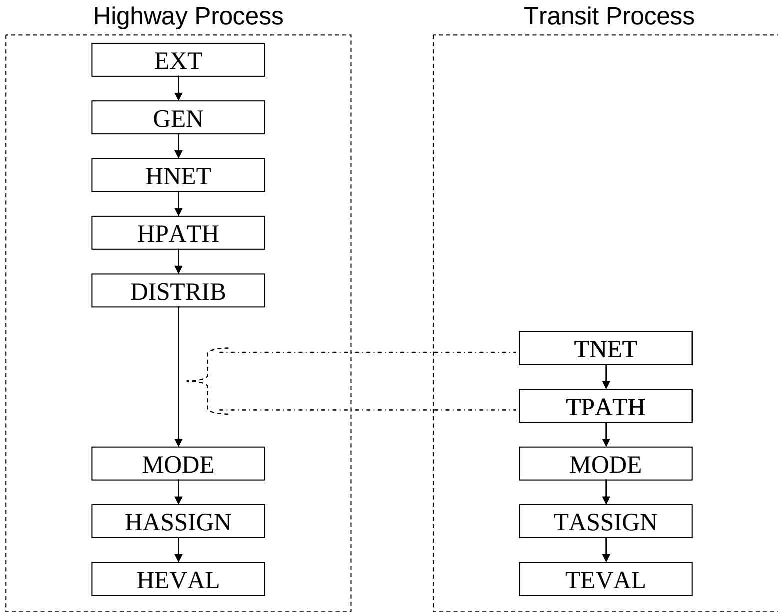

Figure 3.1 Transit and highway demand modeling processes (FDOT, 1997a)

Among the relevant modules shown in Table 3.1 and Figure 3.1, TNET aims at building transit network and summarizing transit network characteristics; TPATH generates transit skims for the MODE module, which conducts modal split, and is the key module to predict transit demand, and TASSIGN loads transit demand to transit lines to predict the ridership for each line.

More specifically, the TNET module is to build the transit network based on the input data. Transit travel times by time of day are one of the required inputs. In order to avoid the inconsistency between the transit network and the highway network, transit network characteristics are calculated based on the highway network properties. Area type, facility type and mode are all considered to define the operational characteristics of a transit line. The calculation includes travel speed, transit vehicle headway, the number of vehicles required for a particular line and vehicle capacity. For the multi-path options, transit networks will be built for the peak period and the off-peak period respectively, and various ways of accessing the transit line will be considered (FDOT, 1997b).

The TPATH module computes the minimum paths from all origin zones to all other zones in a transit network, and generates zone-to-zone transit level of service tables, such as travel time, transit fare and number of transfers with respect to the minimum paths. For the multi-path option, travel times for different access modes are calculated separately and transit fares vary among different transit types (FDOT, 1997c).

The MODE module performs modal split among auto and transit modes by applying multinomial logit or nested logit models. For the single path option, the choice model is for four mode (drive alone auto, 2 person carpool, 3+ personal carpool and local bus) with three purposes: home-based work (HBW), home-based other (HBO), and non-home-based (NHB). For the multi-path options, a variety of choice alternatives are created based on combinations of line haul and access/egress modes (FDOT, 1998a).

Finally, the TASSIGN module loads transit trip tables to transit networks and develops a loaded transit network database. For the single path option, a single transit trip table is loaded to a single transit network representing the situation of the entire day. For the multi-period option, two periods are usually considered: one represents a three-hour morning and three-hour afternoon peak period (AM) while the other represents all off-peak hours (MD or midday). Consequently, the HBW trips are assigned to the AM network while HBO and NHB trips are loaded to the MD network (FDOT, 1998b).

The following observations are relevant to the discussions of the TOD transit modeling with FSUTMS/Tranplan:

- Transit assignment in FSUTMS/Tranplan is tightly linked to the stage of mode choice, and the assignment is essentially a loading process without any route choice and equilibrium involved. The paths selected in the path building procedure are directly used for the loading purpose. Therefore, it is critical to maintain the consistency in the path building process between the stages of mode choice and transit assignment. First, the path parameters used for path selection and skimming should be consistent with those in the modal split models. Second, transit service and highway traffic characteristics by time of day should be consistent in the path building for mode choice and transit assignment.
- Considerations of TOD variations have been incorporated in the procedure to a certain extent. For example, in trip distribution, work trips are distributed with respect to peak-period accessibility measures and non-work trips with respect to off-peak measures. Similar treatments have been applied in mode choice and transit assignment. Such treatments do not accurately reflect actual travel conditions because many work trips occur during the off-peak period, and many non-work trips occur during the peak. Nevertheless, they are used frequently because of their simplicity.

- Most mode choice models are applied on a PA basis and output PA trip tables as well. Note that the choices of modes (auto or transit) and access/egress for P-A trips are usually the same for the return trips (A-P trips), particularly for auto access. In other words, the peak network is not symmetric. At the production end of a home-based transit trip, auto or walk access may be chosen while at the attraction end, only walk egress is possible. Therefore transit assignment is usually conducted in a PA format, rather than OD format. Consequently, one additional procedure is needed to modify assigned line volumes to be the correct values with the right directions.

3.2.2 Transit Modeling with FSUTMS/Voyager

As aforementioned, FSUTMS is experiencing a major conversion from Tranplan to Cube Voyager. In 2005, FDOT and the Florida Model Task Force agreed to develop a new transit modeling system for FSUTMS/Voyager. The new modeling system is expected to be different from its ancestor in a number of ways, particularly in the use of the public transportation (PT) moduel offered by Cube Voyager. Below we provide a short description on the proposed FSUTMS/Voyager transit modeling procedure (drawn from Schmitt, 2006).

Three alternatives have been proposed for transit modeling in FSUTMS/Voyager, namely PT multi-path, PT best-path and PT-TRNBULD hybrid. The first alternative uses PT as it was originally designed. PT is able to conduct transit network development, route enumeration, route evaluation, skimming, transit loading and crowd modeling. The module enumerates a set of attractive routes between zone pairs with the corresponding probabilities of use determined by the route evaluation function. Average skims are calculated by weighting each attractive route in accordance with its probability of use. Since the enumerated paths include transit segments, and access, egress, transfer and park and ride legs, the mode choice modeling structure of FSUTMS will be affected. More specifically, the mode choice model will not split trips among transit modes (e.g., local bus, express bus and rail etc). Instead, an aggregate transit mode with its average skim matrix could be incorporated into the mode choice models to determine the splits among drive alone, car-pool, transit, and other non-motorized modes.

The PT best-path alternative is to make use of the best-path option that Citilabs recently added to its multi-path path builder in PT. The option allows the multi-path path builder to select one single shortest path between two zones, mimicking the single-path builder used in

FSUTMS/Tranplan. Therefore, this alternative should maintain the current modeling structure of path building and mode choice. At the same time, the network coding and path-building procedures would remain in PT.

The third option is to use the PT to do network coding and another stand-alone module called as TRNBUILD to do the path building. Similarly, the current modeling structure of path building and mode choice is likely to be maintained.

At this point of time, the PT best-path alternative is preferred. This implies that the basic structure of transit modeling illustrated in Figure 3.1 will be maintained; network coding and path building will be handled by PT; the FORTRAN programs may continue to be used for mode choice or may be converted to Voyager scripts; the nested logit structure will still be used, reflecting the paths produced in path building; finally the transit assignment still follows the same methodology. Nevertheless, the new transit modeling system will differ in a number ways, such as determining access and transfer connectors, details of network coding, and path building etc (Schmitt, 2006).

3.3 TOD Transit Modeling with FSUTMS

FDOT has investigated the options to refine FSUTMS for the purpose of TOD demand modeling (Pendyala et al, 2002). The pros and cons of each option have been documented in Pendyala et al. (2002), Cambridge Systematics (1997) and Rossi (2002), and modelers may weight these pros and cons to determine which one to adopt based on specifics of their applications. In the following, we offer additional observations and discussions on the pros and cons of post-generation, distribution and split approaches. Issues may arise in the implementation of these approaches for transit modeling. These issues may be either unique from the standpoint of transit modeling or not so severe for highway modeling.

Overall

- As pointed out in the previous FDOT study (Pendyala et al, 2002), no approach is ideal or perfect, since all these are essentially marginal refinements within the framework of the trip-based four-step process. The process was created based upon a static daily-basis concept. More specifically, the notion of production and attraction is daily basis as well as the ways we predict trip production and attraction.

- TOD factors are usually introduced to the demand modeling as exogenous factors, determined from household travel survey data, on-board transit survey data and/or traffic data.
- The earlier TOD factors are introduced into the four-step process, the more detailed and accurate results can be expected, at the cost of more modeling efforts. In addition to their distinct drawbacks, the above procedures all suffer from inconsistency to some extent. Feedback mechanisms are needed to mitigate the inconsistency.

Post-generation approach

- FSUTMS adopts gravity model for trip distribution. Lacking a behavior sound mechanism, the gravity model is a forced analogy between social systems and physical systems and thus the aggregation level affects its accuracy. In other words, the more disaggregate level the model is applied at, the less accurate the results would be. As a consequence, the stability of calibrated parameters of the gravity model for each time of day over times or major changes is questionable. This may be another drawback of this approach in addition to the computational disadvantage.
- This approach makes the feedback-loop implementation more straightforward (peak times fed to peak distribution and mode choice) and gets away from the use of peak times for work trips, off-peak for non-work trips for trip distribution. Compared with the post-distribution approach, it requires more trip distribution runs (one for each period), but not more skims since the skims by time of day period are also needed for mode choice in the post-distribution approach.

Post-distribution approach

- The approach will lead to separate mode split models for different times of day, allowing for the variations in transit service throughout the day. Moreover, the consistency in transit path building between mode choice and transit assignment can be maintained.
- For each time period, additional attention should be paid to the transit path building for the A-P trips. It is possible the A-P trips use incorrect paths or even can not find a path. For example, if the P-A trip selects an auto-access-linehaul-walk-egress mode, and then the return A-P trip would use a walk-access-linehaul-auto-egress mode. However, it is

likely that a different path with auto access would be found for the return trip. Certainly the post-generation approach shares the same issue.

- In trip distribution, the peak times may be used for work trips and off-peak for non-work trips. A more realistic way is to compute a weighted average using the TOD factors and feed it to trip distribution.

The post-split approach:

- TOD factors may vary by travel mode. For example, transit trips tend to have a more concentrated AM peak than autos (Schimpeler-Corradino Associates, 1984). Therefore, the TOD factors used in the post-split approach may capture such characteristic. If TOD choice models are developed to calculate the TOD factors and explicitly consider peak spreading, the models can take into account the fullest range of variables, such as trip purpose, trip length as well as chosen mode.
- In a sense, the current transit modeling practice under FSUTMS is already a post-split TOD modeling with the assumption that all work trips occur during the peak period and all non-work trips during the off-peak peak period.
- If fixed TOD factors (e.g., those developed in Task 1) are applied, transit trips may be predicted for the zone pairs without off-peak transit services. For example, a zone pair has transit service during peak and no service otherwise. However, since work trips are split with respect to the peak-period measures, if multiplied by generic TOD factors, the off-peak trip table still contains a positive number of trips for that particular cell. This problem might be mitigated by using a logsum-type composite variable in the mode choice models, but this would significantly complicate the mode choice process (Pendyala et al, 2002). Another way is to develop TOD choice models with chosen mode and travel time as variables to determine the TOD factors for each zone pair. As a consequence, the transit off-peak TOD factor for the zone pair without off-peak transit service would be zero.
- Mode choice is done on a daily basis. For the multi-period process, this implies that work trips use the paths and skims from the peak-period network and non-work trips use the off-peak network. However, when applying TOD factors, work and non-work trips actually occur across the day, contradictory to the assumption made in the mode choice.

Moreover, since transit assignment is conducted in each time period, paths have to be built for the periods, creating a severe inconsistency in the path building process between mode choice and transit assignment.

Recommendation

- The post-generation, distribution and split approaches may be selected for transit TOD modeling. Modelers should weight the pros and cons of each approach to determine which one to adopt based on specifics of their applications.
- In areas with significant amounts of transit, the issue of path inconsistency may be severe, making the post-split approach unsuitable.
- The post-distribution approach has been recommended by FDOT based on the previous study (Pendyala et al, 2002).
- The post-generation approach is also worth considering, since it makes the feedback loop more straightforward and produces more accurate and detailed forecasts. Compared with the post-distribution approach, it requires not much more computation effort.

3.4 TOD Transit Modeling Procedures with FSUTMS

TOD modeling in transit demand forecast is critical because both the demand and the supply vary substantially by time of day. Below we recommend two TOD transit modeling procedures within the framework of FSUTMS. As per FDOT's recommendation, both procedures apply TOD factors after trip distribution. The first procedure is based on Tranplan since it is still used in Florida for transit modeling. The second procedure makes use of the PT module in Cube Voyager.

To facilitate the presentation, the procedures are described for a general case with multiple paths and periods. Assume that a day is split into four time periods: AM peak, mid-day, PM peak and night, and the trip purposes include HBW, HBO and NHB.

3.4.1 FSUTMS/Tranplan Procedure

Step 1: After trip distribution, obtain trip tables by time of day.

The factors are by time of day, by trip purpose and by direction (P-A and A-P for home-based trips), such as the ones presented in Table 2.4. Apply the directional TOD factors to obtain directional P-A and A-P trip tables for each time period. For a simplified analysis, apply the unidirectional TOD factors (summation of P-A and A-P factors of each time period) to obtain the TOD unidirectional trip tables in PA format.

Step 2: Build transit network.

Build transit network based on the characteristics of both the highway and transit systems for each time period.

Step 3: Build transit paths.

For a complete analysis, generate transit paths, transit skims, and transit fare matrices for all time periods for both directional P-A and A-P trip tables. Prohibiting bus-to-auto transfers when creating skims for home-based P-A trips. Since the home-end of a trip is the only end that can be allowed to have auto access, for home-based A-P trips one may permit bus-to-auto and prohibit auto-to-bus transfers in path building and then use the transpose of the resulting skim table for those A-P trips. To save time, one approximation may be applied that one set of skims will be generated for each time period for P-A trips and then the transposition of the skim table is directly used for the A-P trips without further conducting another path building.

A simplified procedure is to generate one set of skims for all trips at each time period, if there are only small percentages of A-P trips occurring at the AM period and P-A trips occurring at the PM period. In this case, essentially the A-P trips at the AM are treated the same as the P-A trips for path skimming and vise versa. Note that for the PM period, the transposition of the resulting skim tables should be used. The simplified analysis can be justified for off-peak periods as well when there is no much directional difference in the transit and highway systems and therefore the resulting skim tables are mostly symmetric.

Step 4: Mode choice.

For a complete analysis, mode choice may be conducted for home-based P-A and A-P trips respectively. There will be 20 scenario combinations (HBW P-A and A-P; HBO P-

A and A-P; NHB versus AM, Mid-day, PM and Night) where the trip tables will be split into different modes, say, local bus, line haul/walk access, line haul/auto access. Note that for the A-P trip, the egress mode for the home end is considered as the access mode in the mode choice models.

For a simplified analysis, mode choice will be conducted for all trips in a PA format and there will be 12 scenarios (HBW, HBO and NHB versus AM, Mid-day, PM and Night).

Step 5: Transit assignment.

For a complete analysis, transpose the resulting home-based directional A-P trip tables to obtain the OD tables. Load transit trips on the corresponding transit paths for four periods and three modes (local bus, line haul bus/walk access, line haul auto access).

For a simplified analysis, apply the directional splits to the unidirectional home-based trip tables by mode in a PA format, and then obtain the OD tables by adding the transposition of the resulting A-P tables to the P-A tables. Proceed to do the transit assignment.

Apply another peaking factor, defined as the ratio of peak-hour patronage to the peak-period patronage, to obtain the peak-hour ridership. The peaking factor is determined from on-board transit survey data or passenger counts data. If the volume of a line segment is greater than the maximum capacity, reduce the peaking factor to consider the peak spreading within the peak period and re-do the assignment until the capacity constraint is satisfied.

Step 6: Feedback.

If necessary, a feedback can be made to trip distribution to ensure consistency. For each trip purpose, weighted averages of travel time matrices obtained from the highway assignments for these four time periods can be computed and be fed back to the trip distribution models. Moreover, it is feasible to compute composite impedances using the modal splits, TOD factors and travel time matrices from both highway and transit assignments.

3.4.2 FSUTMS/Voyager Procedure

FSUTMS is in the process of conversion to Cube Voyager and transit modeling will be based on the PT module. As Section 3.2 described, at this time the PT best-path alternative is preferred, which implies that the current structure of transit modeling will be maintained. Consequently, the TOD modeling procedure in FSUTMS/Voyager would be very similar to the one proposed in Section 3.4.1.

In transit assignment, the crowding process offered in PT may be used to allow the transit capacity to influence the travel times, and then a link-based peak spreading procedure suggested in (Loudon et al, 1988) (also discussed in Cambridge Systematics, 1997) can be adopted to model the peak spreading within the peak period. The functional form for peak spreading model becomes:

$$P = 1/N + ae^{b(T_c/T_U)}$$

where: P = the peaking factor; N = the number of hours in the time period; a, b = model parameters to be calibrated; T_c/T_U = congested time divided by uncongested time. Note that the above procedure was originally developed for highway congestion. To use it for transit, the crowding process offered in PT must be implemented.

3.5 New Starts Program and Requirements

The Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) authorized a total of $52.6 billion for federal transit programs through 2009 to provide financial assistance to states and localities to develop, operate, and maintain transit systems. One of these programs, the New Starts program (http://www.fta.dot.gov/planning/newstarts/) provides funds to transit providers for constructing or extending certain types of mass transit systems. A full funding grant agreement establishes the terms and conditions for federal participation, including the maximum amount of federal funds available for the project, which by statute cannot exceed 80 percent of its estimated net cost. The grant agreement also defines a project’s scope, including the length of the system and the number of stations; its schedule, including the date when the system is expected to open for service, and its cost. To obtain a grant agreement, a project must first progress through a local or regional review of alternatives, develop preliminary engineering plans, and obtain FTA's approval for final design (General Accounting Office, 2005). More specifically, there are three phases in the New Starts project development process: alternative analysis, preliminary engineering and final design.

FTA evaluates each proposed project according to project justification and local financial commitment criteria, and rates the project on these criteria to develop an overall project rating using five-point descriptive indicators: high, medium-high, medium, medium-low and low, and then makes a decision for advancing the project in the New Starts project development process, and for recommending projects for funding. The project justification criteria includes: mobility improvements; environmental benefits; operating efficiencies; cost-effectiveness and public transit supportive land use policies and future patterns (all these have strong ties to travel forecasting) while the local financial commitment criteria are the proposed share of total project costs from sources other than the New Starts funding, the strength of the proposed capital funding plan; and the strength of the proposed operating funding plan (FTA, 2006a).

Of the project justification criteria, cost-effectiveness and land use are most important since FTA assigns a weight of 50 percent each and averages them to establish a summary project justification rating. When the average of the cost effectiveness and land use rating falls equally between two ratings, the mobility improvements rating may be introduced as a tiebreaker. If judged by FTA to be compelling enough, a rating for "other factors" may be further introduced after the assignment of an initial summary project justification rating. If the other factors rating is higher than the summary project justification rating, FTA may increase this initial summary justification rating by a maximum of one step (FTA, 2006a).

3.5.1 Cost-Effectiveness Measure

Cost effectiveness is defined as the incremental cost per hour of transportation user benefit. The incremental cost is the annualized incremental capital cost of the proposed project plus the incremental operating and maintenance cost of the transit system in the forecast year (currently 2030). The user benefit is defined as the equivalent hours of time savings resulted by the project for all users of the transportation system. Mathematically it is calculated as the change of the expected utility across all modes (logsum in the multinomial logit model) divided by the in-vehicle time coefficient in the utility function. Both incremental costs and user benefits are computed against a base alternative that represents the most cost-effective transit service possibly offered without a major guideway investment.

As per its definition, the cost-effectiveness measure takes into account all changes in mobility of all travelers, across all modes of travel, and is expressed in terms of hours of time saving. Therefore, the measure is supposed to capture all quantifiable benefits to travelers using the transit and highway system (FTA, 2006b). The value of the cost-effectiveness measure determines FTA's rating of cost effectiveness in a way as reported in Table 3.2.

Table 3.2 Cost-effectiveness breakpoints (FTA, 2006a)

Cost Effectiveness Rating	Cost Effectiveness Value
High	≤ $11.49
Medium-High	[$11.50, $14.99]
Medium	[$15.00, $22.99]
Medium-Low	[$23.00, $28.99]
Low	≥ $29.00

FTA derived the above breakpoints by giving some allowances to the value of travel time that accommodate unquantified benefits, such as highway congestion relief, economic development and all other indirect benefits. More specifically, USDOT specified the value of travel time as one-half of the median household income, which is $11.10 per hour in 2004. Therefore, if a project generates the user benefit as a cost less than $11.10, it is worth investing. In addition, allowances of 20 percent for congestion relief and 100 percent for indirect benefits yield $24.42. After adjusted by inflation, FTA rates the project as low that returns benefits at a cost of $29 (FTA, 2006b).

