Use of Dynamic Traffic Assignment in FSUTMS in Support of Transportation Planning in Florida

Final Report

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By the

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Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Metric Conversion Chart

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^{o}F	Fahrenheit	5*(F-32)/9 or (F-32)/1.8	Celsius	^{o}C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	pound force	4.45	newtons	N
lbf/in^2	pound force per square inch	6.89	kilopascals	kPa

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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16. Abstract

There have been considerable advancements in the research and development of simulation-based dynamic traffic assignment (DTA) modeling approaches. However, there are many issues that need to be addressed for the successful and optimal implementation of DTA.

The goal of this project is to develop processes and associated tools for a successful implementation of dynamic traffic assignment in Florida. The specific activities of the project are: review state-of-the-art applications of DTA modeling, identify the needs and issues related to DTA implementation in Florida, develop processes to allow assessment of the abilities of existing DTA tools to meet the identified needs, develop tools to support effective and efficient use of the DTA, and document the project effort and results.

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Executive Summary

The past few years have seen a considerable interest in applying Dynamic Traffic Assignment (DTA) to support transportation system planning and traffic engineering analyses. Modelers have realized that static assignment methods cannot consider the effects of the variations of traffic flows over time, dynamic changes in transportation systems, congestion impacts, and advanced strategies and technologies. Thus, DTA, in most cases, combined with traffic simulation models, has been proposed to provide more realistic representations of traveler behaviors and time-variant traffic conditions, allowing better modeling of traffic congestion effects and alternative solutions to these effects.

There have been considerable advancements in the research and development of simulation-based DTA modeling approaches. These approaches have been implemented as parts of a number of off-the-shelf DTA tools, which vary in their capabilities and the underlying models and procedures used. Some of these tools have been released as open source software, allowing further improvements and customization to specific needs.

The Florida Modeling Task Force (MTF), with input from the transportation planning community in Florida, has identified the incorporation of DTA in conjunction with the demand forecasting and transportation system analysis as a high priority required improvement to the current modeling practices. However, there are many issues that need to be addressed for the successful and optimal implementation of DTA. Despite advancements in DTA research and development, major efforts are still needed to support widespread applications of DTA, including providing transportation agencies with detailed understanding of the capabilities and limitations of existing DTA models as well as guidelines, methods, and tools to support DTA applications.

The goal of this project is to develop processes and associated tools for a successful implementation of dynamic traffic assignment. The specific objectives are:

- Review state-of-the-art and applications of DTA modeling
- Identify the needs and issues related to DTA implementation in Florida

- Develop processes to allow assessment of the abilities of existing DTA tools to meet the identified needs
- Develop tools to support effective and efficient use of the DTA
- Document the project effort, results, and conclusion

The report does **<u>NOT</u>** compare one package against another. Different software packages may be required for different purposes, and to say that one package is better than another for all applications would be completely inappropriate.

Review of State-of-the-Art and Applications of DTA

The review of DTA research and documentations available about DTA methods and tools revealed that these tools and methods vary considerably in their implementations of DTA components. These variations include the determination of time-dependent shortest path (TDSP), assigning traffic to these paths, loading the traffic to the network and assessing performance utilizing simulation models, and assuring convergence of the solution. It is important to understand the differences between the implementations of DTA in different tools and how these differences affect the computational performances and the quality of the solutions of these tools.

Identification of DTA Issues

DTA issues were identified in this study using a combination of methods, including a detailed review of DTA research and documentations available about DTA methods and tools, a survey of the modeling community in Florida, a user needs workshop, and a phone interview with agencies that had experience with DTA applications. The results from these methods were informative and were documented, analyzed in detail, and used to guide other tasks of the project.

The survey addressed issues such as how DTA will be most useful as part of the modeling process, the main technical and institutional constraints to DTA applications, the maximum size of the network that the DTA must be able to handle, the needed temporal model resolution (the

assignment period), the required details of modeling, and the needed support of the modeling community.

The DTA user needs workshop was attended by approximately 50 modelers. The research team made a presentation of the state-of-the-art in DTA modeling, which was followed by interactive discussion. The areas covered in the discussion included DTA model alternatives, hardware/software issues, calibration requirements, convergence, data requirements, intersection modeling, relationship to traditional four-step models, and integration with activity-based models.