3.5.2 FTA's Other Perspectives on Travel Forecasting for New Starts

In addition to the general requirements, such as reasonableness of the methodology and consistency in the modeling procedures, some of FTA's perspectives on travel forecasting for New Starts (FTA, 2006b) are summarized as follows:

- In view of the fact that current models are not able to predict reliably the magnitudes and geographic locations of highway congestion relief benefits caused by a transit project, FTA evaluates New Starts projects with respect to transit user benefits only.
- FTA requires fixed person-trip tables for both the base and build alternatives even though a major guideway investment is likely to induce travel demands and cause changes in travel patterns. The considerations are that the associated benefits are modest and relatively few model sets in the U.S. readily support the calculation of that portion of benefit.
- FTA emphasizes the use of quality control tests to ensure reliable forecasts for proposed New Starts projects. For example, a parallel “quality control” forecast may be generated using methods that are in part independent of locally developed models, and then insights may be gained by comparing these two set of forecasts to adjust appropriately the original forecasts. FTA has recommended a “quality control” forecasting approach (FTA, 2006a), which relies on the “best” walk-access paths and the “best” auto-access paths built by using FTA’s specified weights, and uses an FTA-specified incremental-logit model to predict ridership changes and user benefits for the build alternative.

3.6 Impacts of TOD Modeling on the New Starts Analysis

Generally speaking, TOD transit modeling provides the new starts analysis more accurate forecasts and enables more detailed reporting of forecasts, which may offer opportunities for understanding and refining the project, or making a better case for the project.

Specifically, one of the direct impacts of TOD transit modeling is to compute cost effectiveness, the most important measure for the New Starts analysis. This can be demonstrated by the following example: assume that there are 100 trips (P-A and A-P) between a zone pair connected by two transportation mode: auto and transit. Among these daily trips, 45%, 20% and 35% occur in the AM peak, off-peak, and PM peak periods respectively. The network is symmetric for P-A and A-P trips and the in-vehicle time (IVT in minute), out-of-vehicles time (OVT in minute) and costs (cent) for the base and build alternatives are reported in Table 3.3. A binary logit model is used to describe mode choice, and the coefficients associated with IVT, OVT and cost are -0.02, -0.05, and -0.003 respectively and the mode specific constant for transit is -0.5.

Table 3.3 presents the resulting user benefit in minute for each time period. In the calculation, the price in IVT is computed as $p = \ln\left(e^{U_{auto}} + e^{U_{transit}}\right)/\theta_{IVT}$, and the benefit is equal to the difference of the prices in IVT between the base and build alternatives times the number of trips occurring during the time period. From Table 3.3, it can be seen that the resulting user benefit is 25.605, 16.434 and 19.915 minutes for the AM peak, off-peak and PM peak respectively. The total daily benefit is the sum of the benefits for the three time periods, which is 61.954 minutes. The daily value of price in IVT is also reported in Table 3.3, calculated as the weighted average of the prices in IVT for the three periods. The weighing factors are the TOD factors.

Table 3.3 Benefit calculation using TOD values

	AM				Off-peak			
	Base		Build		Base		Build	
	Auto	Transit	Auto	Transit	Auto	Transit	Auto	Transit
IVT	20.0	40.0	21.0	30.0	15.0	25.0	15.0	22.0
OVT	3.0	30.0	3.0	30.0	2.0	15.0	2.0	15.0
Cost	240.0	125.0	240.0	125.0	240.0	125.0	240.0	125.0
Logsum	-1.131		-1.120		-0.808		-0.792	
Price in IVT	56.563		55.994		40.404		39.582	
Benefit	25.605				16.434			
	PM				Daily			
	Base		Build		Base		Build	
	Auto	Transit	Auto	Transit				
IVT	25.0	45.0	26.0	35.0				
OVT	3.0	30.0	3.0	30.0				
Costt	240.0	125.0	240.0	125.0				
Logsum	-1.231		-1.220					
Price in IVT	61.563		60.994		55.081		54.462	
Benefit	19.915				61.954			

Table 3.4 reports the user benefit if daily level of service characteristics are used. The IVT, OVT and cost in Table 3.4 are the weighted averages of the values in Table 3.3, representing the forecasts given by a daily-basis demand model. The total daily benefit is calculated as 73.999 minutes, 19.44% more than the sum of the benefits by time of day. In other words, the daily basis modeling overestimates the user benefit by 19.44% for this particular example.

It should be pointed out that daily-basis modeling does not always overestimate the user benefit. To see this, check the equation of the price in IVT: $p = \ln\left(\sum_{\text{mode}} e^{U_i}\right) \Big/ \theta_{IVT}$. The price in IVT is a concave function with respect to the level of service characteristics (Sheffi, 1985). Assume that daily-basis modeling is able to produce a forecast that is the weighted average of the forecasts made by the TOD modeling, the daily-basis approach will always overestimate the price in IVT because $f\left(\alpha x + (1-\alpha) y\right) \geq \alpha \cdot f\left(x\right) + (1-\alpha) \cdot f\left(y\right)$ holds for a concave function $f\left(\cdot\right)$. Therefore, it is consequential to observe that in the above example, the prices in IVT given by the daily modeling (55.552 and 54.812 respectively) are greater than the TOD modeling values (55.081 and 54.462 respectively). However, the user benefit is the difference of the prices between the base and build alternatives times the number of trips, and the difference between two overestimates is not necessarily an overestimate. Depending on the patterns of differences of system conditions across different time periods, the user benefit could be either overestimated or underestimated by the daily-basis modeling approach.

Table 3.4 Benefit calculation using daily values

	Base		Build	
	Auto	Transit	Auto	Transit
IVT	20.8	38.8	21.6	30.2
OVT	2.8	27.0	2.8	27.0
Cost	240.0	125.0	240.0	125.0
Logsum	-1.111		-1.096	
Price in IVT	55.552		54.812	
Benefit	73.999			

In summary, the procedures recommended in this report may be implemented to provide more accurate and detailed forecasts to the New Starts analysis and improve the calculation of project justification criteria.

Some implementation issues may be encountered when using the PT module of Cube Voyager. For example, the current multi-path path builder in PT is not able to provide information required by FTA’s program “Summit” for quality control tests and benefit computation, and some path-building feature in PT may lead to strange user benefit results (FDOT, 2006).

CHAPTER 4. MODELING HIGH-OCCUPANCY/TOLL LANES IN FSUTMS

4.1 Introduction

This chapter examines methods to incorporate analysis of HOT lanes within the FSUTMS framework. The rest of this chapter is organized as follows: Section 4.2 presents a background on toll roads in the US whereas Section 4.3 reviews the development of HOT lanes. Subsequently, the next two sections examine the modeling of toll lanes. Section 4.6 presents methods to incorporate modeling of toll lanes within FSUTMS. This chapter concludes with a discussion on procedures to determine optimum tolls.

4.2 Background on Toll Roads

Toll roads first appeared in the U.S. in the late 18th century, when private investors constructed and maintained the roads, and then charged motorists for using them. Their primary goal was to maximize profits (Hranac, 2006). Some studies show that even in the first half of the 19th century, private toll roads still outnumbered public roads. The construction of toll roads declined since 1956, since the Federal Highway Act established a federal gasoline tax to support the interstate highway system and prohibited tolling on new, federally-funded highways (Parsons Brinckerhoff, 2002). Recently, road pricing has resurged as an outcome of the Intermodal Surface Transportation Efficiency Act of 1991 and the National Highway System Destination Act of 1995 that allowed the use of federal-aid highway funding for toll facility. In May 2006, USDOT launched a new national congestion relief initiative that promotes congestion pricing and variable tolling (USDOT, 2006). In addition to tolling on individual facilities, USDOT is partnering with five metropolitan areas (Miami, Minneapolis Area, New York City, San Francisco and Seattle Area) to implement and demonstrate system-wide congestion pricing.

As one of the most prevalent forms of road pricing, HOT lanes have attracted more and more attention since the opening of the State Route 91 Value-Priced Express Lanes in Orange County in December 1995. HOT lanes refer to HOV facilities that allow low-occupancy vehicles to pay to gain access to the lanes. HOT lanes were first advocated from the perspective of congestion pricing and can be viewed as the first step for more widespread pricing of congested roads (Dahlgren, 1999). Later on, concern over the efficiency of HOV lanes becomes a new impetus for implementing HOT lanes. Although studies have demonstrated the benefits of HOV lanes in terms of air pollution, fuel consumption, and bus service efficiency, there are always doubts whether a HOV lane can generate greater benefit than a general-purpose (GP) lane. For example, by constructing and analyzing a simple model concerning person-delay and emissions, Dahlgren (1995) concluded that HOV lanes are not preferable in many circumstances. Dahlgren (2002) further investigated when to implement HOT, HOV and GP lanes, and suggested that HOT lane seemed to perform as well as or better than an HOV lane in any circumstance. In other words, HOT lanes may offer a win-win solution to the issue of under-utilization of HOV lanes.

The advantages of HOT lanes can be generally summarized as follows (Li, 2001; Ensor, 2006):

- HOT lanes are a market-based solution for congestion mitigation, in which users can make flexible choices according to specific conditions;
- HOT lanes may not price off road users, compared with the strategies of pricing the whole road;
- HOT lanes generate greater overall throughput by increasing the utilization of HOV lanes and reducing congestion on the GP Lanes;
- HOT lanes can create revenues, which can be used for further investment.

4.3 The Implementation of HOT lanes in the U.S.

Currently, there are five HOT lanes (more precisely, managed lanes) in operations across the country.

4.3.1 State Route 91 Express Lanes - Orange County

The State Route 91 express lanes opened in December 1995 as a four-lane toll facility in the median of one of the most congested highways in the U.S. Variable tolls are set in different times of day to ensure that the toll lanes are operated under free-flow traffic conditions. The latest toll schedule since August 2005 provides different price levels between \$1.10 and \$7.75 for traveling through this 10-mile facility. Initially, the HOV 3+ vehicles were allowed to travel free, while since May 2003, they are also charged half of the toll to use the facility (FHWA, 2006a).

Since its opening, daily traffic volume on the tolled lanes has been growing steadily. During the fiscal year of 2006, the facility served over 12.7 million vehicles, averagely 35,000 vehicles per day (FHWA, 2006a). Due to the traffic diverted into the toll lanes, traffic conditions in the GP lanes during the peak periods have been improved significantly, with the average delay falling from 30-40 minutes to 5-10 minutes (The ITE Task Force, 1998).

4.3.2 I-15 HOV Lanes - San Diego

San Diego's HOT lanes were first open to traffic in December 1996, when solo drivers needed to purchase a monthly permit with unlimited use of HOV lanes in the month. Then in March 1998, a value pricing program was implemented and single-occupancy vehicles (SOVs) need to pay a toll each time they use the HOV lanes. Toll rates may vary from 50 cents to $4 per trip in order to maintain a level of service C for the HOV lanes. The tolls would fluctuate in response to the changing traffic conditions in the HOV lanes (The ITE Task Force, 1998; FHWA, 2006a).

During its opening year, the average daily traffic on HOV lanes increased by 18% from 11,700 vehicles/day to 13,838 vehicles/day (Hultgren and Kawada, 1999). Currently, 75 percent of the weekday daily traffic using the HOT lanes is HOVs with two or more occupants, and 25 percent are paying SOVs (FHWA, 2006a).

A telephone survey of 1,500 commuters, including 500 HOT lane users was carried out in Sept/Oct 1997. The results showed that 89 percent of the participants thought that the program is a success, and another finding is that equity is not a major obstacle to implementing pricing on HOV lanes in the San Diego region (The ITE Task Force, 1998).

4.3.3 The QuickRide Program - Houston

The QuickRide program refers to two radial corridors in Houston, I-10 and US 290. The program was first implemented on existing HOV lanes of I-10 (known as Katy Freeway) in January 1998, allowing a limited number of travelers in two-person carpools to use the HOV lanes during the peak periods for a toll of $2.00, while HOV3+ vehicles continued to use the lanes for free. SOVs are not allowed to use the HOV lanes. In November 2000, this program was expanded to US 290 (Northwest Freeway) HOV lanes. Because the Northwest Freeway HOV lanes were not as congested in afternoon peak period, QuickRide was only implemented during the morning peak period, and all HOV2+ vehicles continued to use the lane for free during afternoon peak (FHWA, 2006a; Burris, 2003).

The average QuickRide demand on the I-10 HOT lane in 1998 was 103 trips per day, and after the introduction of QuickRide on US 290, the average demand on both HOT lanes rose to 131 trips per day in 2000 and 182 trips per day in 2002, significantly below the expected 600 QuickRide vehicles per peak hour. Results from survey on the I-10 HOT lanes indicated that the main source of the participants were those who used to travel in SOVs on regular lanes (FHWA, 2006a).

4.3.4 I-394 MnPass Lanes - Minneapolis

The MnPass program was initiated in May 2005, which converted the HOV lanes on I-394 into HOT lanes. These lanes are free to HOVs and motorcyclists during peak hours while SOVs are charged to use the lanes. The toll rates vary from $0.25 to $4.00, adjusted as often as every three minutes based on the detected traffic density in order to maintain a free-flow travel speed. When a change in the detected density occurs, the rate is adjusted upward or downward, determined from a "look-up" table (Halvorson et al., 2006). A comprehensive evaluation plan is being implemented to thoroughly assess conditions and public attitudes before and during the project operations (FHWA, 2006a). Preliminary performance data of this new facility were obtained for the first six months: the average number of toll trips per week is around 15,918 and the average revenue per week is around $12,484 (FHWA, 2006a).

4.3.5 HOT Lanes on I-25/US-36 - Denver

The facility was recently opened in June 2006, which consists of seven miles of I-25 HOV lanes, between Downtown Denver and US-36. No tolls are charged to carpools, motorcycles, or buses. Only SOVs are required to pay a toll each time they enter the HOT lanes. The toll rates also vary by time of day, ranging from 50 cents to $3.25 per trip (FHWA, 2006a). During its second month of operation, 31,467 vehicles paid a toll and approximately $63,000 in toll revenue was collected, which is a 46% increase in usage from the first month of operation with 21,551 toll-paying vehicles using the facility in June (CDOT, 2006).

In additional to the programs that are currently in operations, more projects are now in planning or under study. The quarterly report (April-June 2006) on federal funded road pricing projects lists a total of 59 projects across the country, nine of which involve converting HOV to HOT lanes (FHWA, 2006b).

4.4 State-of-the-Practice Toll Modeling

The proliferation of HOT lanes has imposed a pressing need to enhance travel demand models to assess more accurately their impacts in time and space. More specifically, three aspects may need to be considered (Vovsha et al, 2005):

- Motorists' perception and response to pricing;
- Improvement of level of service, featured by changes in travel time, delay, traffic volume, travel costs, reliability, driving conditions, accessibility etc;
- Delay due to toll collection, which, however, may hardly be an issue when electronic toll collection is implemented.

4.4.1 Modeling Approaches

Many studies have been conducted on modeling techniques for different pricing strategies. There is no consensus as to the best technique for developing traffic forecasts for tolling facilities. By reviewing the practices of value pricing projects, four modeling procedures can be identified:

1) ***Activity-based models*** assume that travel is derived in a general framework of the everyday activities undertaken by households and individuals, including in-home activities, intra-household interactions and time allocation to activities, etc. Price or cost is included explicitly into the daily decision hierarchy. The models show promise for analyzing pricing policies in an integrated way, although they are much more complex than the traditional four-step modeling procedure. To date, this type of model has been applied to only one analysis of value pricing in Portland, Oregon. (Vovsha et al, 2005).

2) *Modal split procedures* are supposed to be the easiest way to implement with current travel modeling software and have been most often used to evaluate the impacts of converting HOV lanes into HOT lanes (Spear, 2005). In the models, auto trips on a tolled or non-tolled road are considered as distinct modes and multinomial logit models are then used for mode choice. Such an approach was used to analyze “MnPASS” HOT lanes system (Kriger, 2005).

The primary advantage of using this procedure is its convenience since tolls can be easily included as another variable in the utility functions of travel modes. The primary drawback is that treating the tolled road as a separate mode can be hardly justified since it is an integral part of the road network and the assumption of independence of irrelevant alternatives associated with multinomial logit models may be severely violated.

3) *Trip assignment procedures* are used to model route choice decisions. Both deterministic and stochastic assignments can be applied. The former translates the toll into a time-equivalent, through the value of time (VOT), and then incorporates it into the link performance functions to assign trips across the network. The latter may be a logit-based or probit-based stochastic traffic assignment that essentially calculates the probability of using a tolled facility as a function of the relative cost/disutility between the tolled and non-tolled routes.

The primary benefit of modeling toll roads in trip assignment is the ability to evaluate the influence of traffic congestion on demand for the toll facility. However, since different users have different VOTs, in order to be more accurate, multi-class trip assignment models need to be used.

4) *Post processor* first calculates the market share of motorists who would use a toll facility under certain toll charge, and then uses a separate procedure to divert the calculated volume into toll lanes (Kriger, 2005; Spear, 2005). This procedure was applied in Washington D.C. and San Diego, California. In the approach, at least two alternative paths need to be developed: one using the toll route and the other using the best available non-toll route, and then diversion formulae are used to assign a percentage of the motorists to each route (Spear, 2005).

Essentially, the post processor is a simplified stochastic loading procedure. The primary benefit is that the processor can be applied without modifying or recalibrating the existing four-step model while it may only capture part of the impacts that pricing may impose and the results are likely inaccurate.

4.4.2 Four-Step Modeling Procedure

We can see from above that the state-of-the-practice of modeling HOT in travel demand forecasting still largely remains in the realm of the four-step transportation demand modeling arena. Pendyala (2005) examined each step of the procedure to see whether the current travel demand modeling methodologies would be able to accurately predict travel behaviors under a pricing scenario even if the inputs were perfectly accurate.

Trip Generation procedures mainly rely on regression equations to estimate productions and attractions in different traffic analysis zones. Though trip generation models are generally sensitive to socio-economic and demographic characteristics, they are rarely sensitive to spatial-temporal accessibility and travel times/costs. However, with a pricing policy, at least travel time and travel cost would change, which will likely influence trip production and attraction. *Trip Distribution* models are mostly gravity models, sensitive to zonal productions, attractions and also inter-zonal impedances. Since generalized cost functions are used to represent impedances, it is plausible to expect trip distribution models to reflect the impacts of pricing policies. *Modal Split* models rely on multinomial or nested logit models to reflect mode choice behaviors. Since most model split models incorporate the attributes of time and cost on different types of travelers and trips, it's possible to reflect mode shift behavior due to pricing strategies. *Network Assignment* generally uses static equilibrium models, which are sensitive to link impedance. In response to pricing policies, travelers may shift to lower priced routes even if there is no change in destination and mode, and network-wide redistribution of traffic may occur. However, these static models can not accurately replicate route choice behavior in the event of dynamic or time of day value pricing.

In summary, the traditional four-step travel demand modeling procedures, to some extent, can accommodate different pricing policies. There are a lot of elements that potentially lead traditional procedures to offer erroneous forecasts. For example, due to its trip-based nature, the modeling process is not able to capture and reflect the inter-dependency among trips that are linked in chains. As Pendyala (2005) pointed out, these shortcomings are not unique to analysis of pricing policies, but also other problems like current and emerging policy issues, mobility options, and modal technologies.

4.5 Other Issues in Toll Modeling

4.5.1 Optimal Tolls

Generally speaking, the optimal tolls should reflect the operation objectives of the tolling projects, which may include maximizing revenue, throughput, or social welfare. The current operating policies (FHWA, 2003) of HOT lanes are to provide a superior free-flow traffic service on the HOT lanes while maximizing the throughput rate of the freeway (i.e., the combined throughput of both GP and HOT lanes). Note that between these two objectives, the operators often give higher priority to the former, because the HOT lanes are designed “first and foremost to provide less congested conditions for carpoolers and transit users” (Munnich, 2006).

As aforementioned, in practice, several transportation authorities price their HOT lanes dynamically. For example, the base price for I-15 HOT lanes in San Diego varies from $0.50 to $4.00 depending on time of day. Moreover, the price can be adjusted real time in response to the traffic condition. When traffic congestion is high, the toll price can be as high as $8.00. In Minnesota, the toll rates for I-394 HOT lanes can be adjusted as often as every three minutes. Similar to the I-15, the toll price on I-394 varies from $0.25 to $4.00. The rate can be adjusted based on the detected traffic density in order to maintain a free-flow travel speed. When a change in the detected density occurs, the rate is adjusted upward or downward, determined from a “look-up” table (Halvorson et al., 2006). The table was created based on static traffic assignment models and assumptions regarding travel demands and value of time. The utilization of the HOT lanes did increase after the implementation of dynamic tolling. However, the increase is not at the fullest extent possible.

Pricing strategies in practice are simple and heuristic. The literature does not offer a practical and sensible approach for determining dynamic toll rates for HOT lanes. Previous studies (see, e.g., Arnott et al., 1998; Chu, 1995; Liu and McDonald, 1999; Yang and Huang, 1997) have examined time-varying tolls for bottlenecks. However, most, if not all, of these papers consider hypothetical and idealized situations in which analytical solutions can be derived. For example, the travel demand function or travel demand is usually assumed to be known. In contrast, without making any restrictive assumption, Yin and Lou (2006) proposed two readily-implementable approaches for determining time-varying tolls in response to the detected traffic arrival. The first approach adjusts the toll rate based on the concept of the feedback control, while the second approach would 'learn' in a sequential fashion motorists' willingness to pay and then determine pricing strategies to explicitly achieve the operating objectives.

4.5.2 Forecasting Errors

Previous studies show that there are persistent forecasting errors in revenue and traffic volume. In addition to deficiencies in the four-step modeling procedure as previously discussed, there are numerous other factors that contribute to the errors (Ash, 2004). In the following, we examine two of these factors.

4.5.2.1 VOT

Travel demand models should capture and reflect travelers' attitudes and responses towards pricing policies. Therefore incorporating users' willingness to pay or VOT is very essential in demand modeling, and VOT has a large influence on the modeling accuracy. According to Zmud (2005), Fitch Ratings calls VOT the "X-factor of toll road forecasting." Standard & Poor's identifies the miscalculation of users' willingness to pay as a "key error driver in forecast failures." Both agencies suggest that VOT errors are resulted from using a single average VOT instead of a distribution of values of time.

VOT can be defined as the marginal rate of substitution of travel time for cost in users' utility function that represents the relative desirability of the available alternatives (Brownstone and Small, 2005). Consequently, many previous studies have applied discrete choice models and estimated VOTs using traveler survey data (Brownstone, 2003). Therefore survey design is critical to capturing the real-world VOT. The data from which VOT estimates are derived must represent the population of inference. Another issue is that we should be cautious with using VOT estimates from another regions or previous projects, because the specific geographic, political, and environmental contexts in which users or potential users were being asked will affect their VOTs (Zmud, 2005; Spear, 2005).

4.5.2.2 Reliability

There is more and more compelling evidence that users' willingness to pay is not simply related to individual VOT, but many other factors, among which the improved reliability of a toll road has been considered as important as time savings (Vovsha et al., 2005). Value of reliability (VOR) can be defined as the marginal rate of substitution of variability of travel time for cost in users' utility function. Lam and Small (2001) measured VOT and VOR from the data on actual behavior of commuters on State Route 91 in Orange County, California, and their most trustworthy model produced a VOT of $22.87 per hour and VOR of $15.12 per hour for men and $31.91 per hour for women.

Unfortunately there are few examples of operational travel demand models that explicitly include reliability as a variable. Significant enhancements are needed to enable the current static modeling framework to predict changes in variability of travel time caused by pricing policies.

4.6 Modeling HOT Lanes in FSUTMS

4.6.1 Modeling Approach

Two approaches are generally applicable in FSUTMS to model HOT lanes: the modal-split and trip-assignment approaches. The former treats auto-trips on a toll facility as a distinct mode and then applies a nested logit model and a subsequent loading procedure to estimate the flows while the latter incorporates tolls into the generalized cost functions for route choice and then allocates trips among different paths using the notion of deterministic or stochastic user equilibrium. As aforementioned, both approaches have pros and cons and modelers may weight these pros and cons to determine which one to adopt based on specifics of their applications. However, the trip-assignment approach may be more preferable based on the following considerations:

- In the modal-split approach, the paths with and without using toll facilities generated from path building are very likely to have many shared links/segments, particularly when and where toll facilities are not prevalent. These shared links/segments will lead to biased estimates of modal splits due to the independence from irrelevant alternative property of multinomial logit models. It would be cumbersome to overcome this shortcoming within the current modeling structure.
- In the modal-split approach, the sequential trip assignment for the toll mode is essentially a traffic loading procedure without considering user equilibrium. Iterations need to be performed until a consistency or equilibration is reached for the travel times used in mode choice and those resulted in trip assignment respectively. Such iteration is time

consuming and the consistency may never be reached. It seems not wise to create another inconsistency (in addition to the existing inconsistency between trip assignment and modal split), if we can avoid it in the first place by using the trip-assignment approach. Moreover, the values of time in mode choice models are almost always low (on the order of $2 to $5 per hour) compared to those used in toll diversion models or the trip-assignment approach.

- For the trip-assignment approach, a multiclass stochastic user equilibrium assignment model is preferred where different VOTs may be used for classes with different trip purposes and income. Ideally, to address the issue of overlapping paths, more advanced models or techniques can be adopted, such as the C-Logit model by Cascetta et al. (1996) and the subnetwork technique by Frejinger and Bierlaire (2007). These approaches, the C-Logit model in particular, are easy to implement and can be incorporated into the current modeling framework.

4.6.2 Modeling Procedure with FSUTMS

Below we propose a practical procedure to model HOT lanes within the TOD framework of FSUTMS. As per FDOT's recommendation, the procedure adopts the post-distribution TOD modeling approach.

To facilitate the presentation, we assume that the TOD factors calculated in Chapter 2 are used, and a day is split into four time periods: AM peak, mid-day, PM peak and night, and the trip purposes include HBW, HBO and NHB.

Step 1: Highway network building.

Code the HOT lanes as separate links and specify the associated toll rates for each time period (toll rates to be discussed in Section 4.7).

Step 2: After trip distribution, obtain trip tables by time of day.

The factors are by time of day, by trip purpose and by direction (P-A and A-P for home-based trips). Apply the directional TOD factors to obtain directional P-A and A-P trip tables for each time period.

Step 3: Mode choice.

Determine modal split for each combination of time period and trip purpose. SOV and shared ride (HOV2 and HOV3+) may be considered in the hierarchy of auto trips.

Step 4: Trip assignment.

Use VOTs to translate the tolls into time-equivalents and then incorporates them into link performance functions. Because willingness to pay is sensitive to variables such as trip purpose and income, VOT should be determined by trip purpose and income. However, VOT is known to vary even among travelers with the same incomes and trip purposes, therefore, if sufficient empirical data exist, additional segmentation can be further made. Conduct an iterative multi-class assignment to assign the low-occupancy HBW, HBO and NHB trips to the network. If average income of the production end, in addition to trip purpose, is used to classify VOT, directional P-A and transposed A-P trip tables should be assigned separately for the home-based trips.

Step 5: Feedback.

If necessary, a feedback can be made to trip distribution to ensure consistency. For each trip purpose, weighted averages of travel time matrices obtained from the highway assignments for these four time periods can be computed and be fed back to the trip distribution models. Moreover, it is feasible to compute composite impedances using the modal splits, TOD factors and travel time (plus toll) matrices from both highway and transit assignments.

4.7 Determination of Tolls

Determination of tolls is another important practice for modeling HOT lanes. Ideally toll rates should vary dynamically and proactively in order to achieve the operating objectives of HOT lanes. In practice, several HOT lanes are priced dynamically, such as I-15 HOT lanes in San Diego and I-394 in Minnesota. Theoretically, the pricing strategies can be determined by combining principles from the static network models with concepts from (analytical) dynamic traffic assignment (DTA). Results on DTA are substantial since Merchant and Nemhauser (1978a, b) (see, e.g., Ran and Boyce, 1996; Peeta and Ziliaskopoulos, 2001; Yin et al., 2004 and references cited therein). However, because of their extremely large size, existing DTA models are often intractable in determination of meaningful pricing strategies, especially those that are second best. Moreover, for the planning and policy analysis purpose, details of traffic dynamics should not be a major concern. Therefore, in the planning stage, we recommend treating traffic in each individual time period as static and determine fixed optimal toll rates accordingly for the time of day. Those TOD optimal tolls may serve as the base toll schedule and tolls may be adjusted marginally in response to the changing traffic conditions. Design of such real-time pricing strategies should be a concern in the stage of traffic operation analysis, as the one proposed by Yin and Lou (2006).

4.7.1 Theoretical Model

The current operating policies (FHWA, 2003) of HOT lanes are to provide a superior free-flow traffic service on the HOT lanes while maximizing the throughput rate of the freeway (i.e., the combined throughput of both GP and HOT lanes). Under a static modeling framework, the objectives are approximately equivalent to operating the HOT lane at a throughput close to its capacity while keeping it from being congested, more specifically, maintaining the volume-capacity ratio close to a certain level, say, 0.80.

For each time period, optimal link tolls can be determined for solving the following bi-level programming model:

$$\text{Min} \quad \sum_{a\in\bar{A}} \left(v_a / c_a - \eta_a\right)^2$$

$$\text{s.t.} \quad \tau_a^{\min} \le \tau_a \le \tau_a^{\max}, \ \forall a \in \bar{A}$$

where $v_a, a \in A$ is obtained by solving the following program:

$$\min \quad \sum_{a\in A} \int_0^{v_a} \left(t_a(\varpi) + \tau_a\right) d\varpi$$

$$\text{s.t.} \quad v_a = \sum_{w\in W} \sum_{r\in R_w} \delta_{ar} f_r, \qquad \forall a \in A,$$

$$\sum_{r\in R_w} f_r = d_w, \qquad \forall\, w \in W,$$

$$f_r \ge 0, \qquad \forall\, r.$$

In the upper-level problem, v_a and c_a are the flow and capacity of link *a*; $\bar{A}$ is the set of tolled links in the network; η_a is the targeted volume-capacity ratio; $\tau_a^{\min}$ and $\tau_a^{\max}$ are the minimal and maximum allowable charges on link *a*, respectively and τ_a is the link toll to be determined. In the lower-level problem, t_a is the link travel time given by the link performance function; *W* denotes the set of OD pairs, and *A* is set of all links; d_w represents the travel demand for OD pair *w*; R_w is the set of all routes between OD pair $w \in W$, δ_{ar} indicates (0 or 1) whether route *r* uses link $a \in A$, and f_r is the amount of flow on route *r*.

In the above bi-level programming model, the upper-level problem represents decision makers' behavior of setting up optimal tolls to achieve the targeted volume-capacity ratios while the lower-level problem is a tolled user equilibrium assignment, representing the users' response to the tolls. The bi-level problem can be efficiently solved using existing algorithms in the literature (e.g., Chiou, 2005).

4.7.2 Heuristic Procedure

An iterative procedure can be developed and implemented in FSUTMS to determine optimal TOD tolls. The procedure essentially solves the bi-level optimal toll problem in a heuristic way. For example, the sequential simplex method (Nelder and Mead, 1965) or the Golden Section method can be adopted in the iterative procedure to seek for optimal tolls. At each iteration, the assignment procedure proposed in Section 4.6 is used to evaluate the performance of the HOT lane. A script can be developed to automate the above solution process.

The feasible region of the toll rate can be specified by examining current HOT lanes across the country. As shown in Table 4.1, tolls may vary from $0.06 to $0.85 per mile depending on the congestion level.

Table 4.1 Toll rates of HOT lanes

	Toll	Facility length	Toll rate per mile
State Route 91 express lanes	$1.15 to $8.50	10-mile	$0.115 to $0.85
I-15 HOV lanes	50 cents to $4	8-mile	$0.06 to $0.5
Houston QuickRide program	$2	13-mile	$0.15
I-394 MnPass lanes	$1 to $4 maximum $8	11-mile	$0.09 to $0.73
HOT lanes on I-25/US-36	50 cents to $3.25	7-mile	$0.07 to $0.46

CHAPTER 5. APPLICATION OF TOD MODELING FOR PEAK-SPREADING ANALYSIS

5.1 Introduction

Within the overall scope of the project, this chapter describes the application of TOD modeling procedures for peak spreading analysis. The rest of this chapter is organized as follows. Section 5.2 defines peak spreading. Section 5.3 examines conceptual approaches to incorporating peak spreading within the FSUTMS framework. Finally, Section 5.4 presents a summary of the discussion and identifies the key findings.

5.2 The Concept of Peak Spreading

The phenomenon of "peak spreading" may be broadly described as an overall increase in the duration of day during which the transportation system is congested. The effect of this phenomenon is a lengthening and flattening of the "peaks" of the temporal profile of travel demand (see Figure 5.1).

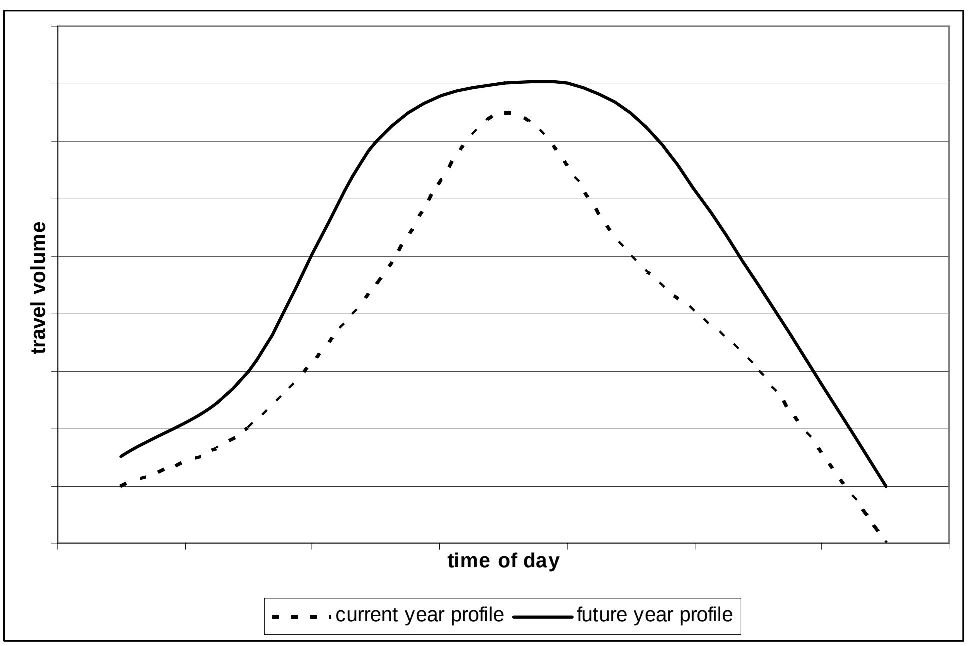

Figure 5.1 Schematic illustration of peak spreading (Barnes, 1998)

Peak spreading results because of two factors. First, increasing total travel demand and non availability of adequate roadway capacity may result in longer travel times and hence increased time-periods of the day when the roadways are congested. This is also referred to as "passive peak spreading" (Barnes, 1998). Failure to capture this may result in over-assignment of trips to certain links during specific periods of the day (*i.e.,* the flow predicted exceeds the physical capacity of the link). Second, travelers may consciously switch their TOD of trip making to less-congested (or low cost) periods as a response to either growing congestion during the peak period or policy actions such as congestion pricing. This is also referred to as "active peak spreading" (Barnes, 1998). Ability to capture these behavioral shifts is required for realistically evaluating the impacts of transportation policy actions. Thus, rigorous analysis of peak spreading requires that the underlying travel demand models be sensitive to system capacity constraints as well as behavioral responses of travelers to congestion and policy actions.

5.3 Incorporating Peak Spreading within FSUTMS

The FSUTMS framework predominantly has a four-step like structure. An additional TOD factoring/modeling component has been proposed which will be incorporated between the trip-distribution and mode-split steps. This additional component will take as inputs the 24-hour PA matrices by trip purpose (output from trip distribution) and generates the PA matrices by trip purpose for each of several discrete time periods of the day. Each discrete time period may comprise several hours. For example, one may divide the day into the following periods: Morning (midnight – 7 AM), AM Peak (7-9 AM), Midday (9 AM – 3 PM), PM Peak (3 – 6 PM), and Evening (6 PM – midnight). The conversion is accomplished (for each trip purpose) by apportioning the overall 24-hour demands into specific time periods of the day. Each of the TOD specific person-trip PA matrices is then run through the mode choice models to obtain the vehicle-trip PA matrices. Next, the PA matrices are converted to OD matrices using TOD specific directional factors (i.e., fraction of trips during the TOD period under consideration that are from P to A and A to P) and subsequently through the network assignment models to determine the link flows, speeds, and travel times in the network during the corresponding time of the day.

Within the current FSUTMS framework, apportioning the daily demand into TOD periods can be accomplished using one of two broad approaches. In the first approach, constant factors (called the TOD factors or TOD factors) are used with the assumption that the temporal profile of travel demand remains unchanged in any forecast year. Factors generally vary across trip purposes but the spatial variability in the temporal distribution of travel is most often not captured. The second approach employs "TOD choice models" which allow the temporal profile of travel demand (or equivalently, the TOD factors) to vary based on the prevailing transportation system characteristics and other relevant explanatory factors. Separate models may be developed for each trip purpose. Further, the reader will note that the factors also vary spatially as a function of the geographical differences in the transportation system characteristics.

The rest of this section discusses procedures for analyzing the peak-spreading phenomenon using each of the two demand-apportioning techniques indicated above. Section 5.3.1 is focused on procedures when the TOD components comprise fixed factors whereas Section 5.3.2 addresses the case when the TOD choice models are used.

It is useful to mention here that we do not present the transit modeling components in our discussions in this chapter as the focus is on auto trips. Secondly, an analysis of temporal profiles of external trips and freight trips is beyond the scope of current work. Hence, we assume that vehicle-trip OD matrices by TOD periods for these trips are available as inputs and can be simply added to the vehicle trip OD matrices of internal trips prior to network assignment.

5.3.1 Factor-Based Approach

As already mentioned, the factor-based approach uses a set of (constant) TOD factors to determine the proportion of total travel demand within each discrete time period of the day. These factors are developed separately for the different trip purposes and using data from the household travel surveys. In addition to the TOD factors, peak-hour factors may also be developed for each discrete period. These represent the ratio of the travel volume during the peak one hour of a TOD period to the total travel during the corresponding period (expressed as a percentage). The use of peak-hour factors indicate that travel demand is not uniformly distributed even within any specific time-period of the day.

The FSUTMS structure with the inclusion of such a TOD factoring step is presented in Figure 5.2. The reader will note that the transportation system characteristics are not direct inputs to the TOD factoring step. This is because the factor-based approach assumes that the temporal profile of the travel demand (*i.e.*, the fraction of total travel demand within any discrete time period of the day or within the peak hour of any discrete time period) remains unchanged for any future year scenario. Consequently, the use of constant TOD factors and peak-hour factors does not support evaluating the temporal shifts in travel because of changes in transportation system characteristics (in other words, “active” peak spreading cannot be captured).

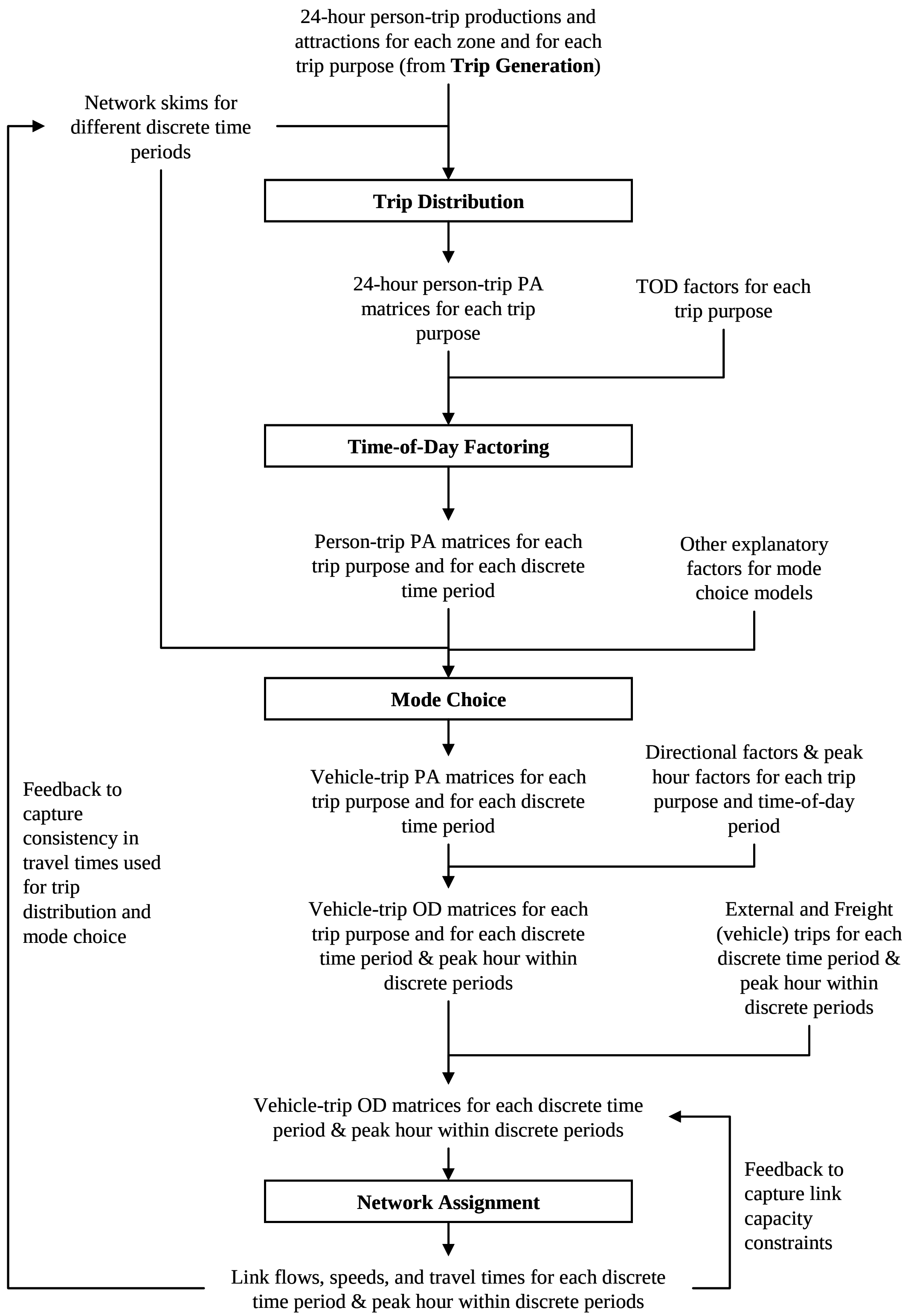

Figure 5.2 FSUTMS with TOD factoring

Further, a one-shot application of this procedure for forecasting is not guaranteed to generate link flows which are within the corresponding capacity limits (*i.e.*, capturing passive peak spreading is not guaranteed). This may be expected to happen particularly when examining scenarios in which there is a very large growth in travel demand without a corresponding growth in system capacity. In this context, it may be possible to enforce capacity constraints using an iterative procedure in which the demands for specific zonal pairs are reduced (*i.e.*, reduce values of specific cells in the vehicle trip OD matrix) based on the links in which flows exceed capacity. To further discuss this iterative procedure assume that the 24-hour day is simply divided into two discrete time periods: the peak period and the off-peak period. The procedure begins with performing (unconstrained) network assignment using (1) the peak-period OD matrix and (2) the peak-hour OD matrix of the peak period. Based on these two assignments, one of two situations may emerge[1] :

(a) All link flows for the peak period demands are within capacity and some flows for the peak hour demands exceed capacity.