The interviews with users who have applied DTA in their analyses covered issues such as the size of the network analyzed, purpose of the analysis, additional information provided by DTA analysis, level of technical support, levels of difficulty, and other related issues.

Development of Assessment Criteria

A catalog of assignment assessment criteria was produced in this study to form a basis for comparing the capabilities of different assignment platforms. These requirements were based on the identified issues, derived as described above. The purpose of developing the criteria was not to select a specific DTA tool for use in Florida, but to provide a mechanism for the assessment of different tools and methods, relative to the criteria. It is recognized that not all of the identified criteria are applicable in all cases, and agencies can select a subset of these criteria for the particular application under consideration.

To assist the agencies in this selection, a statement was given for each of the requirements in the catalog, specifying whether the requirement should be considered as a general requirement for all applications, or for specific types of applications such as long range plan modeling, short range plan modeling, planning for operations/intelligent transportation systems (ITS), and/or corridor/impact studies. The criteria covers general hardware and software, shortest path and path choice modeling, traffic flow modeling (TFM), network geometry modeling, network

demand modeling, transit modeling, and calibration/validation and convergence assurance support.

Utilization of Assessment Criteria

The project also included a demonstration of how the developed assessment criteria can be used to examine DTA tool capabilities. For this demonstration, the static Cube assignment currently included in the FSUTMS models and three existing DTA tools were assessed utilizing the developed criteria. The three DTA tools included two open-source tools originally developed with support of the USDOT (DynusT and TRANSIMS) and a DTA tool (Cube Avenue) from the developer of Cube, the modeling engine of the FSUTMS. The assessments were conducted utilizing a number of simple, hypothetical networks and three real-world networks, depending on the test under consideration. Other assignment tools can also be assessed using the assessment criteria presented in the previous section and the assessment procedure presented in this section.

Development of Support Environment

A support environment referred to as Integrated System Support for Trip Assignment (ISSTA) was developed in this project to satisfy identified needs for calibration and development support of DTA applications. ISSTA allows the use of data from multiple sources, different developed and existing tools, and existing techniques to support static or dynamic trip assignment. The tool supports dynamic (time-variant) trip matrix estimation at a fine-grained resolution (15-30 minutes) based on available trip matrices from demand forecasting models and count data. In addition, the tool supports the model calibration process, in which an adjustment is made to model parameters to produce measures comparable to those observed in the real world. ISSTA is also able to import and use data from multiple sources as needed, as long as the data is coded in standard formats to support model development and calibration.

Project Findings and Recommendations

Travel modeling is in the midst of an evolution away from static assignment and trip-based paradigms to dynamic assignment and activity based models. Both the dynamic assignment and tour based approaches provide much greater detail in modeling network conditions and individual behavior, both of which are needed to address today's transportation issues. However, to get to this end point, further work needs to be done in the short term and long term. Based on the findings of this project with regard to the methods, tools, applications, benefits and issues of DTA, this project provides recommendations to allow Florida to move forward toward the goal of wide spread implementation of DTA.

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List of Abbreviations

ABM	Activity-Based Modeling
AE	Assignment Environment
AMS	Anisotropic Mesoscopic Simulation
API	Application Programming Interface
ATIS	Advanced Traffic Information System
AVL	Automatic Vehicle Location
BPR	Bureau of Public Roads
CS	Corridor/Impact Studies
DCAP	Data Capture and Performance Management
DMS	Dynamic Message Signs
DTA	Dynamic Traffic Assignment
DUE	Dynamic User Equilibrium
DynusT	Dynamic Urban Systems for Transportation
EPA	Environmental Protection Agency
ETL	Express Toll Lanes
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FSUTMS	Florida Standard Urban Transportation Modeling System
GFV	Gap Function Vehicle-Based
GIS	Geographic Information Systems
GPL	General-Purpose Lanes
GUI	Graphical User Interface
HCM	Highway Capacity Manual
HOT	High Occupancy Toll
HOV	High-Occupancy Vehicles
ISSTA	Integrated System Support for Trip Assignment
ITS	Intelligent Transportation Systems
LRP	Long Range Plan
ME	Matrix Estimation
ML	Managed Lanes
MOVES	Motor Vehicle Emission Simulator
MPO	Metropolitan Planning Organization
MSA	Method of Successive Averages
MTF	Modeling Task Force
NERPM	Northeast Florida Regional Planning Model
O-D	Origin-Destination
ODME	Origin-Destination Matrix Estimation
PA	Packet Allocation
PC	Passenger Car
PO	Planning for Operation