(b) Some link flows for both the peak period and peak hour demands exceed capacity.

Case (a) suggests peak spreading within the peak period (*i.e.*, a flattening of the temporal profile of travel demand within the peak period) in certain areas of the region whereas Case (b) suggests spreading of peak both within and beyond the peak period (*i.e.*, a flattening of the temporal profile of travel demand within the peak period as well as a shift of demand from the peak to the off-peak period).

In the scenario corresponding to Case (a), we try to achieve a redistribution of demand within the peak period. Conceptually, this procedure involves reducing the peak hour demands and assuming that these reduced trips are simply moved to the non peak hours within the peak period (hence the total demand within the peak period remains unchanged). Further, the methodology described below also ensures that the demand re-distribution is largely confined to specific areas of the region in which the unconstrained flows are found to exceed capacity (for a more detailed discussion with an example, see Rossi *et al.*, 1990):

1. Based on the unconstrained assignment of the peak hour demand, identify the network links/corridors in which flows exceed capacity

[1] A third situation is the non-problematic case in which the link flows for both the peak period and peak hour demands are within capacity and hence no iterative procedures are required.

2. Reduce the peak hour demands between those OD pairs which contribute to flows on the over-assigned links. Broadly, the reduction is done by multiplying the OD demand with the ratio of the capacity to flow. It should be noted that this is not necessarily a straightforward procedure especially when some OD pairs contribute to flows on more than one over-assigned links. Rossi *et al.* provide one approach to systematically deal with this issue. However, other heuristics may be explored depending on the region under consideration.
3. Perform network assignment using the reduced peak hour OD matrix. If the new link flows are reasonable, then stop, else repeat steps 1-2 based on the newly identified problematic links.

In the scenario corresponding to Case (b), we try to achieve a redistribution of demand first across the peak and off-peak periods and then (if needed) within the peak period. Specifically, procedure involves first reducing the peak period demands and assuming that these reduced trips are moved to the off peak period (hence the total demand within the peak period decreases in this case). As discussed in the context of Case (a), the reductions are performed only on those OD pairs which contribute to flows on the over-assigned links. After obtaining the "reduced" peak period OD matrix that produces reasonable flows (using procedure similar to steps 1-3 described in the context of Case (a)) , calculate the new the peak hour OD matrix (of the peak period) by multiplying the original peak-hour matrix with the ratio of the reduced to the original peak period OD matrix. Perform network assignment using the reduced peak hour OD matrix. If the new link flows are reasonable, then stop, else perform a re-distribution of demand within the peak –period using the methodology described in Case (a)

Although the above-described iterative demand-reduction procedures are conceptually simple, there are several operational difficulties associated with this methodology. <u>First</u>, with increasing number of links exceeding capacity and/or increase in the number of discrete time periods considered in the analysis, the iterative procedure become complex and cumbersome. If such substantial over-assignment is observed, it may be more appropriate to enhance the trip generation and TOD factoring approaches as well as the representation of the transportation system characteristics in the model rather than trying to apply several iterations of the demand-reduction process. <u>Second</u>, the speed of convergence of this procedure is unknown. <u>Third</u>, after performing the demand shifts, the so-called off-peak hours or off-peak periods may have higher demands than the corresponding peak hours and peak periods necessitating additional reasonableness checks. Finally, the iterative procedure may involve case-specific heuristics and/or significant analyst involvement making the development of generic software difficult.

In summary, the use of the factoring approach (which is the simplest approach to capturing the temporal distribution of travel demand) is extremely limited in addressing the peak spreading phenomenon. At best, this methodology may be applied only in cases in which the issue of active peak spreading is not of interest and passive spreading is confined to one or two well-defined travel corridors. At the same time, performing network assignments using both peak-hour and peak-period OD matrices may provide preliminary insights into the extent of passive peak spreading in the region and the need for more advanced methods.

5.3.2 Model-Based Approach

The model-based approach to apportioning the daily demand into different periods of the day allows the temporal profile of travel demand (or equivalently, the TOD factors) to vary based on the prevailing transportation system characteristics. This variability is captured by developing econometric models (often having the logit structure) which relate the probability that a trip is made during a specific time of day to the temporal variability in the transportation system characteristics and other relevant explanatory factors (such as land use at the trip ends and trip purpose). Consequently, the temporal profile of travel patterns is also allowed to vary spatially as a function of the geographical differences in the transportation system characteristics and land use patterns.

The FSUTMS structure with the inclusion of such a TOD modeling step is presented in Figure 5.3. The reader will note that the transportation system characteristics are direct inputs to the TOD modeling step. Consequently, the use of TOD choice models will reflect shifts in travel demand away from periods of high travel-time (or cost) to periods of lower travel-time (or cost) as a result of growing congestion and/or policy actions that differentially change the travel times/costs during the day (*i.e.,* both passive and active peak spreading is captured).

Unlike in the case of the factoring approach, the feedbacks to capture link capacity constraints are not included in the framework for FSUTMS with TOD modeling. The expectation here is that this may not be needed in general as the temporal apportioning of demand is explicitly sensitive to the differential levels-of-service across the day. However, it should be noted that satisfying the capacity constraints is still not automatically guaranteed. This is because, (1) the total daily travel demand obtained from the trip generation stage is not sensitive to transportation system characteristics and (2) the temporal apportioning is dependent only on aggregate inter-zonal performance measures and not explicitly on link-level capacities. In the event of few links exceeding capacities, the demands may be further temporally re-distributed using methods as described in section 5.2.1. However, if substantial over-assignment is observed, it may be more appropriate to enhance the trip generation and TOD choice models as well as the representation of the transportation system characteristics in the model.

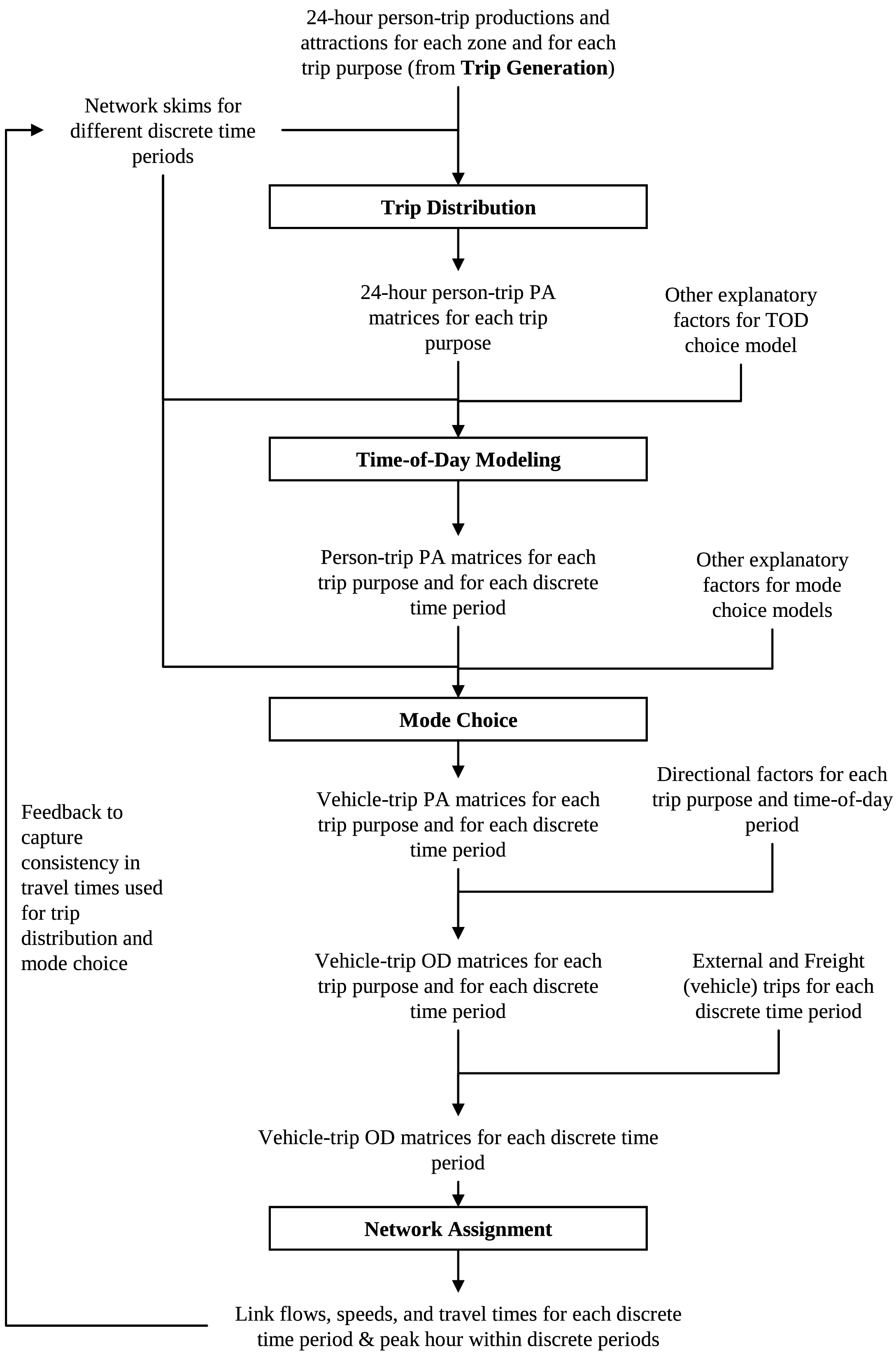

Figure 5.3 FSUTMS with TOD modeling

Conceptually, the following issues need to be considered in the development of the TOD choice models. First, the TOD choice models should include the relevant policy variables (such as travel times, costs, transit frequencies, and parking fee[2]) as explanatory factors. Second, suitable levels of spatial aggregation must be chosen. Specifically, demand is modeled at the level of Traffic Analysis Zones (TAZs) and hence the models use corresponding inter-zonal transportation system measures as explanatory factors. However, the policy changes are often implemented at the level of links or corridors. Hence, when very aggregate zoning systems are used, the inter-zonal measures may not be very sensitive to the link-level times/costs. Third, the 24-hour day must be suitably divided into the appropriate discrete time periods. The reader will note that the models capture only shifts *between* pre-defined time-periods and not shifts *within* time-periods. Hence, it may be appropriate to divide the day into several discrete periods based on both the expected temporal trends of the travel demand as well as the TOD resolution of the policy actions. For example, one may consider inclusion of "shoulder" periods around the AM and PM peaks as alternatives in the choice model if spreading in the vicinity of the existing peak-periods is expected. Similarly, if tolls are proposed to be imposed between 7-10 AM, the corresponding time may explicitly be chosen as a discrete period for the analysis. Finally, reasonableness checks must be included to ensure consistency of demands/flows across the different time periods of the day. Specifically, Purvis (1999) highlights the possibility of the "snow plow" effect, *i.e.*, excessive demands being shifted away from the peak period to the shoulder periods leading to effectively higher speeds during the peak compared to the shoulder hours.

In addition to the above-described conceptual consideration, there are other practical issues which make the estimation of TOD choice models that are consistent with the rest of the existing demand forecasting procedure difficult. Specifically, there are two major issues:

(1) Estimation of TOD models require inter-zonal travel times during different periods of the day as data. Currently these are obtained from network skims by performing static assignments. It is known (see for example Rossi *et al.*, 2005) that static assignment procedures under predict travel times in hyper-congested networks. This is because of the lack of consideration of queue formation and dissipation effects and the spill-over of demand from one period to

[2] In the proposed approach, the temporal apportioning of travel demand is done prior to mode choice. Hence it would be appropriate to include composite/multi-modal transportation system characteristics as variables in the time-of-day choice models

another. Consequently, the relative magnitudes of travel times between congested and free-flow periods obtained from static assignment are not reflective of the "true" relative travel conditions. Therefore, TOD choice models that are estimated using these data are perhaps not realistic descriptions of travelers' sensitivity to congestion.

(2) To ensure that the TOD choice models fit into the four-step framework (without any changes to the other components), these models have to be estimated using only land-use and transportation system characteristics as explanatory variables. Now, in such models, which do not control for traveler characteristics as explanatory factors, it is possible to obtain a positive coefficient on the travel time variable. Such a positive coefficient is reflecting that fact that travel times during certain periods are high *because* more people are traveling during that period (it does not appear reasonable to interpret this as people "preferring" to travel during congested periods). However, the real intent of the model is to understand the impact of congestion *on* the choice of TOD (and not the influence of the TOD choices of people on congestion as indicated by the positive coefficient). This is, in part, because the TOD choice models are not controlling for traveler-specific characteristics which compel them to choose a specific time of day irrespective of the prevailing travel times (for example, the need to be at work by 8 AM). When such factors are controlled for, one may be more confident of obtaining a negative coefficient on travel time variable, as would be expected.

In summary, the TOD choice models offer a conceptually attractive approach to capture both active and passive peak spreading. With appropriately chosen spatial and temporal scales and empirical specifications, these models can be effective in reflecting temporal (re)distributions of travel demand. The application of these models can be automated within travel-modeling software. Further, the reader will note that applying TOD choice models involve matrix manipulation methods which are very similar to those used in the context of applying mode choice models and hence are already available in software such as CUBE. At the same time, this approach requires *a priori* specification of the discrete time periods, which may not necessarily be straightforward to determine. Further, this methodology becomes less attractive with the increase in the required temporal resolution of the demand (such as in the case of evaluating dynamic pricing schemes in which demands may be needed at 15 minute intervals). Finally, and perhaps the most critical issue is that estimation of robust TOD choice models that are purely a function of land-use and transportation system characteristics, and using travel time measures from static assignment may be problematic. With the adoption of dynamic assignment models and simulation approaches for the determination of travel time measures and by developing disaggregate demand-modeling approaches (*i.e.*, by explicitly incorporating the traveler characteristics in all travel-related decisions), the TOD modeling approach can be expected to perform better.

5.4 Summary

The phenomenon of peak spreading is a consequence of two factors: (1) disproportionate increase in travel demand in relation to system capacity resulting in increased times of the day when the roadway network is congested (passive peak spreading) and (2) travelers consciously switching their TOD of trip making to less-congested (or low cost) periods as a response to either growing congestion during the peak period or policy actions such as congestion pricing (active peak spreading). Hence, an analysis of peak spreading requires that the underlying travel demand models be sensitive to system capacity constraints as well as behavioral responses of travelers to congestion and policy actions.

The use of constant TOD and peak hour factors is the simplest approach to capturing the temporal demand profiles. However, this approach is extremely limited in capturing the peak spreading phenomenon. At best, this methodology may be applied only in cases in which the issue of active peak spreading is <u>not</u> of interest and passive spreading is confined to one or two well-defined travel corridors.

The TOD modeling approach is conceptually capable of more realistically capturing both active and passive peak spreading within the four-step travel forecasting framework. These models can also be readily implemented within available travel forecasting software such as CUBE. However, we also identify practical issues that make the robust estimations of TOD choice models difficult.

We conclude by noting that it is not always possible to completely capture the temporal dimension of travel demand and the related effects of peak spreading by simply introducing an additional TOD apportioning component (either using fixed factors or a time of day choice model) without any changes to the rest of the demand-forecasting framework. Specifically the following items are to be noted:

(1) Incorporation of a good representation of the transportation system characteristics (especially capacity constraints): In particular, in regions of rapid demand growth, it is important to

capture supply side constraints in trip generation models to ensure that unreasonably large demands are not generated which cannot be handled by the available capacity.

(2) Use of a dynamic assignment or traffic simulation methods to develop better estimates of travel times for use in model estimations

(3) Explicit accommodation of the heterogeneity in the overall travel behavior across different segments of the population: In the case of TOD models, it is necessary to recognize that all persons are not equally flexible in choosing their TOD of travel and that there are factors beyond transportation system characteristics which (and perhaps more critically) determine the temporal characteristics of a person's travel.

To take a step further, even if the above items are included to develop a disaggregate, trip-based travel-forecasting model, certain key behavioral limitations still remain. Specifically, an implication of the trip-based structure in the context of TOD choice is that people determine the TOD of each trip (of given trip purpose) independently. When examined in the context of policy evaluations, this might mean, for example, a non-home-based shopping trip is moved from the peak to the off-peak period. Now, this is not very realistic, as the real decision of the traveler might be to reschedule the shopping activity within the overall daily activity pattern. As a consequence, the shopping activity which was previously undertaken at the end of a non-home-based trip (perhaps during the return-home commute) is now undertaken as a home-based trip (during the post-home-arrival period). This issue is of critical relevance in realistically evaluating the impacts of policy actions which could change the temporal profile of travel behavior (*i.e.*, active peak spreading). Therefore, when the objective of the travel forecasting process increasingly becomes evaluating the impacts of policy actions which can result in complex temporal changes in travel behavior, it would be appropriate to start evaluating the adoption of activity-based travel modeling methods (which holistically describe the timing and durations of activity-travel behavior) instead of adding a TOD component to the trip-based/four-step demand modeling framework.

CHAPTER 6. PILOT IMPLEMENTATION: ENHANCEMENTS TO THE OLYMPUS MODEL

6.1 Introduction

This chapter describes our pilot implementation of the post-distribution TOD procedures for both the highway and transit modes. All our enhancements were made to an original version of the Olympus training model which has already been coded using Cube Voyager. Empirical results comparing the original and enhanced models are also presented.

Prior to further discussion it is useful to mention here that we chose not to change the *empirical* content of the original Olympus model to enable a realistic comparison of the effects of *structural* changes made to model. Primarily, we retain the same TOD periods and factors from the original model. Other constraints imposed/retained are discussed throughout the document at appropriate places.

The rest of this chapter is organized as follows. Section 6.2 presents the detailed structure of the current Olympus model whereas Section 6.3 describes the enhanced model which implements post-distribution TOD procedures for both the highway and transit modes. Section 6.4 compares system-wide highway and transit performance measures from the original and the enhanced models. Section 6.5 presents a summary.

6.2 Structure of the Current Olympus Model

The overall structure of the current Olympus model is presented schematically in Figure 6.1. In the first step (trip generation), the zonal-level trip productions and attractions are determined. Next, the "Network" module generates the inter-zonal free-flow travel times. These travel times are used to calculate the friction factors required for the third step, trip distribution. The third step implements a gravity model to generate the 24-hour person-trip PA matrices for each trip purpose. As a part of this step, a "pre-assignment" is performed to generate the "peak" inter-zonal highway travel times. To perform the pre-assignment, the 24-hour PA matrix is converted to an OD matrix.

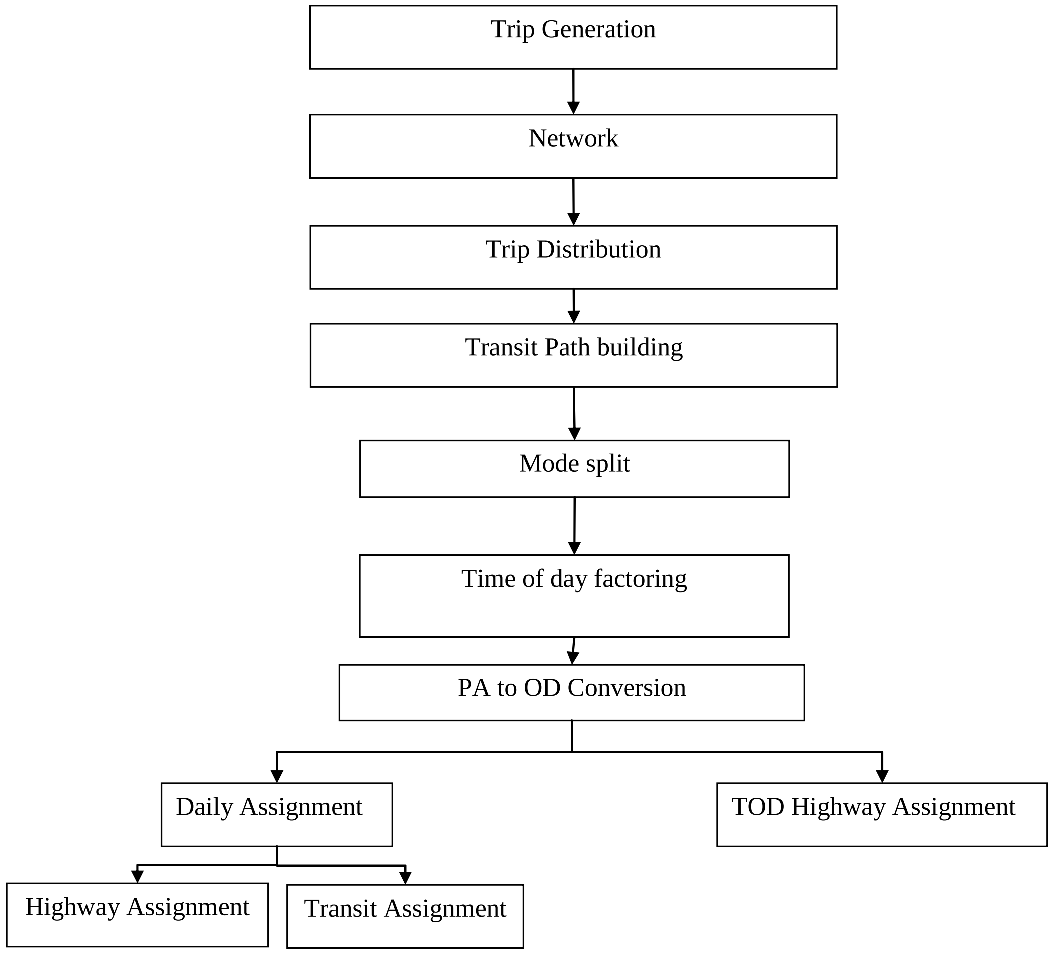

Figure 6.1 Current Olympus model

In the fourth step, the transit paths are built and the inter-zonal transit travel times and costs are generated. The person-trip PA matrices (from step 3) along with the inter-zonal transportation system characteristics (from steps 3 and 4) are used as inputs to the "Mode Split" step. Here, the person-trip PA matrices are converted to vehicle-trip PA matrices (using a logit model of mode choice and auto occupancy factors). Simultaneously, the transit demand is also determined. The 24-hour vehicle trips by auto mode are next factored by TOD to obtain the volumes (PA matrices) during the AM-peak, Mid-day, PM-peak and Off-peak periods. The PA matrices for each time-period are then converted to OD matrices using directional factors. The last major step includes highway and transit assignments. While the transit assignment is performed only for the overall 24-hour period, the highway assignments are performed for both the entire-day as well as for the specific TOD periods.