PS	Packet Split
SERPM	Southeast Florida Regional Planning Model
SHRP2	Strategic Highway Research Program2
SIR	Speed Influencing Region
SO	System Optimal
SOV	Single Occupancy Vehicle
SRP	Short Range Plan
TDM	Transportation Demand Model
TDSP	Time-Dependent Shortest Path
TFM	Traffic Flow Modeling
TMIP	Travel Model Improvement Program
TOD	Time of Day
TOT	Truck Only Toll
TRANSIMS	Transportation Analysis and Simulation System
TRB	Transportation Research Board
UE	User Equilibrium
USDOT	United States Department of Transportation
VMT	Vehicle Mile Traveled

1.   Introduction

1.1   Background Statement

Traffic assignment is a critical component of travel demand forecasting models and transportation system analysis. It can be defined as the allocation of trip-based or activity-based demands to transportation network routes to produce a set of link flows, by considering various factors that affect traveler's route choice. Some of the objectives of assignment are listed below (Ortuzar and Willumsen, 2001):

- Obtaining estimates of link flows and identifying congested links
- Estimating zone to zone travel cost for use in other modeling steps, such as trip distribution and mode split
- Estimating performance measures at the network, facility, and link levels
- Estimating comparative routes and associated demand for each origin-destination (O-D) pair
- Estimating diversion due to recurrent and non-recurrent congestion with and without the provision of traveler information
- Analyzing which O-D pairs use a particular link or route
- Obtaining turning movements at intersections and flows between on- and off-ramps on a freeway corridor

Traffic assignments can be categorized into static and dynamic assignments. Static assignment assumes that link flows and link travel times remain constant over the modeling horizon. In dynamic traffic assignment (DTA) models, the link flows and link travel times are time-variant. Existing demand forecasting models, including those associated with the Florida Standard Urban Transportation Model Structure (FSUTMS), use static traffic assignment as part of the travel demand forecasting process. DTA provides a more realistic representation of traveler behaviors and traffic conditions and provides a better approach for assigning traffic and estimating travel cost and time, thus supporting better demand and performance measure forecasting. This is particularly important for time-of-day modeling, congested networks, operational analysis, and when evaluating the impacts of management strategies, such as intelligent transportation systems

(ITS), signal timing, managed lanes, and congestion pricing. However, the implementation requirements of DTA are much higher. (NOTE: Multiple definitions have been proposed for DTA. This paper assumes a very generic definition in that a DTA is a process that incorporates time into the assignment process. This can include simulation as well as the more traditional DTA.)

The state-of-the-art of simulation-based DTA was significantly advanced by Professor Mahmassani at the University of Texas (now at Northwestern University) and Professor Ben-Akiva at Massachusetts Institute of Technologies with research funding provided by the United States Department of Transportation in the 1990s. Since the original development, several DTA packages have been developed and more advanced versions of the original methods have been incorporated into these packages.

Not only has the concept of DTA expanded, but applications of DTA tools have also expanded. Originally designed for the analysis of vehicles in traffic, advanced DTA tools can now include tracking of the movement of people as well as vehicles and the explicit representation of person travel on transit as well as on the highway network. Advanced DTA tools are currently being combined with activity based models to provide for the estimation of both demand and network conditions for all modes on a continuous basis throughout the day.

A number of tools have been developed to perform DTA. These tools vary in their capabilities and in the underlying models and procedures used in these tools. Some of these tools are or are expected to be open source allowing further improvements and customization to specific state needs.

In April 2009, the TRB Network Modeling Committee conducted a DTA user survey through the FHWA Travel Model Improvement Program (TMIP) mail list. This survey showed that more than 70% of the 85 respondents plan to apply DTA tools within 2 years. On the other hand, they also clearly identified the following top 5 technical and institutional barriers (Tung and Chiu, 2011).

- DTA requires more data than is often available or accessible (47%)
- Setting up a DTA model takes too much resources (44%)
- Cost/benefit is unclear (45%)
- DTA tools take too long to run (35%)
- Modeling approaches are unclear (35%)

Addressing these concerns is an extremely important and challenging task, as DTA is increasingly being considered for implementation.

The Florida Modeling Task Force (MTF), with input from the transportation planning community in Florida has identified the incorporation of dynamic traffic assignment in conjunction with the demand forecasting and transportation system analysis as a high priority required improvement to the current modeling practices.   However, there are many issues that need to be addressed for the successful and optimal implementation.

1.2   Goal and Objectives

This project goal is to develop processes and associated tools for a successful implementation of dynamic traffic assignment. The objectives of this project are:

- Review state-of-the-art in DTA modeling
- Identify the needs of the Florida demand modeling with respect to DTA
- Develop processes to allow assessment of the abilities of existing DTA tools
- Develop tools to support effective and efficient use of the DTA
- Document the project effort, results, and conclusion

The report does **NOT** compare one package against another. Different software packages may be required for different purposes and to say that one package is better than another for all applications would be completely inappropriate. In addition, the DTA field and DTA methods continue to rapidly evolve. As an example, during the two-year course of this project both DynusT and TRANSIMS, the packages used in the SHRP2 program, have undergone significant improvements in application capability and run time reduction. Cube Avenue has also been

improved. In addition, computer hardware continues to rapidly evolve, providing significant increases in speed and corresponding decreases in run time. It is important to understand various aspects of DTA and how to compare existing methods and tools to make informed decisions and effective applications of DTA.

1.3   Overview of Project Activities and Document Organization

This section presents the project activities and the related chapters in this document.

Review of DTA Literatures and Tools: This task included a review and assessment of existing DTA modeling components and tools. The results of this task are documented in **Chapter 2** of this document. This chapter first introduces the DTA concept and then discusses the main components of DTA for the purpose of understanding these components and differentiating between the different implementations of these components in different tools. The main DTA components are the time-dependent shortest path identification, assignment of the trip demands to the identified attractive paths (and the associated convergence assurance), and network loading based on traffic flow models. Then, this chapter presents an overview of existing off-the-shelf DTA tools that have been used by the modeling community.

Coordination and Outreach Activities: This project has included extensive coordination and outreach activities with the FDOT management team and the transportation demand modeling community in Florida that are described in **Chapter 3**. These included the formation of a subcommittee with members from the modeling community in Florida, the formation of a project review group, conducting a DTA User Survey, and conducting a requirement workshop.

Identification of Assessment Criteria Catalog: **Chapter 4** includes assessment criteria for an advanced assignment environment (AE) in Florida. The main purposes of writing these assessment criteria is to allow the comparison and testing of various assignment methods and tools including static and dynamic assignment. These criteria are based on the review of literature, the requirement workshop of this project, and a survey of the modeling community conducted as part of this project. It should be recognized that some of the criteria might not be

satisfied by any existing methods and tools. The criteria are written based on the needs rather than the existing capabilities of assignment tools.

Utilization of Criteria to Assess Assignment Tools: **Chapter 5** presents a demonstration of how the assessments criteria presented in Chapter 4 can be used to assess different assignment tools and methods. For this demonstration, an assessment is made of the ability of the static Cube assignment currently included in the FSUTMS models and three existing DTA tools to meet the criteria presented in the requirement catalog. These three DTA tools are two open source tools originally developed as part of USDOT efforts (DynusT and TRANSIMS) and a DTA tool (Cube Avenue) from the developer of Cube, the modeling engine of the FSUTMS. Other assignment tools can also be assessed using the assessment criteria.

Development of Assignment Support Tool: **Chapter 6** presents an environment developed in this study incorporating tools to support advanced assignment applications such as importing data from different real-world sources (ITS data, statistics office data, private sector data, etc.), visualizing and summarizing the data, converting other tools inputs, estimating time-variant O-D matrices, supporting the calibration process, and convergence support. Additional tools and processes can be added to this tool in the future.

2.   Review of Literature

This chapter includes a review and assessment of existing DTA modeling components and tools. First, this chapter presents an overview of the DTA concept and then discusses the main components of DTA, differentiating between the different implementations of these components in different tools and the implications of these differences. The main DTA components are the time-dependent shortest path identification, assignment of the trip demands to the identified attractive paths (and the associated convergence assurance), and network loading based on traffic flow models. Then, this chapter presents an overview of existing off-the-shelf DTA tools that have been used by the modeling community.