6.3 Structure of the Enhanced Olympus Model

Note that since there are only small percentages home-based A-P trips at the AM period and P-A trips at the PM period, we implemented a simplified analysis procedure that does not treat P-A and A-P trips separately. Starting from the original Olympus model (as described in the previous section), the pilot implementation of the post-distribution TOD procedures for both the highway and transit modes comprised the following developments:

- A module to perform post-distribution TOD factoring of PA matrices (to replace the equivalent post-mode-split module)
- A module to build transit networks for each time period
- A module to perform TOD specific pre-assignments to generate highway skims by TOD for input to the mode choice models
- A module to generate transit paths and transit skims by TOD for input to the mode choice models
- A module to apply the mode choice model separately for each time period using the appropriate demands (PA matrices) and travel times
- A module to convert the PA matrices from mode-split step into OD matrices (for inputs to highway and transit assignment) by using TOD and purpose specific directional factors.
- A module to perform TOD specific transit assignment
- Integrate all the components

The enhanced Olympus model thus implements the post-distribution TOD procedures for both the highway and transit modes. It is useful to note here that this implementation corresponds to the simplified procedure as described in Chapter 3 (see Step 3 under Section 3.4.1). Figure 6.2 identifies the major components of this model. The first three steps (i.e., trip generation, the network module, and the trip distribution) remain the same as in the case of the original Olympus model. Further, no changes are made to the processing of external trips and truck trips. At the end of the trip distribution step, 24-hour person-trip PA matrices by trip purpose are generated.

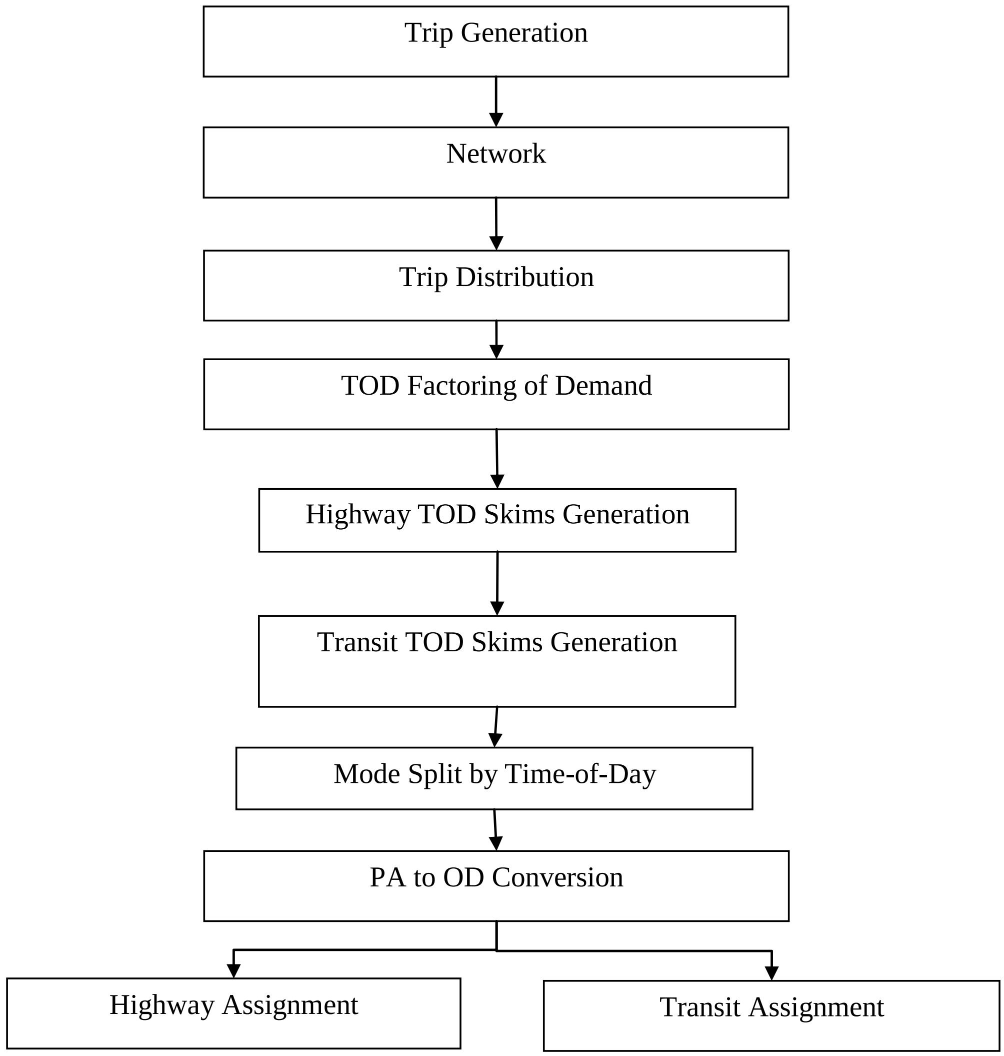

Figure 6.2 Enhanced Olympus model

In the fourth step (Figure 6.3), purpose-specific factors are applied to apportion the 24-hour demands into the four time-periods of the day. Therefore, the output from the TOD factoring step comprises four person-trip PA matrices for each trip purpose.

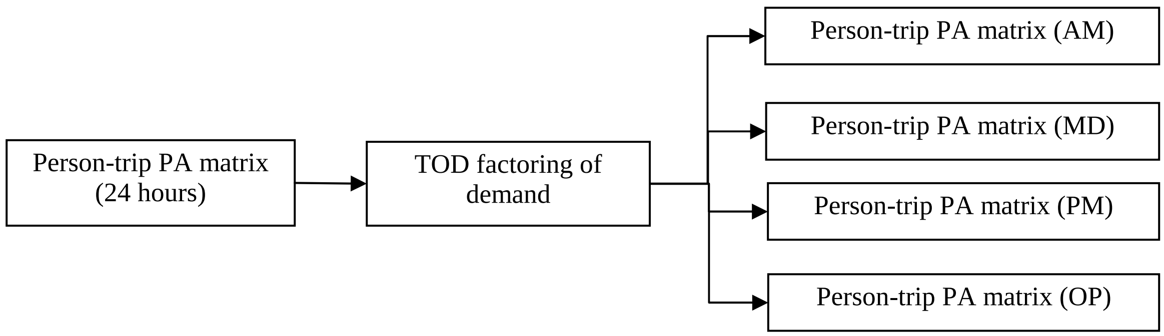

Figure 6.3 Step 4: TOD factoring of demand

The next two steps generate the TOD specific travel-times (skim files) for the highway and transit modes for use in the mode choice models. Specifically step 5 produces the highway skims and step 6 produces the transit skims.

To generate the highway skims for a TOD period (Figure 6.4), the person-trip PA matrices (all purposes) for the appropriate TOD period are used as inputs to perform an equilibrium assignment. The link capacities are scaled by the duration of the TOD period to be consistent with the duration of the demand. This assumes a uniform distribution of demand within each TOD period. An alternate approach is to perform the network assignments for the peak one-hour of each TOD period. This can be implemented using the “CONFAC”-type variables used in the models without TOD modeling. Such peak hour factors for each TOD period have been developed as part of this research (See Chapter 2). For this pilot implementation, we chose the former approach to enable a more realistic comparison of the enhanced model with the original model. The outputs from this step include the loaded highway networks and the highway skims (shortest inter-zonal travel times) for each TOD period.

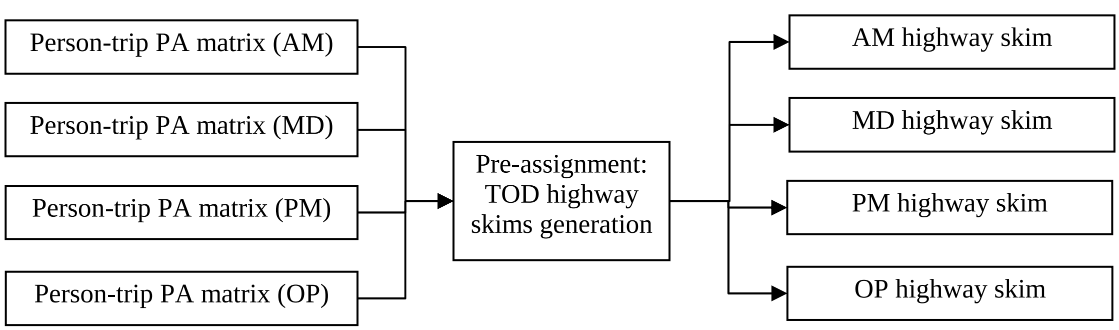

Figure 6.4 Step 5: Generation of TOD-specific highway skims

The sixth step (Figure 6.5) generates one set of transit paths, transit skims, and transit fare matrices for each time periods. Since there is no auto-access transit mode in the Olympus model, the transit path building is much simpler than what has been described in Chapter 3.

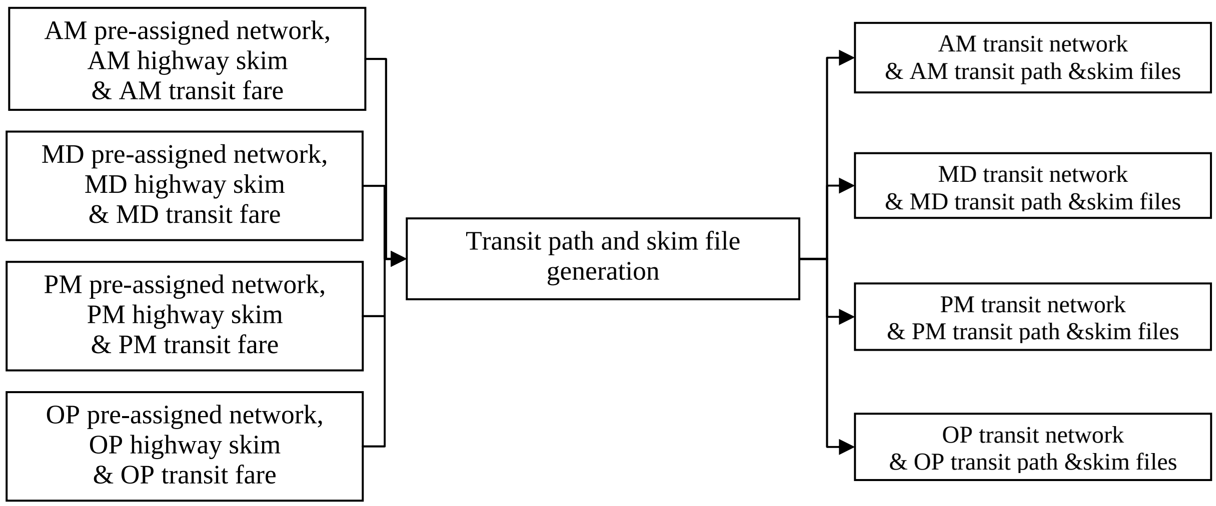

Figure 6.5 Step 6: Generation of TOD-specific transit skims

The seventh step (Figure 6.6) in the model is the modal split. The fractions of total person-trips by auto and transit modes are determined for each purpose and TOD period. Further, for auto-trips, the person trips are converted into vehicle trips by using suitable vehicle occupancy factors. As shown in Figure 6.6, the mode split is performed using TOD specific demands and inter-zonal travel time measures (obtained from the skim files). This is in contrast to the post-mode-split TOD modeling approach in which the congested skims are used in the mode split of certain trip purposes such as home-based work and free-flow skims are used in the case of the other trip purposes. The output from this mode split step is the TOD specific vehicle and transit trip tables (PA matrices) by purpose.

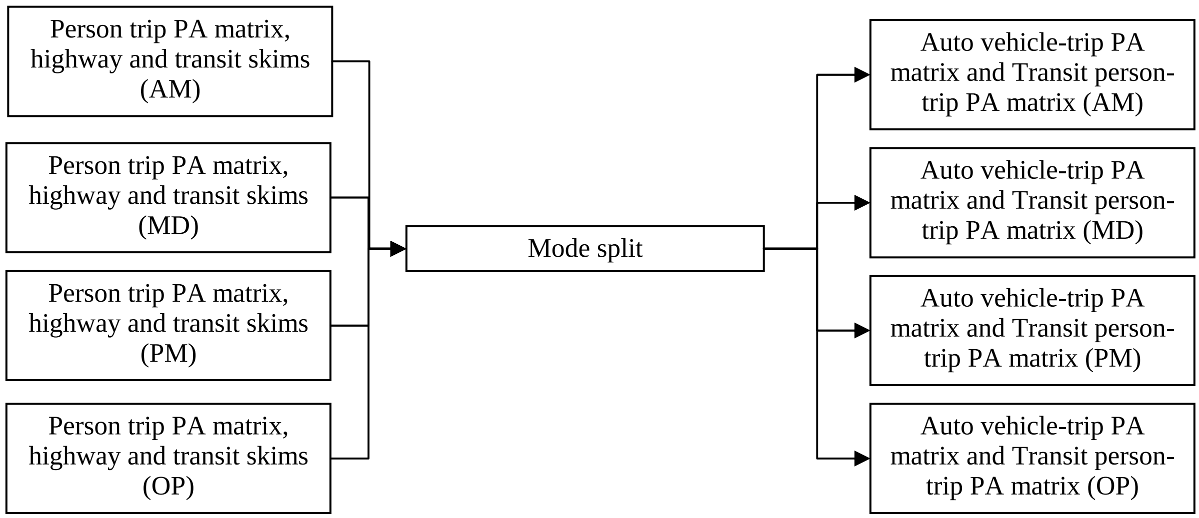

Figure 6.6 Step 7: Mode split

This is followed by Step eight (Figure 6.7) which coverts the PA matrices into OD matrices for highway and transit assignment. This is accomplished using the directional factors by purpose for each TOD periods.

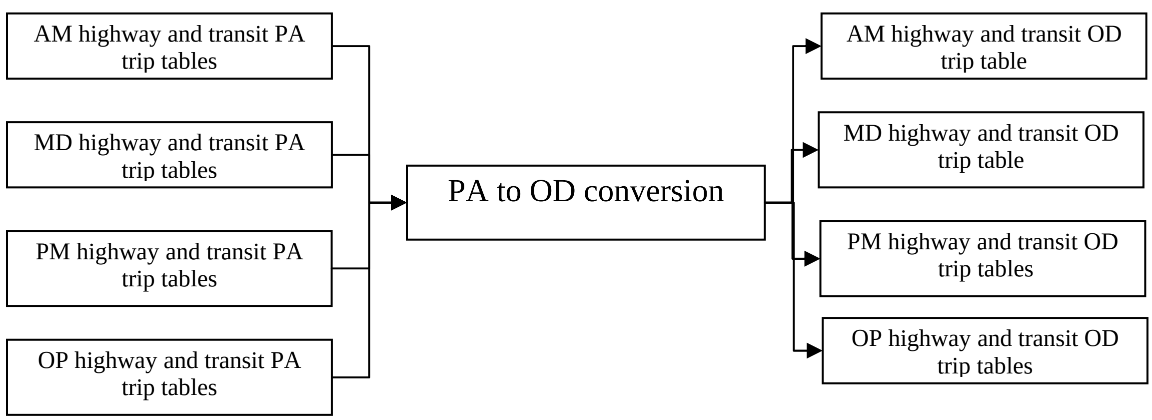

Figure 6. 7 Step 8: Conversion of PA to OD matrices

The TOD specific vehicle-trip OD matrices are the input to the highway assignment step which performs an equilibrium assignment for each TOD period to determine the link flows. As already discussed in the context of step five, the link capacities are scaled by the duration of the TOD period to be consistent with the duration of the demand.

The time-of-say specific transit-trip OD matrices are the input to the transit assignment step (Figure 6.8) which performs the loading for each TOD period. For a complete analysis, the loading should be conducted for P-A and A-P trips respectively. Since we chose to do a simplified analysis, the same loading procedure used in the original Olympus model is applied to estimate the ridership on each transit line at each time period.

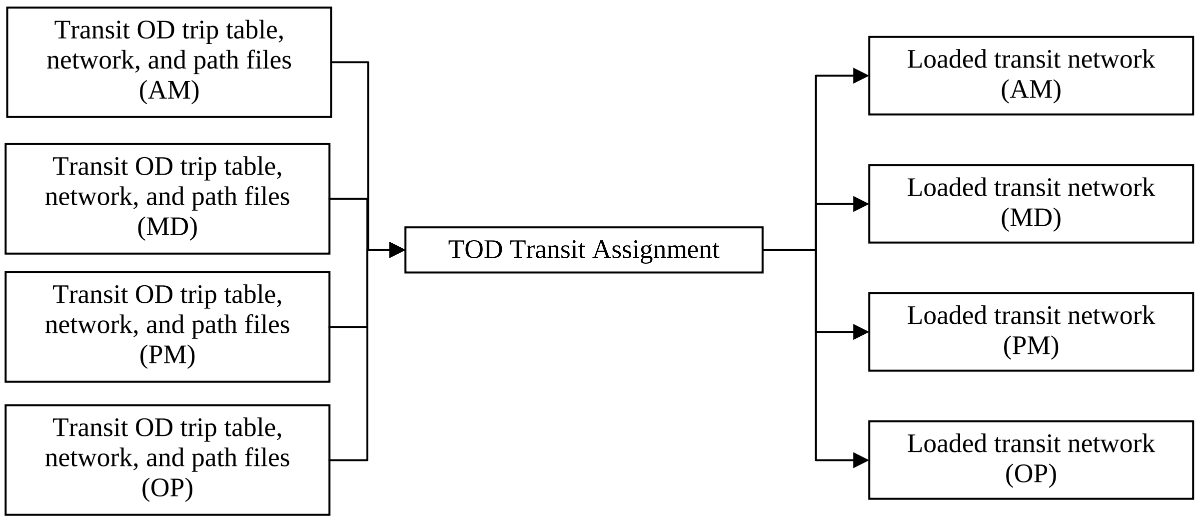

Figure 6.8 Step 9: Transit assignment by TOD

6.4 An Empirical Comparison of Original and Enhanced Olympus Models

6.4.1 Run Times

The original Olympus model (post modal-split TOD factoring with TOD specific highway assignment and peak/off-peak transit assignment) had a run time of approximately 7.5 minutes. On adding the TOD specific transit assignment component to this model, the run time increases to 11 minutes. The final enhanced Olympus model (post-distribution with TOD specific highway and transit assignment) has a run time of about 23 minutes.

6.4.2 Highway Performance Measures

Four system-wide performance measures are used to compare the original (post modal-split TOD) and enhanced (post distribution TOD) Olympus models. These measures are total vehicle miles of travel (VMT), total vehicle hours of travel (VHT), average V/C ratio, percentage congested links in the network (V/C ratio for links > 0.9).

The results for the post mode-split and the post-distribution models across all TOD periods are listed in Tables 6.1 and 6.2 respectively. Table 6.3 provides the system performance measures for a 24-hour model (i.e. no TOD component).

Table 6.1 Performance measures for original Olympus model (post modal-split)

Time of Day	Total VMT[1]	Total VHT[2]	% congested	Average V/C
AM	2,513,178	65,152	1.788	0.210
MD	4,323,115	106,593	0.418	0.163
PM	4,261,222	132,809	10.093	0.350
OP	3,810,357	95,254	0	0.078
TOTAL - Full day	14,907,873	399,809		

1 Rounded to the nearest mile
2 Rounded to the nearest hour

Table 6.2 Performance measures for enhanced Olympus model (post distribution)

Time of Day	Total VMT[1]	Total VHT[2]	% congested	Average V/C
AM	2,513,120	65,151	1.788	0.210
MD	4,323,113	106,592	0.418	0.163
PM	4,260,999	132,800	10.093	0.350
OP	3,810,375	95,254	0	0.078
TOTAL -Full day	14,907,608	399,798		

1 Rounded to the nearest mile
2 Rounded to the nearest hour

Table 6.3 Performance measures for 24-hour Olympus model (no TOD)

Time of Day	Total VMT[1]	Total VHT[2]	% congested	Average V/C
Full day	14,923,928	451,908	11.131	0.363

1 Rounded to the nearest mile
2 Rounded to the nearest hour

Several interesting observations can be made from the above tables. First, there are only minor differences between the post-distribution and post mode-spit values. We believe that this is case-specific issue. The original Olympus model implementation does not appear to allow for time-varying TOD skims for transit. This limits the ability of our post-distribution approach to effectively capture the differences in the relative attractiveness of auto and transit modes across the time periods. Further, the use of TOD specific peak-hour factors in the assignment procedure (to capture the non-uniform distribution of travel demand even within TOD periods) could further introduce quantitative differences between these two approaches. Second, there is little difference in the total VMT across all the three models. This is as expected as all the three models use exactly the same trip distribution procedure (which fundamentally determines the trip distances). The minor differences may be ascribed to changes in the total auto-trip demand because changes to the mode split step. Third, taking the ratio of VMT to VHT as a surrogate to the system average speed, we find that the TOD specific models imply speeds of approximately 40 miles per hour for MD and OP periods, 38 mph for AM peak and 32 mph for the PM peak. The relative magnitudes appear reasonable. Fourth, the total VHT from a 24-hour assignment seems to be significantly higher (approximately 11% more) than those from TOD specific assignment. Equivalently, the overall (daily) system average speed is 33 mph for the daily assignment as opposed to 37.3 mph for the TOD specific assignments. This suggests that the procedure without TOD is perhaps overestimating the congestion probably due to an inappropriate value of CONFAC.