2.1   Overview of the DTA Concept

Traffic assignments can be categorized into static and dynamic assignments. Static assignment assumes that link flows and link travel times remain constant over the modeling horizon. In dynamic traffic assignment (DTA) models, the link flows and link travel times are time-variant.

Despite the differences between static assignment and DTA, these two categories of assignments share basic concepts. Thus, the discussion of dynamic traffic assignment in this chapter also includes a discussion of basic concepts from static assignment.

The main components in assignments are (Ortuzar and Willumsen, 2001, Sheffi 1985):

- Time-dependent shortest path identification (also referred to as tree-building): This includes the identification of a set of attractive paths (routes) between each O-D pair in the system. In DTA, this component includes updating the set of attractive paths given the updates to the estimated travel times of the paths during the assignment process (Peeta and Ziliaskopoulos 2001).
- Assignment of the trip demands to the identified attractive paths: This component results in the estimation of link flows by assigning the demands to the competing attractive paths. In DTA, the proportions of demands assigned to each path are

calculated for each assignment time period. In general, a time period of 15-30 minutes is most widely used.

- Network loading: This component refers to the representation of the movement of vehicles in the network as they travel from their origins to destinations. Network loading allows the estimation of performance measures for use in the assignment such as route travel time between origins and destinations. In DTA models, network loading procedures can be classified as analytical procedures or simulation procedures. Due to the complexity of traffic operations, particularly with the presence of congestion and traffic control, simulation-based procedures are the most widely used at the present time.

Figure 2-1 shows an overview of the DTA process (Mahut et al., 2007). More details about each of the above components are presented in the sections below.
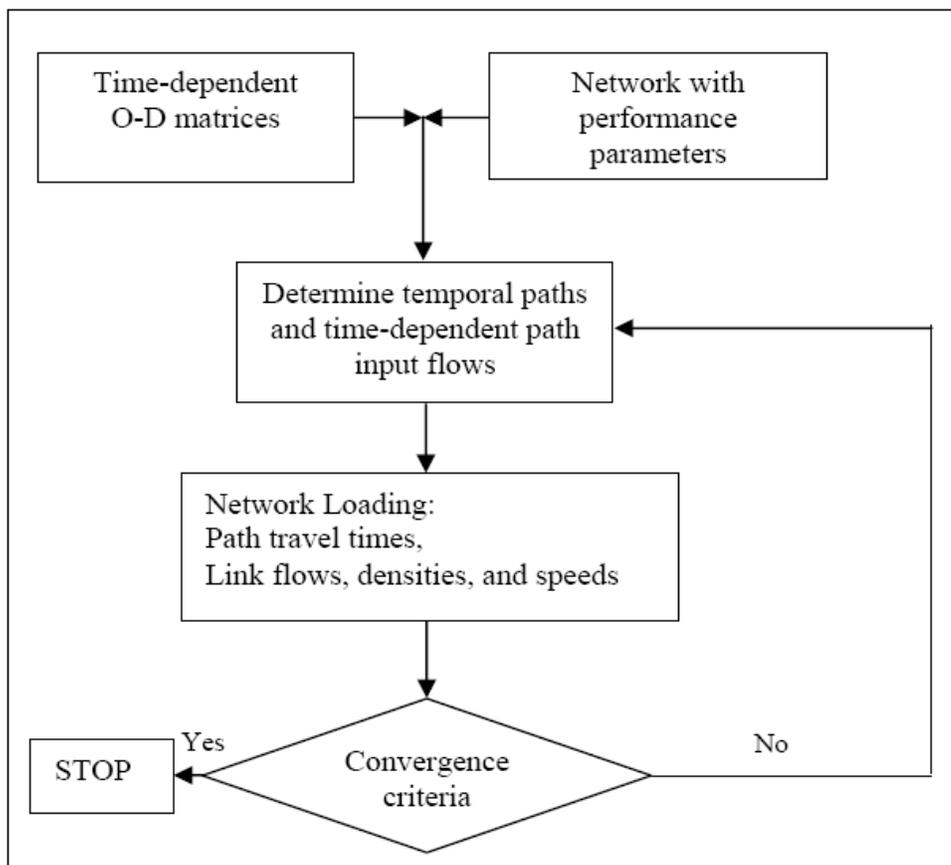
Figure 2-1 Structure of the solution algorithm for the DTA model (Mahut et al. 2007)