6.4.3 Transit Performance Measures

Five performance measures are used to compare the original (post modal-split with peak/off-peak transit assignment) and two enhanced Olympus models (post distribution and split with TOD transit assignment). These measures are total passenger miles of travel (PMT), total passenger hours of travel (PHT), total ridership, average travel distance (in mile) and travel time (in hour) in the network.

Tables 6.4-6.6 compare these performance measures resulted from three different models. The following observations can be made from these tables. First, the full-day results of the post-split model with TOD assignment are quite similar with those of the original Olympus model. In the implementation of the post-split model with TOD assignment, the TOD transit trip tables are obtained by simply applying the TOD factors to the transit trip tables from modal split, and then transit loading is conducted for each time period. Therefore, these two models share the same daily modal split, and it is thus not a surprise to observe that the results by periods add up the same. Second, the post-distribution procedure generates different performance measures, because it has TOD specific modal split. It is important, however, to recognize that the overall transit demands are low and hence it is not straightforward to conclude the directionality of the impact.

Table 6.4 Performance measures for original Olympus model

Time of Day	Total PMT	Total PHT	Total Ridership	Average Travel Distance	Average Travel Time
Peak	7,951	269	1,760	4.518	0.153
Off-Peak	18,788	636	4,439	4.232	0.143
TOTAL - Full day	26,739	906	6,199	4.314	0.146

Table 6.5 Performance measures for post-split model with TOD assignment

Time of Day	Total PMT	Total PHT	Total Ridership	Average Travel Distance[4]	Average Travel Time[5]
AM	5,229	177	1,197	4.369	0.148
MD	6,814	231	1,616	4.216	0.143
PM	7,648	259	1,806	4.236	0.144
OP	7,030	238	1,645	4.273	0.145
TOTAL - Full day	26,721	905	6,264	4.266	0.145

Table 6.6 Performance measures for post-distribution with TOD assignment

Time of Day	Total PMT	Total PHT	Total Ridership	Average Travel Distance	Average Travel Time
AM	4,941	167	1,147	4.306	0.146
MD	6,349	215	1,549	4.097	0.139
PM	6,709	228	1,612	4.162	0.141
OP	6,333	215	1,549	4.087	0.139
TOTAL – Full Day	24,331	825	5,858	4.153	0.141

There are 32 transit lines in the Olympus model, and we select the transit line with the largest ridership, Line 31 Fla Ave -, to conduct a line-level comparison. The ridership profiles of this line from these three models are illustrated in Figure 6.9, and reported in Table 6.7. It can be seen that for this specific line, the original Olympus model procedure higher ridership than two enhanced models while the latter two models produce similar results. However, we believe it occurs by chance. Moreover, since the total number of transit trip is small in the Olympus model, if breaking down into each line, absolute differences are indeed minor.

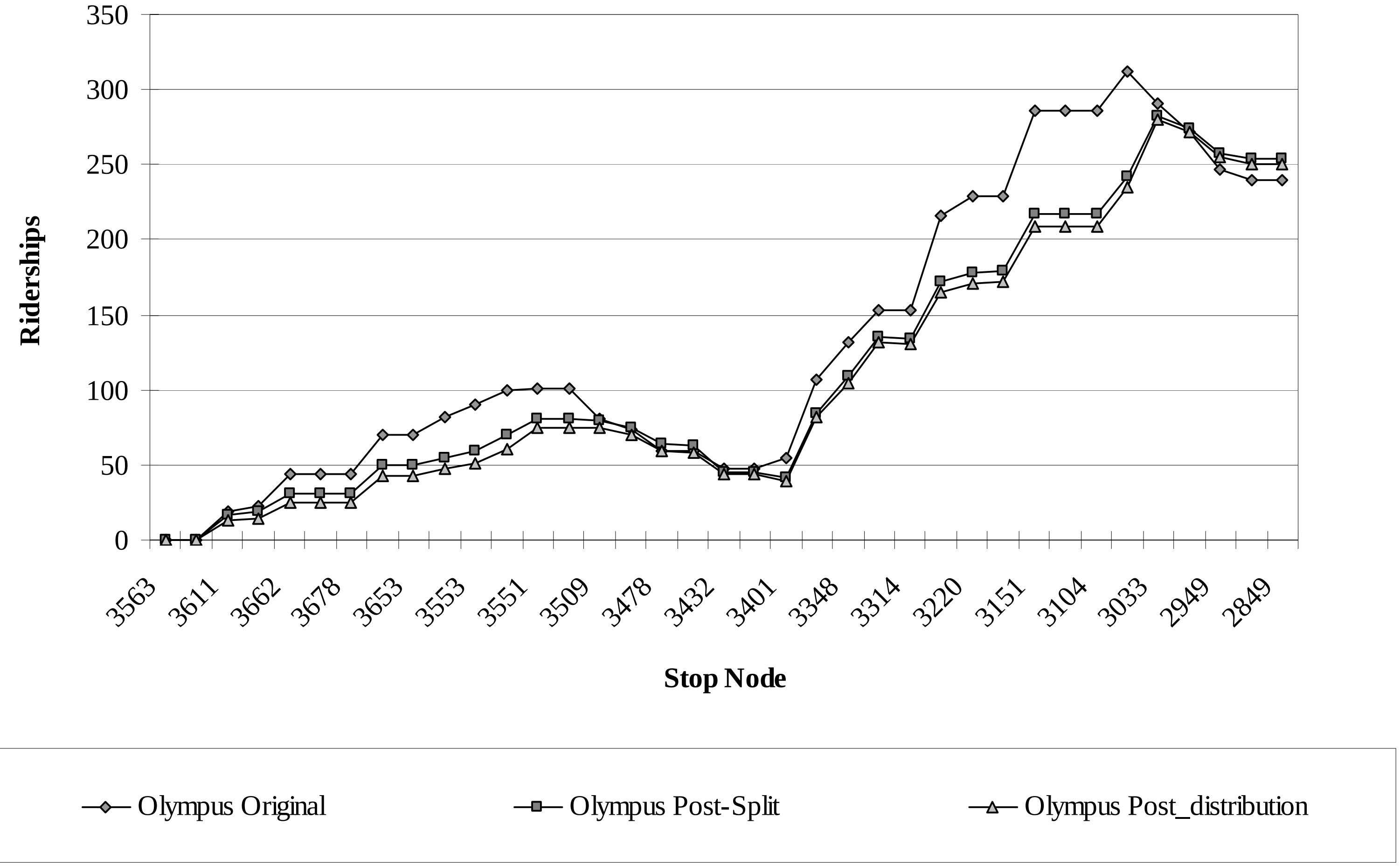

Figure 6.9 Daily ridership profiles of Line 31 Fla Ave - from three models

Table 6.7 Comparison of daily riderships of Line 31 Fla Ave - from three models

	Olympus Original	**Olympus Post-Split**		**Olympus Post-Distribution**	
Stop Node	**Daily Ridership**	**Daily Ridership**	**Difference %**	**Daily Ridership**	**Difference %**
3563	0.3	0.19	-36.67	0.19	-36.67
3589	0.3	0.19	-36.67	0.19	-36.67
3611	19.49	16.63	-14.67	13.13	-32.63
3645	22.14	18.41	-16.85	14.55	-34.28
3662	44.04	30.77	-30.13	25	-43.23
3679	44.04	30.77	-30.13	25	-43.23
3678	44.04	30.77	-30.13	25	-43.23
3661	70.1	49.77	-29	42.41	-39.5
3653	70.1	49.77	-29	42.41	-39.5
3598	81.41	55.14	-32.27	46.97	-42.3
3553	90.71	59.64	-34.25	50.58	-44.24
3552	99.85	70.43	-29.46	61.05	-38.86
3551	100.58	80.79	-19.68	74.74	-25.69
3529	100.58	80.79	-19.68	74.74	-25.69
3509	80.2	79.32	-1.097	74.23	-7.444
3502	73.43	74.41	1.335	70.17	-4.44
3478	58.89	64.01	8.694	59.71	1.392
3439	58.94	62.29	5.684	58.39	-0.933
3432	47	45.24	-3.745	44.13	-6.106
3400	47.02	45.25	-3.764	44.13	-6.146
3401	54.53	42.06	-22.87	39.67	-27.25
3374	107.01	84.05	-21.46	81.32	-24.01
3348	132.17	109.03	-17.51	104.16	-21.19
3329	153.39	134.76	-12.15	131.21	-14.46
3314	153.49	134.43	-12.42	130.95	-14.69
3250	216.15	171.57	-20.63	165.25	-23.55
3220	229.16	178.19	-22.24	171.02	-25.37
3195	229.36	178.69	-22.09	171.52	-25.22
3151	285.47	217.34	-23.87	208.94	-26.81
3132	285.47	217.34	-23.87	208.94	-26.81
3104	285.47	217.34	-23.87	208.94	-26.81
3080	311.69	242.46	-22.21	235.11	-24.57
3033	290.5	282.92	-2.609	280.09	-3.583
2976	272.14	274.03	0.695	271.22	-0.338
2949	246.63	257.8	4.529	254.67	3.26
2909	240.02	253.8	5.741	250.25	4.262
2849	239.99	253.77	5.742	250.26	4.279

6.5 Summary

This chapter described the enhancements made to the Olympus model to incorporate post-distribution TOD factoring and TOD specific assignment for both highway and transit modes. This is intended as a pilot implementation exercise to demonstrate the feasibility of building a post-distribution TOD factoring model within the CUBE/FSUTMS structure. We find that the run time of the enhanced model is almost double that of the model without any TOD factoring. As already indicated, we retained empirical factors and other constraints (such as the assumption on uniform distribution of demand within each TOD period) from the original model and compared the effects of structural changes to the model using system-wide performance measures for both the highway and the transit modes. We find that there are clearly differences between the 24-hour and the TOD models especially in terms of the average speeds and system travel times. However, the differences between the post-distribution and post-mode split models were minor (at least in the context of the highway performance measures).

For a more rigorous assessment, our implementation can be applied to a study region for which TOD and peak-hour factors developed from local data are available. The generated link flows and transit volumes by TOD can then be compared with hourly counts and any other validation measures.

CHAPTER 7. SUMMARY

This report has addressed a series of critical issues relevant to the TOD modeling in the FSUTMS framework, namely development of TOD factors to apportion the 24-hour PA matrix into TOD specific PA matrices, development of TOD transit modeling procedure, and investigation of modeling HOT lane operations and representing peak spreading phenomenon in FSUTMS. Further, a pilot implementation of the post-distribution TOD factoring approach was also undertaken by enhancing the Olympus training model. The rest of this chapter presents a brief summary of major results from each of the research tasks.

7.1 TOD Factors

The "factoring" approach represents the simplest way to capture the temporal variation in the travel demand within the four-step travel demand modeling framework such as FSUTMS. This approach requires TOD factors which are defined as the ratio of trips made in a time period to those made in one day.

In Chapter 2, TOD factors were developed for the different regions in Florida for five discrete time periods: midnight – 7 AM, 7-9 AM, 9 AM – 3 PM, 3 – 6 PM, and 6 PM – midnight. These time-of-periods were determined based on the observed temporal profiles of the total travel volumes over the day. Factors are developed separately for rural and urban areas and for each of the trip purposes included in the FSUTMS framework (except truck/taxi, IE, EI, and EE trips) and for each direction (*i.e.,* P to A and A to P). In addition to the TOD factors, peak hour factors were also developed for each time-period to facilitate the creation of peak one-hour OD matrices for network assignment.

In the case of urban areas, factors were developed from travel survey data from different parts of Florida. Preliminary "reasonableness" assessment of the developed factors indicates that they fall within the typical values obtained from elsewhere in the country. However, it is also found that the TOD factors depend on whether or not sampling weights are used in the calculations. At the same time, it is not readily apparent that one of the approaches is necessarily better. Therefore, case-specific validation exercises are recommended for the determination of the appropriate factors to be used. Further, although the intent of this project is to develop "generic" TOD factors for use across the state, our analysis indicates that the overall concentration of travel during the AM peak is significantly higher in the SE Florida region compared to the rest of the state and significantly lower in the Volusia County (again, compared to the rest of the state). Hence, the use of the "generic" factors (presented in this chapter) based on data pooled from all regions of the state may result in an overall under-prediction of AM peak travel in the SE Florida region and an over-prediction of AM peak travel in the Volusia region. Therefore, it might be more appropriate to use local factors for the different regions of Florida.

In the context of rural regions, national level data were used due to lack of sufficient data at the state level. Preliminary "reasonableness" assessment was not performed for rural factors due to lack of data. Further, as already discussed, we find the temporal profiles of travel in urban and rural areas to be very similar based on the NHTS analysis. This suggests the need for further data and analysis in the context of development of TOD factors for rural regions.

7.2 TOD Transit Modeling

TOD Modeling Procedure

Since both the demand and the supply of transit services vary substantially by time of day, implementation of a TOD procedure in the framework of FSUTMS may improve transit demand forecasting and system modeling, and ensure them in conformity with FTA's New Starts Program requirements.

FSUTMS is experiencing a major conversion from Tranplan to Cube Voyager. In 2005, FDOT and the Florida Model Task Force agreed to develop a new transit modeling system for FSUTMS/Voyager. The new modeling system is expected to be different from its ancestor in a number of ways, particularly in the use of the PT module offered by Cube Voyager. Transit modeling in FSUTMS/Tranplan is tightly linked to mode choice. The skims generated in the path building and skimming process for each combined transit mode are directly used as input to the mode choice to determine the split of each combined mode. Moreover, the paths built are directly used for the transit assignment, which is essentially a loading process without any route choice and equilibrium involved. In contrast, PT module in Cube Voyager enumerates a set of attractive routes between zone pairs with the corresponding probabilities of use determined by the route evaluation function. Average skims are calculated by weighting each attractive route in accordance with its probability of use. Since the enumerated paths include transit segments, and access, egress, transfer and park and ride legs, the mode choice modeling structure of FSUTMS will be affected. More specifically, the mode choice model will not split trips among combined transit modes (e.g., auto- or walk access to local bus, express bus and rail etc). Instead, an aggregate transit mode with its average skim matrix could be incorporated into the mode choice models to determine the splits among drive alone, car-pool, transit, and other non-motorized modes.

Primarily due to the fact that the multi-path builder of PT is not compatible with existing FSUTMS mode choice structure and PT is not able to provide necessary information for New Starts quality control tests, the PT best-path option has been recommended as a short-term solution. The option allows the multi-path path builder of PT to select one single shortest path between two zones, mimicking the single-path builder used in FSUTMS/Tranplan. Of consequence, the basic structure of transit modeling in FSUTMS/Tranplan will be maintained.

With the consideration that the Tranplan procedure is still used in Florida for transit modeling and the PT best-path option will maintain the same modeling structure, we have proposed a TOD transit modeling procedure presented in Chapter 3. One of critical issues that the procedure recognizes is that the auto-access transit modes are not symmetric. At the production end of a home-based transit trip, auto or walk access may be chosen while at the attraction end, only walk egress is possible. The choices of modes (auto or transit) and access/egress for P-A trips are usually the same for the return trips (A-P trips), particularly for auto access. To address this issue, two set of transit paths, transit skims and transit fare matrices will be generated for each time period for directional P-A and A-P trips respectively. Bus-to-auto transfers are prohibited in path building for home-based P-A trips while bus-to-auto transfers are permitted and auto-to-bus transfers are prohibited in path building for A-P trips. The transposition of the resulting skim tables will be used as input to mode choice for those A-P trips. The pilot implementation in Chapter 6 has demonstrated the use of the proposed procedure in the Olympus model.

New Starts Analysis

FTA's New Starts program provides funds to transit providers for constructing or extending certain types of mass transit systems. To obtain a grant agreement, a project must first progress through a local or regional review of alternatives, develop preliminary engineering plans, and obtain FTA's approval for final design. Generally speaking, TOD transit modeling may provide the New Starts analysis more accurate forecasts and enables more detailed reporting of forecasts, which may offer opportunities for understanding and refining the project, or making a better case for the project. More specifically, the TOD procedure may improve the calculation of project justification criteria, e.g., cost effectiveness, the most important measure for the New Starts analysis. A numerical example has been presented in Chapter 3 to demonstrate that the daily-basis modeling overestimates the user benefit while the TOD procedure provides more accurate estimates. However, we further note that although the prices produced by the daily modeling for the base and build alternatives are always greater than those by the TOD modeling, the difference of the prices, i.e., the user benefit, is not necessarily an overestimate. Depending on the patterns of differences of system conditions across different time periods, the user benefit could be either overestimated or underestimated by the daily-basis modeling approach.

7.3 Modeling HOT Operations

Since the first HOT lane was implemented in 1995 on State Route 91 in Orange County, California, the concept has been becoming popular among governors and transportation officials, in state legislatures and the media. The proliferation of HOT lanes has imposed a pressing need to enhance travel demand models to assess more accurately their impacts in time and space. The state-of-the-practice of modeling HOT in travel demand forecasting still largely remains in the realm of the four-step transportation demand modeling arena.

Two approaches are generally applicable in FSUTMS to model HOT lanes: the modal-split and trip-assignment approaches. The former treats auto-trips on a toll facility as a distinct mode and then applies a nested logit model and a subsequent loading procedure to estimate the flows while the latter incorporates tolls into the generalized cost functions for route choice and then allocates trips among different paths using the notion of user equilibrium. Both approaches have pros and cons, but the trip-assignment approach may be more preferable. For the trip-assignment approach, a multiclass stochastic user equilibrium assignment model is recommended where different values of time may be used for classes with different trip purposes and income. To address the issue of overlapping paths, more advanced models or techniques can be adopted, such as the C-Logit model by Cascetta et al. (1996) and the subnetwork technique by Frejinger and Bierlaire (2007). Chapter 4 presents a practical procedure to model HOT lanes within the TOD framework of FSUTMS

Determination of tolls is another important practice for modeling HOT lanes. Ideally toll rates should vary dynamically and proactively in order to achieve the operating objectives of HOT lanes. In practice, several HOT lanes are priced dynamically, such as I-15 HOT lanes in San Diego and I-394 in Minnesota. Theoretically, the pricing strategies can be determined by combining principles from the static network models with concepts from analytical DTA. However, because of their extremely large size, existing DTA models are often intractable in determination of meaningful pricing strategies, especially those that are second best. Moreover, for the planning and policy analysis purpose, details of traffic dynamics should not be a major concern. Therefore, in the planning stage, we recommend treating traffic in each individual time period as static and determine fixed optimal toll rates accordingly for the time of day. Those TOD optimal tolls may serve as the base toll schedule and tolls may be adjusted marginally in response to the changing traffic conditions. Design of such real-time pricing strategies should be the concern of the operation analysis.

Chapter 4 further presents a bi-level programming model and a heuristic iterative procedure to solve the model to determine optimal toll rates. The iterative procedure can be easily implemented in FSUTMS.

7.4 Peak Spreading

The phenomenon of “peak spreading” may be broadly described as an overall increase in the duration of day during which the transportation system is congested. The effect of this phenomenon is a lengthening and flattening of the “peaks” of the temporal profile of travel demand. Rigorous analysis of peak spreading requires that the underlying travel demand models be sensitive to system capacity constraints (to capture passive spreading) as well as behavioral responses of travelers to congestion and policy actions (i.e. active spreading). Chapter 5 discusses the ability to capture the phenomenon of peal spreading within the FSUTMS framework using alternate approaches.

The use of constant TOD and peak hour factors is the simplest approach to capturing the temporal demand profiles. However, this approach is extremely limited in capturing the peak spreading phenomenon. At best, this methodology may be applied only in cases in which the issue of active peak spreading is not of interest and passive spreading is confined to one or two well-defined travel corridors. The TOD modeling approach is conceptually capable of more realistically capturing both active and passive peak spreading within the four-step travel forecasting framework. These models can also be readily implemented within available travel forecasting software such as CUBE. However, we also identify practical issues that make the robust estimations of TOD choice models difficult.

We conclude by noting that it is not always possible to completely capture the temporal dimension of travel demand and the related effects of peak spreading by simply introducing an additional TOD apportioning component (either using fixed factors or a time of day choice model) without any changes to the rest of the demand-forecasting framework. Specifically, it is necessary to incorporate a good representation of the transportation system characteristics, explore the use of dynamic assignment or traffic simulation methods, and explicitly accommodate heterogeneity in the travel behavior across different segments of the population for realistically capturing the temporal variability of travel patterns.

Finally, it is also useful to note that when the objective of the travel forecasting process increasingly becomes evaluating the impacts of policy actions which can result in complex temporal changes in travel behavior, it would be appropriate to start evaluating the adoption of activity-based travel modeling methods (which holistically describe the timing and durations of activity-travel behavior) instead of adding a TOD component to the trip-based/four-step demand modeling framework.

7.5 Pilot Implementation

A pilot implementation of the post-distribution TOD procedures for both the highway and transit modes has been conducted to enhance an original version of the Olympus training model powered by Cube Voyager. This exercise demonstrates the feasibility of building a post-distribution TOD factoring model within the CUBE/FSUTMS structure. We find that the run time of the enhanced model is almost double that of the model without any TOD factoring. We retained empirical factors and other constraints (such as the assumption on uniform distribution of demand within each TOD period) from the original model and compared the effects of structural changes to the model using system-wide performance measures for both the highway and the transit modes. We find that there are clearly differences between the 24-hour and the TOD models especially in terms of the average speeds and system travel times. However, the differences between the post-distribution and post-mode split models were minor (at least in the context of the highway performance measures).