2.2   Assignment Types

Three different types of DTA have been implemented in DTA tools: non-iterative (sometimes referred to as one-shot dynamic assignment), dynamic user equilibrium (iterative) assignment, and system optimal (iterative). User Equilibrium (UE) assignment is the most widely used and involves assigning portions of the flow to a number of attractive alternative paths such that an equilibrium condition is achieved. This principal of equilibrium is referred to Wardrop's first principal that states: "Under equilibrium conditions traffic arranges itself in congested networks in such a way that no individual trip maker can reduce his/her path costs by switching routes." (Ortuzar and Willumsen, 2001). Ran and Boyce, (1996) provided the following definition of the user equilibrium principle in DTA, which is referred to as dynamic user equilibrium (DUE) as follows: "for each O-D pair at each interval of time, if the actual travel times experienced by travelers departing at the same time are equal and minimal, then the dynamic flow over the network is in a travel time-based ideal dynamic user-optimal state." An important distinctive feature of DUE implemented as part of DTA is that the user equilibrium assumption of equal travel times on the utilized routes is applicable only to travelers who leave their origins in the same time interval between the same O-D pair.

Equilibrium emulates the long-term selection of drivers of their routes assuming that they are familiar with the recurrent congestion in the network. This principle implies two assumptions: all users exhibit rational behavior in trying to minimize their costs and that they are familiar with the network condition. Since most applications of DTA are related to the user equilibrium principle, most of the discussion related to DTA components are related to such applications.

The assumptions associated with UE are not valid under all conditions. For this reason, the Dynasmart software (and other tools that derived from it such as DynusT, see: Mahmassani et al., 2009, Chiu et al., 2012) allows non-iterative assignment that involves assigning the whole volume in one iteration. This procedure is suitable for use to model diversions in the presence of information due to short-term work zones and incidents and to model unfamiliar travelers such as tourists.

In addition to the above two types of assignment, a third type of assignment referred to as System Optimal assignment (SO) has been proposed. In SO, the total disutility of all links in the network is minimized. In other words, when the system is in optimal state, no driver can alter his path without increasing the total time/cost of the system; even though he might increase his own travel time/cost. SO was implemented as an option in the original version of Dynasmart. The SO assignment assumes that there is a management system that determines the routes of individual travelers that minimize the overall system performance rather than the individual travel times, as is the case with UE. This concept is difficult to implement in most real-world conditions since travelers are not likely to switch to routes that do not minimize their travel time. The SO assignment has been disabled in the newer versions of Dynasmart and DynusT and has not been implemented in other commonly available DTA tools.

One difference between DUE methods is whether experienced travel time or instantaneous travel time is used in the assignment (Chiu et al., 2011). Instantaneous travel time calculations are based on the "snapshot" of the link travel times at the time of vehicle departure and are usually implemented in non-iterative assignment when modeling diversion with the provision of traffic information. Experienced travel time is more appropriate for UE assignment and accounts for the dynamic change in travel time, as the vehicle travels to its destination (Peeta and Ziliaskopoulos 2001).

Another categorization of DTA assignment types is pre-trip versus en-route assignment. Pre-trip assignment is the assignment utilized in static assignment and also in dynamic traffic assignment tools to model travelers who select their routes before departure, either based on experienced or instantaneous travel time. En-route assignment has been implemented in Dynasmart (and some existing microscopic simulation models like Paramics and AIMSUN) and considers traveler's adjustment of their routes during their trips based on information received about unexpected conditions such as incidents. En-route assignment methods are only required for specific types of applications of travelers information systems.

2.3   Time-Dependent Shortest Path

As stated above, this step involves the identification of a set of attractive paths between each O-D pair in the system.   The step is important particularly due to its impacts on computational time and memory efficiency of the DTA tool (Chiu et al., 2011). It was reported that, when using Dynasmart, more than 60% of the computational time required for solving the dynamic traffic assignment problem on large-scale traffic networks is spent in finding the time-dependent shortest paths (TDSP) between origin-destination (O-D) pairs (DTA Lite web site 2012).