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APPENDIX A. TEMPORAL PROFILES OF TRAVEL BY TRIP-PURPOSE, DIRECTION, AND SURVEY REGION

Table A1 Temporal profile of travel by trip-purpose and direction: NHTS-Fl/Urb (Unweighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1 - 2 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 - 3 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 - 4 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 - 5 AM	0.87	1.42	0.00	0.00	0.08	0.00	0.00	1.21	0.42	0.50	0.17	0.38	0.63
5 - 6 AM	2.73	0.00	0.66	0.00	0.00	0.00	0.69	0.00	0.42	0.00	0.35	0.00	0.37
6 - 7 AM	11.04	0.00	7.52	0.00	1.13	0.16	0.86	0.34	2.68	0.08	2.45	0.14	1.69
7 - 8 AM	13.44	0.33	16.15	0.00	0.89	0.40	1.55	0.00	5.02	1.42	4.42	0.64	3.28
8 - 9 AM	10.16	0.55	15.04	0.44	2.91	0.49	3.28	0.34	5.10	1.59	5.31	0.84	4.49
9 - 10 AM	3.93	0.22	3.54	0.66	4.13	2.02	2.93	0.34	4.52	2.26	3.98	1.65	5.71
10 -11 AM	1.64	0.00	1.55	0.66	6.23	4.29	3.28	1.38	3.43	2.26	4.16	2.63	7.61
11 - Noon	0.87	1.09	0.44	1.99	4.29	4.78	3.45	3.10	2.59	1.67	3.06	3.06	9.35
12 - 1 PM	1.42	1.86	0.44	1.33	3.72	3.40	4.14	2.24	3.43	4.10	3.26	3.18	10.30
1 - 2 PM	2.19	1.42	0.22	2.65	3.24	4.94	1.72	1.21	2.42	2.68	2.31	3.23	11.36
2 - 3 PM	2.30	3.17	1.77	8.19	3.00	3.89	1.55	1.72	3.34	4.18	2.71	4.19	8.40
3 - 4 PM	1.75	4.48	1.77	9.73	3.40	6.07	1.90	3.28	2.34	4.01	2.57	5.37	9.56
4 - 5 PM	0.77	7.98	0.44	7.96	2.51	6.23	3.10	3.45	3.34	4.10	2.63	5.26	8.56
5 - 6 PM	0.33	10.82	1.33	4.42	1.46	5.02	8.10	2.76	3.76	3.51	3.35	4.04	6.60
6 - 7 PM	0.11	5.25	2.21	1.55	2.27	5.43	6.38	5.34	3.68	3.26	3.44	4.16	3.59
7 - 8 PM	0.00	2.08	1.33	1.33	3.08	3.32	3.10	6.38	2.93	3.93	2.80	3.78	3.22
8 - 9 PM	0.00	1.42	0.44	0.66	1.05	2.43	1.72	4.66	1.42	3.68	1.21	3.00	2.32
9 - 10 PM	0.00	1.42	0.00	1.99	0.08	2.02	0.69	4.83	0.59	2.84	0.35	2.77	2.01
10 - 11 PM	0.00	0.66	0.00	1.55	0.16	0.97	0.86	5.69	0.17	1.34	0.26	1.96	0.48
11 - 12 PM	0.33	1.97	0.00	0.00	0.08	0.40	0.52	1.90	0.17	0.84	0.17	0.75	0.48
Total	53.88	46.12	54.87	45.13	43.72	56.28	49.83	50.17	51.76	48.24	48.97	51.03	100.00

Table A2 Temporal profile of travel by trip-purpose and direction: NHTS-Fl/Urb (Weighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1 - 2 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 - 3 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 - 4 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 - 5 AM	0.99	1.72	0.00	0.00	0.00	0.00	0.00	1.94	0.77	0.70	0.28	0.60	1.00
5 - 6 AM	3.09	0.00	0.76	0.00	0.24	0.00	0.38	0.00	0.53	0.00	0.46	0.00	0.57
6 - 7 AM	11.32	0.00	7.66	0.00	0.73	0.15	1.17	0.08	2.95	0.18	2.77	0.12	1.71
7 - 8 AM	12.63	0.44	17.25	0.00	1.04	0.37	1.67	0.00	6.17	1.44	5.71	0.63	3.91
8 - 9 AM	9.66	0.51	13.48	0.30	1.74	0.64	2.80	0.84	5.19	1.59	5.13	0.97	5.72
9 - 10 AM	3.69	0.27	3.99	0.49	1.25	2.36	2.01	0.26	4.75	1.75	3.12	1.45	5.05
10 -11 AM	1.51	0.00	1.26	0.56	1.82	4.74	2.92	1.07	2.99	2.53	2.35	2.58	7.02
11 - Noon	1.26	0.97	0.32	2.18	1.67	6.21	2.68	1.53	2.01	1.02	1.75	2.81	8.27
12 - 1 PM	1.34	1.92	0.47	1.72	2.16	4.12	3.47	2.22	2.98	4.22	2.42	3.42	9.66
1 - 2 PM	2.36	1.55	0.07	2.50	1.29	4.54	2.07	1.29	2.43	2.15	1.65	2.75	10.67
2 - 3 PM	1.81	3.18	3.26	8.04	1.11	4.17	1.78	2.20	2.97	4.64	2.27	4.63	7.38
3 - 4 PM	1.92	5.44	1.05	7.95	0.84	6.85	1.35	2.94	2.07	3.74	1.41	5.20	9.34
4 - 5 PM	0.89	7.41	0.18	10.02	3.20	7.36	5.14	1.90	3.97	4.40	3.33	5.74	8.94
5 - 6 PM	0.33	10.48	0.60	5.30	4.99	5.63	8.02	2.36	2.90	4.92	4.05	4.73	6.53
6 - 7 PM	0.08	5.29	2.70	1.46	3.77	7.44	6.06	5.48	3.28	2.65	3.82	4.35	4.06
7 - 8 PM	0.00	2.26	1.43	1.11	2.73	5.91	4.39	8.16	2.82	4.35	2.84	4.95	4.09
8 - 9 PM	0.00	1.62	0.46	0.08	1.05	3.01	1.69	4.29	1.41	3.53	1.20	2.94	2.71
9 - 10 PM	0.00	1.33	0.00	1.62	0.53	3.29	0.84	4.31	0.58	2.78	0.52	3.01	2.18
10 - 11 PM	0.00	0.80	0.00	1.75	0.54	1.20	0.86	6.95	0.09	1.06	0.34	2.27	0.52
11 - 12 PM	0.79	1.15	0.00	0.00	0.56	0.77	0.90	1.95	0.37	1.12	0.46	0.98	0.67
Total	53.66	46.34	54.93	45.07	31.24	68.76	50.23	49.77	51.24	48.76	45.88	54.12	100.00

Table A3 Temporal profile of travel by trip-purpose and direction: North East Florida (Unweighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.02	0.24	0.00	0.17	0.00	0.00	0.00	0.54	0.00	0.12	0.00	0.18	0.03
1 - 2 AM	0.00	0.09	0.00	0.04	0.03	0.00	0.00	0.10	0.00	0.12	0.01	0.06	0.01
2 - 3 AM	0.06	0.11	0.00	0.04	0.00	0.03	0.00	0.34	0.00	0.03	0.00	0.09	0.04
3 - 4 AM	0.17	0.02	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.09	0.00	0.06	0.01
4 - 5 AM	0.77	0.02	0.00	0.00	0.00	0.07	0.15	0.00	0.06	0.03	0.05	0.03	0.03
5 - 6 AM	2.94	0.15	0.08	0.00	0.03	0.03	0.73	0.05	0.52	0.06	0.32	0.04	0.28
6 - 7 AM	10.40	0.15	3.88	0.08	0.16	0.10	1.07	0.29	3.09	0.27	2.05	0.19	1.09
7 - 8 AM	17.96	0.58	21.26	0.93	0.91	0.16	3.11	0.19	6.67	0.70	7.57	0.50	3.71
8 - 9 AM	9.30	0.54	12.10	2.19	2.48	0.69	4.04	0.54	6.16	1.24	6.02	1.16	4.91
9 - 10 AM	3.26	0.28	2.70	1.01	4.31	1.73	4.18	1.27	4.76	1.52	4.07	1.42	4.79
10 -11 AM	1.22	0.28	1.98	0.59	6.21	2.84	2.29	1.41	3.61	1.43	3.74	1.64	6.01
11 - Noon	0.90	0.96	1.31	1.10	3.92	4.41	2.00	1.65	2.82	2.09	2.64	2.45	9.77
12 - 1 PM	1.69	2.19	0.97	1.86	1.76	3.85	0.88	2.00	1.52	3.25	1.34	2.87	12.20
1 - 2 PM	2.02	0.99	1.43	2.24	2.68	3.85	1.02	1.95	1.85	2.67	1.84	2.77	9.44
2 - 3 PM	1.26	1.84	2.11	7.00	2.35	4.34	0.63	1.80	2.15	2.55	1.91	3.89	8.52
3 - 4 PM	0.96	4.46	2.11	11.01	2.55	5.19	2.53	2.97	1.97	2.88	2.27	5.34	8.95
4 - 5 PM	0.81	7.10	1.01	3.63	2.65	6.73	3.31	3.21	1.61	4.12	2.10	4.58	8.54
5 - 6 PM	0.36	11.81	1.60	4.56	2.38	7.12	6.08	4.18	4.46	5.88	3.55	5.62	8.47
6 - 7 PM	0.41	5.59	1.14	2.78	2.87	6.73	6.52	6.08	4.97	4.70	3.83	5.12	5.52
7 - 8 PM	0.17	2.14	0.51	1.86	2.94	4.67	4.09	7.45	3.00	4.09	2.64	4.40	3.02
8 - 9 PM	0.15	1.35	0.25	1.77	0.85	4.05	1.41	5.11	0.49	6.43	0.71	4.48	2.15
9 - 10 PM	0.15	1.03	0.13	1.39	0.56	1.86	1.07	6.52	0.42	3.70	0.52	3.21	1.11
10 - 11 PM	0.28	0.94	0.04	0.59	0.23	0.82	0.58	3.80	0.12	1.03	0.22	1.40	0.42
11 - 12 PM	0.24	1.63	0.21	0.34	0.23	0.62	0.39	2.34	0.09	0.64	0.21	0.89	0.99
Total	55.52	44.48	54.83	45.17	40.10	59.90	46.08	53.92	50.35	49.65	47.61	52.39	100.00

Table A4 Temporal profile of travel by trip-purpose and direction: South East Florida (Unweighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.08	0.38	0.00	0.00	0.00	0.06	0.08	0.67	0.00	0.28	0.01	0.24	0.06
1 - 2 AM	0.04	0.22	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.09	0.00	0.11	0.04
2 - 3 AM	0.06	0.20	0.00	0.00	0.00	0.00	0.00	0.25	0.03	0.03	0.02	0.05	0.04
3 - 4 AM	0.12	0.10	0.00	0.00	0.06	0.00	0.00	0.17	0.03	0.03	0.03	0.04	0.04
4 - 5 AM	0.51	0.14	0.00	0.00	0.06	0.00	0.00	0.00	0.07	0.00	0.05	0.00	0.04
5 - 6 AM	2.05	0.08	0.16	0.00	0.25	0.00	0.67	0.00	0.21	0.07	0.26	0.04	0.31
6 - 7 AM	7.19	0.32	4.20	0.10	0.70	0.19	1.09	0.25	1.16	0.12	1.64	0.14	0.98
7 - 8 AM	15.76	0.36	27.49	0.31	2.47	0.25	3.35	0.17	6.31	0.94	9.29	0.63	4.59
8 - 9 AM	12.92	0.38	15.15	0.73	3.61	0.76	5.11	0.84	5.79	1.84	7.11	1.36	7.16
9 - 10 AM	3.87	0.22	2.33	0.41	5.57	1.46	5.03	0.67	3.68	1.73	3.87	1.33	5.46
10 -11 AM	1.90	0.30	0.62	0.36	7.03	2.78	2.60	2.43	2.70	2.95	2.96	2.39	7.36
11 - Noon	0.95	0.73	0.67	1.35	5.89	3.86	3.10	2.26	2.32	3.62	2.65	3.09	8.31
12 - 1 PM	1.07	1.40	0.67	1.56	4.81	2.72	2.26	1.51	1.89	3.59	2.15	2.85	10.71
1 - 2 PM	1.38	1.50	0.88	1.40	5.76	3.29	1.76	0.59	1.91	3.14	2.28	2.55	10.23
2 - 3 PM	1.46	1.86	0.52	12.09	3.73	2.47	3.27	2.18	2.44	4.82	2.38	5.50	9.04
3 - 4 PM	0.87	5.12	0.47	11.98	3.92	2.91	4.44	3.10	1.98	5.17	2.27	5.85	8.72
4 - 5 PM	0.63	7.21	0.41	5.96	4.05	2.66	3.60	3.52	2.36	5.91	2.40	5.16	7.51
5 - 6 PM	0.57	13.35	1.04	4.46	3.35	3.61	5.03	2.93	1.92	7.13	2.33	5.63	7.67
6 - 7 PM	0.49	6.24	0.36	2.13	3.86	2.15	6.37	3.35	2.53	5.22	2.77	3.97	4.63
7 - 8 PM	0.18	2.53	0.10	0.31	4.62	2.72	5.78	3.27	1.72	3.57	2.32	2.81	3.14
8 - 9 PM	0.18	1.50	0.16	0.47	1.46	3.23	2.26	3.10	0.92	3.16	1.01	2.66	2.05
9 - 10 PM	0.16	1.50	0.05	0.52	0.63	1.52	1.26	5.28	0.29	3.29	0.41	2.74	1.07
10 - 11 PM	0.20	0.83	0.00	0.31	0.44	0.51	0.67	3.43	0.21	1.80	0.26	1.52	0.37
11 - 12 PM	0.16	0.69	0.05	0.21	0.19	0.38	0.59	1.26	0.21	0.81	0.22	0.69	0.47
Total	52.81	47.19	55.34	44.66	62.47	37.53	58.29	41.71	40.69	59.31	48.68	51.32	100.00

Table A5 Temporal profile of travel by trip-purpose and direction: Tampa Bay (Unweighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.07	0.02	0.00	0.00	0.00	0.02	0.00	0.03	0.00	0.03	0.00	0.02	0.00
1 - 2 AM	0.06	0.04	0.00	0.00	0.00	0.02	0.00	0.07	0.03	0.00	0.01	0.02	0.02
2 - 3 AM	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
3 - 4 AM	0.22	0.02	0.00	0.00	0.02	0.00	0.03	0.00	0.00	0.00	0.02	0.00	0.03
4 - 5 AM	0.87	0.04	0.11	0.00	0.02	0.00	0.07	0.00	0.03	0.00	0.05	0.00	0.03
5 - 6 AM	2.85	0.06	0.05	0.05	0.07	0.00	0.30	0.03	0.25	0.00	0.17	0.02	0.07
6 - 7 AM	9.18	0.11	2.23	0.11	0.26	0.02	1.43	0.10	2.27	0.11	1.36	0.08	0.79
7 - 8 AM	17.40	0.43	22.60	1.79	1.45	0.31	2.76	0.17	5.07	0.48	5.76	0.53	3.16
8 - 9 AM	9.70	0.48	12.71	2.23	2.53	0.55	3.78	0.40	7.39	1.27	5.60	0.95	5.20
9 - 10 AM	3.29	0.43	3.59	1.30	5.92	1.98	5.28	0.86	6.94	2.21	5.72	1.69	6.25
10 -11 AM	1.34	0.37	0.65	0.49	6.96	4.09	3.05	1.33	5.41	2.35	4.73	2.46	9.11
11 - Noon	1.12	0.76	0.81	1.25	3.65	5.17	2.29	2.66	2.97	3.63	2.75	3.60	10.14
12 - 1 PM	1.23	1.47	0.92	2.01	2.16	4.95	2.56	2.12	2.49	3.51	2.17	3.48	11.75
1 - 2 PM	1.32	1.21	0.98	0.98	3.70	4.20	2.03	1.89	2.75	2.63	2.66	2.78	9.78
2 - 3 PM	1.19	1.81	2.01	10.05	3.19	4.67	1.93	2.66	2.01	2.78	2.41	4.45	8.64
3 - 4 PM	0.99	4.60	1.96	11.57	2.60	6.10	1.66	3.62	2.27	3.57	2.20	5.61	8.97
4 - 5 PM	0.76	8.49	1.20	3.80	2.58	6.12	2.92	4.68	2.29	4.02	2.38	4.88	8.12
5 - 6 PM	0.67	13.01	1.52	2.72	2.38	4.71	5.54	4.58	3.03	5.81	3.17	4.70	8.05
6 - 7 PM	0.65	5.16	1.68	1.47	2.75	4.20	5.48	5.11	4.47	3.99	3.71	3.97	3.89
7 - 8 PM	0.24	2.49	0.27	1.03	2.09	3.48	4.28	4.65	1.50	3.37	2.18	3.37	2.68
8 - 9 PM	0.11	1.30	0.43	2.06	0.88	2.99	1.39	5.18	0.62	3.48	0.87	3.50	1.38
9 - 10 PM	0.09	1.32	0.05	2.34	0.22	1.74	0.70	5.84	0.17	2.86	0.29	3.09	1.12
10 - 11 PM	0.22	1.17	0.05	0.71	0.11	0.48	0.10	4.15	0.14	0.85	0.11	1.47	0.35
11 - 12 PM	0.07	1.51	0.11	0.11	0.22	0.42	0.13	2.16	0.20	0.74	0.18	0.87	0.45
Total	53.69	46.31	53.94	46.06	43.76	56.24	47.71	52.29	52.31	47.69	48.46	51.54	100.00

Table A6 Temporal profile of travel by trip-purpose and direction: Tampa Bay (Weighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.03	0.73	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.01	0.00	0.01	0.00
1 - 2 AM	0.02	0.02	0.00	0.00	0.00	0.02	0.00	0.04	0.00	0.00	0.00	0.01	0.02
2 - 3 AM	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 - 4 AM	0.19	0.01	0.00	0.00	1.31	0.00	0.01	0.00	0.00	0.00	0.42	0.00	0.85
4 - 5 AM	0.39	0.02	0.01	0.00	0.01	0.00	0.02	0.00	0.01	0.00	0.01	0.00	0.01
5 - 6 AM	3.35	0.03	0.05	0.00	0.02	0.00	0.16	0.01	0.07	0.00	0.07	0.00	0.02
6 - 7 AM	8.50	0.06	1.17	0.03	0.13	0.00	2.50	0.06	2.18	0.04	1.39	0.03	0.52
7 - 8 AM	18.45	0.28	14.43	3.04	5.56	1.57	1.38	0.06	3.96	0.49	6.06	1.26	3.56
8 - 9 AM	9.54	0.34	15.56	1.98	2.35	0.73	2.12	0.18	5.78	0.50	5.90	0.80	6.88
9 - 10 AM	2.53	0.11	3.74	0.47	4.20	2.53	4.92	0.44	5.37	3.50	4.56	1.89	7.63
10 -11 AM	1.00	0.84	0.19	0.20	5.11	2.50	4.04	2.36	3.06	1.77	3.33	1.81	7.16
11 - Noon	1.11	1.13	1.34	3.21	2.23	4.05	1.58	1.75	1.68	2.05	1.76	2.86	8.37
12 - 1 PM	0.39	1.42	0.36	4.70	1.07	2.49	1.65	2.67	4.08	1.98	1.82	2.86	10.19
1 - 2 PM	1.20	0.43	2.31	0.40	2.64	5.77	2.83	0.90	3.26	1.00	2.77	2.37	9.24
2 - 3 PM	1.82	1.80	0.79	9.02	3.39	6.14	0.85	4.21	1.15	1.65	1.72	5.16	6.21
3 - 4 PM	0.66	4.98	2.68	7.90	1.89	4.60	1.05	1.93	3.01	6.61	2.15	5.20	10.50
4 - 5 PM	1.74	8.01	0.41	3.23	1.54	6.81	3.10	3.76	5.21	6.44	2.59	5.30	8.02
5 - 6 PM	0.38	11.27	4.62	5.19	3.12	4.59	4.81	3.84	4.21	6.37	4.08	5.00	7.10
6 - 7 PM	0.30	8.06	1.03	0.84	3.34	5.34	4.09	5.57	4.30	5.29	3.27	4.45	3.56
7 - 8 PM	0.82	1.84	0.13	0.40	1.36	3.11	5.94	4.76	1.83	3.16	2.24	2.93	4.04
8 - 9 PM	0.07	2.04	2.13	3.07	2.01	5.44	0.99	5.09	0.26	5.12	1.36	4.79	0.85
9 - 10 PM	0.06	0.80	0.00	5.04	0.17	1.89	2.22	5.69	0.08	2.49	0.57	3.54	3.00
10 - 11 PM	0.25	1.23	0.03	0.23	0.09	0.48	0.02	5.71	0.32	0.59	0.12	1.62	2.00
11 - 12 PM	0.03	1.69	0.09	0.01	0.15	0.23	0.16	6.51	0.07	1.04	0.12	1.79	0.27
Total	52.86	47.14	51.05	48.95	41.69	58.31	44.43	55.57	49.89	50.11	46.32	53.68	100.00

Table A7 Temporal profile of travel by trip-purpose and direction: Volusia (Unweighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.05	0.00	0.05	0.02
1 - 2 AM	0.00	0.16	0.00	0.00	0.00	0.06	0.00	0.10	0.08	0.05	0.05	0.06	0.02
2 - 3 AM	0.05	0.27	0.00	0.00	0.00	0.13	0.00	0.10	0.00	0.05	0.00	0.08	0.00
3 - 4 AM	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.02	0.02	0.00
4 - 5 AM	0.74	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.11	0.00	0.08	0.00	0.05
5 - 6 AM	3.08	0.21	0.59	0.00	0.06	0.00	0.49	0.00	0.16	0.03	0.20	0.02	0.00
6 - 7 AM	8.35	0.16	1.76	0.00	0.25	0.13	1.56	0.00	1.56	0.24	1.25	0.17	0.35
7 - 8 AM	19.46	0.27	25.29	0.00	0.89	0.19	2.63	0.39	7.17	1.19	5.40	0.79	3.28
8 - 9 AM	10.15	0.05	11.76	0.59	2.04	0.83	4.09	1.27	5.23	1.78	4.45	1.44	5.03
9 - 10 AM	3.03	0.37	1.18	0.00	5.47	1.59	4.58	0.97	5.20	1.56	5.06	1.44	5.47
10 -11 AM	1.12	0.16	2.35	0.59	7.45	3.95	3.70	2.34	4.91	1.94	5.26	2.45	8.70
11 - Noon	1.01	0.48	0.00	1.18	3.82	7.45	3.41	1.66	3.72	2.86	3.60	3.74	11.81
12 - 1 PM	1.28	1.75	1.76	2.94	3.18	5.86	3.02	2.24	2.75	2.67	2.87	3.38	12.48
1 - 2 PM	1.70	1.12	1.18	2.35	3.69	5.86	2.53	2.73	3.18	3.07	3.15	3.67	11.24
2 - 3 PM	0.74	2.18	0.59	10.59	3.82	5.03	2.53	3.12	2.88	4.66	3.00	4.66	9.32
3 - 4 PM	1.06	3.88	0.59	8.24	2.36	5.79	3.41	5.17	2.88	3.83	2.78	4.63	8.23
4 - 5 PM	0.90	9.14	1.76	8.24	1.78	6.24	2.83	4.19	2.56	4.82	2.39	5.16	7.50
5 - 6 PM	0.53	13.13	2.35	2.35	1.78	4.52	3.70	4.09	3.40	4.72	3.03	4.51	6.66
6 - 7 PM	0.37	5.00	1.76	1.76	2.36	4.26	5.46	5.56	3.48	3.96	3.47	4.23	4.78
7 - 8 PM	0.32	1.97	0.00	2.94	1.40	2.67	3.22	3.02	1.46	3.50	1.68	3.21	2.56
8 - 9 PM	0.21	1.65	0.00	2.35	0.64	2.48	0.49	6.14	0.62	4.15	0.59	4.01	1.21
9 - 10 PM	0.16	1.22	0.00	1.76	0.19	0.76	0.29	5.65	0.19	2.51	0.20	2.56	0.91
10 - 11 PM	0.21	0.96	0.00	1.18	0.13	0.45	0.10	2.24	0.03	0.59	0.06	0.83	0.30
11 - 12 PM	0.00	0.85	0.00	0.00	0.00	0.45	0.10	0.68	0.00	0.13	0.02	0.29	0.07
Total	54.81	45.19	52.94	47.06	41.31	58.69	48.25	51.75	51.59	48.41	48.60	51.40	100.00

Table A8 Temporal profile of travel by trip-purpose and direction: Volusia (Weighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.08	0.00	0.06	0.04
1 - 2 AM	0.00	0.16	0.00	0.00	0.00	0.05	0.00	0.20	0.06	0.04	0.03	0.07	0.03
2 - 3 AM	0.02	0.22	0.00	0.00	0.00	0.17	0.00	0.13	0.00	0.05	0.00	0.08	0.00
3 - 4 AM	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.15	0.01	0.09	0.00
4 - 5 AM	0.68	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.13	0.00	0.10	0.00	0.04
5 - 6 AM	2.63	0.19	0.72	0.00	0.11	0.00	0.51	0.00	0.13	0.05	0.21	0.03	0.00
6 - 7 AM	8.10	0.09	1.13	0.00	0.36	0.18	1.23	0.00	1.79	0.28	1.37	0.20	0.45
7 - 8 AM	19.04	0.19	26.98	0.00	0.94	0.35	2.39	0.34	9.31	1.42	7.42	0.96	4.38
8 - 9 AM	10.73	0.04	7.63	0.29	1.56	0.76	3.42	0.93	5.01	1.83	4.18	1.39	5.90
9 - 10 AM	2.50	0.28	0.43	0.00	4.63	1.42	3.90	0.79	4.36	1.26	4.14	1.15	5.24
10 -11 AM	1.35	0.27	2.27	0.52	6.91	3.52	3.66	2.13	4.13	1.51	4.54	1.98	7.39
11 - Noon	0.88	0.45	3.59	1.03	3.64	7.07	3.20	1.53	3.04	2.70	3.22	3.34	10.73
12 - 1 PM	1.23	1.69	0.61	3.55	2.53	5.92	2.26	2.17	2.56	2.42	2.41	3.17	12.38
1 - 2 PM	1.73	1.05	0.63	3.68	3.09	4.96	2.05	2.30	2.68	2.74	2.56	3.18	10.96
2 - 3 PM	0.69	1.90	0.45	9.97	3.26	4.64	2.65	2.39	2.71	4.51	2.70	4.49	8.75
3 - 4 PM	1.49	4.13	1.96	6.54	2.02	5.03	3.17	4.49	2.86	3.72	2.69	4.26	7.63
4 - 5 PM	1.35	9.12	2.02	6.16	2.41	5.89	2.93	4.08	2.31	4.74	2.41	4.95	7.51
5 - 6 PM	0.60	12.78	4.18	2.76	2.32	5.42	3.88	3.50	3.36	5.57	3.26	5.08	7.86
6 - 7 PM	0.32	5.27	0.00	2.07	2.90	5.73	6.34	6.81	3.76	4.18	3.78	4.80	5.19
7 - 8 PM	0.21	1.92	0.00	3.79	2.02	3.33	3.93	3.59	1.77	3.94	2.06	3.75	2.75
8 - 9 PM	0.29	1.94	0.00	1.81	0.78	3.21	0.69	6.79	0.62	4.31	0.63	4.33	1.27
9 - 10 PM	0.19	1.32	0.00	2.76	0.24	1.05	0.41	6.48	0.25	2.74	0.26	2.96	1.05
10 - 11 PM	0.13	1.33	0.00	2.49	0.10	0.89	0.13	2.94	0.04	0.71	0.06	1.18	0.34
11 - 12 PM	0.00	0.72	0.00	0.00	0.00	0.60	0.56	0.85	0.00	0.18	0.09	0.36	0.11
Total	54.63	45.37	52.58	47.42	39.82	60.18	47.46	52.54	50.87	49.13	48.13	51.87	100.00

Table A9 Temporal profile of travel by trip-purpose and direction: NHTS-Rural (Unweighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1 - 2 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 - 3 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 - 4 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 - 5 AM	1.37	0.86	0.06	0.03	0.05	0.02	0.21	0.96	0.23	0.19	0.13	0.23	0.22
5 - 6 AM	4.93	0.15	0.20	0.03	0.32	0.05	0.48	0.17	0.87	0.07	0.50	0.07	0.40
6 - 7 AM	11.05	0.09	3.09	0.00	0.73	0.00	0.55	0.10	2.54	0.31	1.75	0.12	1.23
7 - 8 AM	15.54	0.11	26.25	0.11	1.70	0.35	1.92	0.38	7.71	1.31	8.53	0.62	4.47
8 - 9 AM	6.66	0.18	10.88	0.37	2.87	0.76	2.47	0.51	5.15	1.69	5.13	0.94	4.58
9 - 10 AM	2.49	0.53	1.93	0.34	4.66	2.50	3.15	0.89	3.38	1.27	3.46	1.41	4.70
10 -11 AM	1.09	0.49	0.74	0.62	6.40	3.28	2.84	1.13	2.87	1.46	3.56	1.82	6.52
11 - Noon	1.00	1.13	0.88	0.68	3.60	4.47	2.05	1.75	2.86	1.90	2.57	2.44	9.60
12 - 1 PM	1.67	1.97	0.59	1.36	3.26	4.27	2.19	1.27	2.30	2.47	2.25	2.62	12.14
1 - 2 PM	1.46	1.44	0.48	0.99	3.79	4.04	1.61	1.95	2.35	2.40	2.32	2.57	9.88
2 - 3 PM	1.60	2.57	0.25	6.80	2.84	4.68	2.29	2.02	2.58	3.17	2.15	4.18	8.76
3 - 4 PM	1.31	6.28	0.34	17.50	3.09	6.10	2.88	2.74	3.10	4.61	2.51	7.33	9.79
4 - 5 PM	0.95	8.96	0.59	4.11	3.05	6.33	5.03	4.18	2.82	4.95	2.81	5.09	8.36
5 - 6 PM	0.56	10.56	1.81	3.77	2.38	5.53	5.82	5.03	4.04	4.67	3.36	4.82	7.00
6 - 7 PM	0.66	3.95	3.85	1.56	2.46	3.88	8.25	4.86	4.70	4.49	4.41	3.78	4.65
7 - 8 PM	0.24	1.98	1.27	2.29	2.07	2.89	4.14	5.51	2.61	4.28	2.43	3.65	3.18
8 - 9 PM	0.16	1.75	0.08	3.26	0.85	2.93	1.30	4.83	0.64	4.63	0.71	3.85	2.73
9 - 10 PM	0.02	1.66	0.03	2.32	0.25	2.06	0.41	7.71	0.33	2.82	0.26	3.28	1.27
10 - 11 PM	0.09	1.06	0.00	0.34	0.11	0.94	0.45	3.80	0.21	1.17	0.17	1.36	0.31
11 - 12 PM	0.09	1.37	0.00	0.20	0.09	0.34	0.07	2.09	0.12	0.71	0.08	0.72	0.21
Total	52.95	47.05	53.33	46.67	44.57	55.43	48.12	51.88	51.42	48.58	49.09	50.91	100.00

Table A10 Temporal profile of travel by trip-purpose and direction: NHTS-Rural (Weighted)

	Home-based Work		Home-based School		Home-based Shopping		Home-based Social/Recreational		Home-based Other		Home-based Non Work		Non Home Based
	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A	A-P	P-A
12 - 1 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1 - 2 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 - 3 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 - 4 AM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 - 5 AM	1.67	1.16	0.01	0.03	0.05	0.01	0.22	1.01	0.17	0.30	0.11	0.27	0.18
5 - 6 AM	5.26	0.12	0.22	0.01	0.52	0.07	0.56	0.24	0.86	0.11	0.57	0.10	0.50
6 - 7 AM	10.90	0.09	3.24	0.00	0.68	0.00	0.45	0.05	2.38	0.24	1.71	0.09	1.30
7 - 8 AM	15.38	0.12	26.69	0.19	1.68	0.35	1.90	0.52	7.75	1.22	8.85	0.62	4.59
8 - 9 AM	6.03	0.19	9.91	0.38	3.11	0.77	2.59	0.38	5.25	1.88	5.12	0.97	4.89
9 - 10 AM	2.31	0.40	2.29	0.38	4.40	2.59	3.53	1.11	3.25	1.13	3.45	1.42	4.52
10 -11 AM	1.02	0.50	0.71	0.75	6.09	3.11	3.06	1.03	2.63	1.75	3.36	1.84	6.20
11 - Noon	1.28	1.06	0.63	0.58	3.50	4.27	1.81	1.52	2.25	1.63	2.22	2.20	9.29
12 - 1 PM	1.67	2.05	0.67	1.23	3.37	4.01	2.08	1.42	2.25	2.13	2.24	2.40	11.77
1 - 2 PM	1.28	1.54	0.37	1.17	3.37	3.50	1.57	2.09	2.38	2.50	2.13	2.46	9.29
2 - 3 PM	1.67	2.69	0.31	7.24	2.72	4.27	2.31	1.97	2.38	3.00	2.04	4.10	8.67
3 - 4 PM	1.54	6.03	0.36	16.97	3.24	6.09	2.59	2.27	3.00	4.50	2.45	7.20	9.91
4 - 5 PM	1.00	8.97	0.44	4.38	3.11	6.22	4.70	3.76	2.75	5.00	2.71	5.04	9.29
5 - 6 PM	0.54	10.51	2.10	4.00	2.46	5.83	5.41	4.70	3.75	4.88	3.29	4.96	6.82
6 - 7 PM	0.56	3.72	3.43	1.88	2.72	4.01	8.47	4.94	5.25	4.25	4.64	3.80	4.59
7 - 8 PM	0.17	2.05	1.04	2.29	2.20	2.85	4.23	5.64	2.88	4.38	2.52	3.69	3.16
8 - 9 PM	0.21	1.54	0.23	2.67	1.19	3.11	1.35	4.47	0.81	5.00	0.90	3.85	3.10
9 - 10 PM	0.03	1.67	0.04	2.48	0.29	2.46	0.53	7.53	0.40	3.00	0.31	3.49	1.30
10 - 11 PM	0.17	1.28	0.00	0.34	0.13	1.18	0.86	4.47	0.28	1.38	0.27	1.62	0.36
11 - 12 PM	0.11	1.54	0.00	0.32	0.09	0.42	0.08	2.59	0.18	0.87	0.10	0.91	0.25
Total	52.78	47.22	52.69	47.31	44.90	55.10	48.30	51.70	50.85	49.15	48.98	51.02	100.00

APPENDIX B. DEVELOPMENT OF TOD FACTORS FOR RURAL AREAS USING CONTINUOUS COUNT DATA

In this appendix, the development of TOD factors for rural areas from continuous vehicle count data is presented. Further, these factors are developed only for total volumes of vehicle trips, *i.e.*, the factors are not distinguished by trip purpose or by direction. Continuous count stations typically provide hourly directional counts for each day of the year. From these, the weekday average (over the year) volumes are computed for each hour and these are used as the basis for the determination of the TOD factors. It is important to note that these data may be more descriptive of the temporal distribution of long-distance trips rather than local trips. At the same time, these data are specifically from rural areas in Florida (unlike the NHTS-based analysis presented in Chapter 2).

The hourly vehicle count data used for the determination of TOD factors for rural areas were obtained from the 2004 Florida Traffic Information (FTI) CD ROMs. This CD provides data for over 250 continuous count stations across Florida. For the purposes of this research, the focus was restricted to rural stations in the north western (between Tallahassee and Pensacola) and south western (around Fort Meyers) parts of the state [The reader will note that the chosen areas are the predominantly rural portions of the state]. The rural stations were identified based on the location information provided about the count stations and mapping web sites. Nine stations with complete data (all days for an entire year) were identified and are used in this analysis (Table B1).

Table B1 Details of continuous count station locations used in analysis

Count Station Number	Location	Nearest Town/City within County
50272	SR-78,0.9 MI NORTH OF US-27,GLADES CO.	Moore Haven
470337	SR-71,.4 MI N JIM GODWIN RD,BLOUNTSTOWN,CALHOUN CO	Blountstown
480243	SR-97,1.3 MI S OF ALABAMA STATE LINE,ESCAMBIA CO.	Century
510316	SR-30/US-98,0.2 MI E OF CR-30A,PORT ST JOE,GULF CO	Port St. Joe
529939	SR-2,0.97 MI WEST OF CR-173,HOLMES CO.	Noma
539943	SR-10/US-90,1.1 MI W OF SR-69,CYPRESS,JACKSON CO.	Cypress
560301	SR-12,1.7 MI S OF GADSDEN COUNTY LINE,LIBERTY CO.	Bristol
580285	SR-89,1270' SOUTH OF CR-164,SANTA ROSA CO.	Jay
610254	SR-77,406' NORTH OF LONNIE ROAD,WASHINGTON CO.	Wausau

As in the case of the analysis for urban areas, the temporal profiles of traffic volumes were examined to determine the peak periods (see Figures B1 and B2). Based on this analysis, the peak periods were determined to be the same as in the case of urban areas. Hence, the five TOD periods are: Morning (midnight – 7 AM), AM Peak (7-9 AM), Midday (9 AM – 3 PM), PM Peak (3 – 6 PM), and Evening (6 PM – midnight).

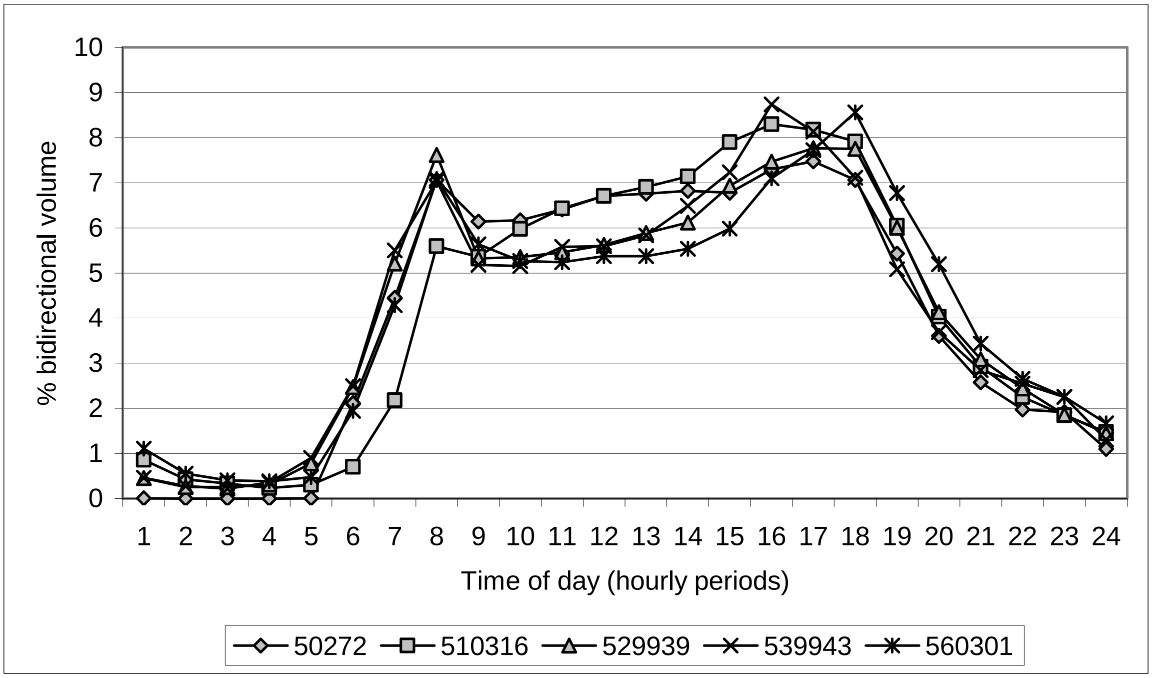

Figure B1. Temporal distribution of trips: count stations with east-west flows

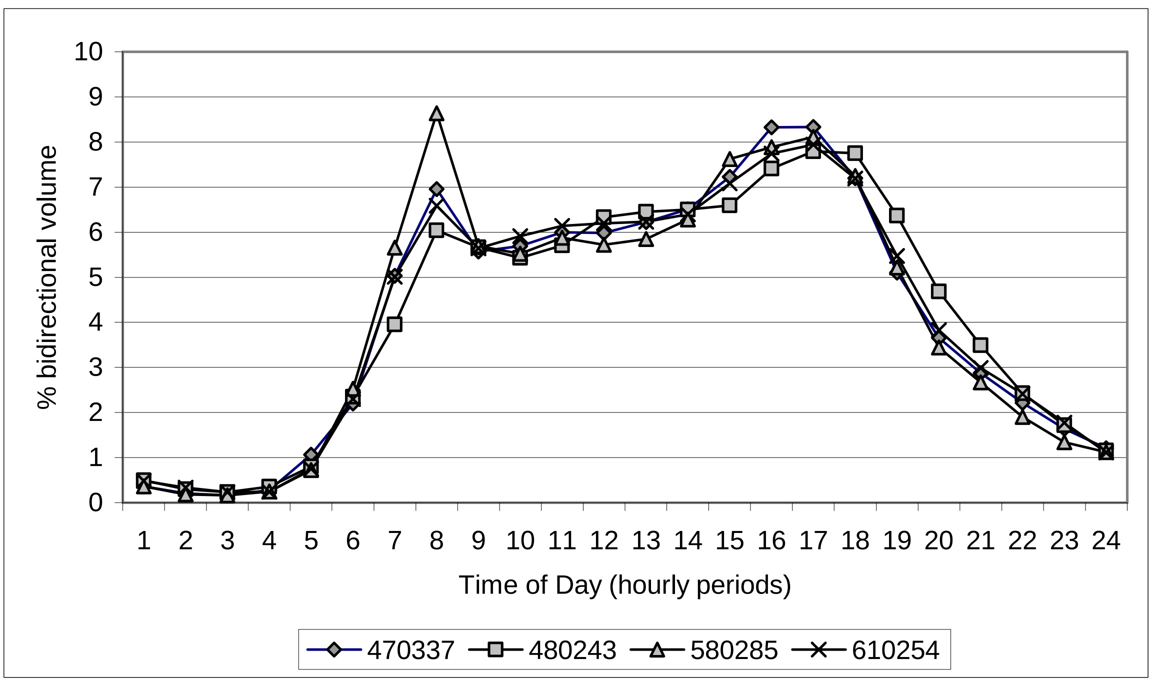

Figure B2. Temporal distribution of trips: count stations with north-south flows

The traffic volumes were then suitably aggregated to determine the TOD and peak hour factors (Table B2). These results presented in the table below are based on the data from all the nine count stations taken together.

Table B2. TOD and Peak-hour factors

	TOD factor	Peak hour factor
Morning (midnight -7 AM)	8.92	51.52
AM Peak (7-9 AM)	17.97	54.91
Mid day (9 AM -3 PM)	31.71	18.84
PM Peak (3-6 PM)	23.27	34.16
Evening (6 PM - midnight)	18.13	31.24