Historically, there have been two algorithms for identifying the shortest paths in static traffic assignment: Moore, (1957) and Dijkstra, (1959).   The main difference between the two algorithms is the procedure used in selecting the next node in the path search (Sheffi 1985). It was found that Dijkstra's algorithm performs better than Moore's algorithm, particularly for large networks. Other algorithms and variations of existing algorithms and the ways they are implemented have been developed to reduce memory requirements and to reduce the running time of the identification of the shortest paths. This is particularly important in DTA, where finding the shortest paths has to be done multiple times to consider the changes in system performance over time.

Ziliaskopoulos and Mahmassani, (1993) developed a TDSP algorithm. In this algorithm, only a few paths between a given O-D pair were selected at each time interval. The algorithm also considered that even if different paths become best at different time intervals, it is likely that the paths share the same "next to origin" nodes. These considerations resulted was improvement in solution stability and time efficiency. The algorithm was implemented in the Dynasmart DTA tool.

Ziliaskopoulos et al., (1997) enhanced Ziliaskopoulos and Mahmassani, (1993) by designing two approaches to parallelize the shortest path algorithm. The first included shared memory design that assigns one destination (or group of destinations) to each processor, resulting in a significant speed-up. The second design did not perform as well. Ziliaskopoulos et al., (2009) improved Dijkstra's algorithm by modifying the node scanning method within the

algorithm. The hybrid algorithm showed a higher flexibility and consequent superiority for traffic network application.

Recognizing the importance of the computational efficiency of TDSP, Ziliaskopoulos et al., (2004) developed an enhancement to the TDSP method developed by Ziliaskopoulos and Mahmassani, (1993). The assignment and the shortest paths were combined into a single software entity, which eliminated the need to record the labels generated by the TDSP algorithm between successive iterations. Another enhancement was made to store only the necessary information in the memory. They also modified the method used to represent the turning movements at intersections when obtaining the shortest paths, resulting in significant reductions in the size of the network representation. The enhancements were incorporated in the Visual Interactive System for Transport Algorithms (VISTA) DTA tool (Ziliaskopoulos and Waller, 2000). The above improvements in the path assignment and data handling capabilities reduced the computer memory requirements, which is important particularly for large networks (Ziliaskopoulos et al., 2004).

Sbayti et al., (2007) reconstruct vehicle path set and path assignments in the Dynasmart DTA tool from the vehicle trajectories rather than storing the path set and assignment in computer memory. This significantly reduced memory requirements, particularly for large size networks where the number of time-dependent has been reported to outgrow the number of vehicles.

The DTALite tool utilizes the OpenMP standards (DTALite web site 2012), allowing the use of multiple processors for shortest path calculation. OpenMP is a new interface standard that allows programmers to decompose computational tasks to different processors. Using this technique, DTALite assigns different origins to different processors to calculate the shortest.

The upcoming 2012 version of DynusT (Chiu et al., 2012) has been fully parallelized in simulation, time-dependent shortest path and assignment algorithms. These made the computational speed 3-4 times faster than the 2011 version.

The solution method used in TRANSIMS is an extension of the Dijkstra's algorithm developed by Barrett et al., (2002). The routine focuses the determination of paths on those that more pointedly lead toward the destination, resulting in improvement in performance. Sherali et al., (2003) enhanced the above model by implicitly working with partial composite graphs rather than constructing the full composite graphs beforehand. Sherali et al., (2003) also proposed several heuristic schemes to increase computational efficiency by focusing the search to proceed from origin to destination while avoiding the searching of paths that are beyond a defined boundary. This technique reduced the search and was demonstrated to find solutions within 7% of optimality while saving 33.57% computational time as compared with the base method. Sherali et al., (2006) later showed that additional improved implementation can produce solutions within 0.78% of optimality while reducing the effort required by the exact method by 56.77%.

In conclusion, examining the implementation of TSDP component in DTA tools is important due to its impacts on the computational time and memory efficiency of these tools. Some newer implementations of TDSP utilize more efficient algorithms and data handling capabilities (see for example Ziliaskopoulos et al., (2004), Ziliaskopoulos and Mahmassani, (1993), and Sherali et al., (2003), as discussed above). Other works have utilized parallel processing to improve efficiency (see for example Ziliaskopoulos and Mahmassani, 1996, DTALite web site 2012 and Chiu et al., 2012). For tools to be used for large size networks, it is important to increase the computational efficiency of the TSDP component. For example, there may be opportunities for further development of Cube Avenue to allow Cube Cluster to utilize multi-processing in TDSP implementations.

2.4   Path Choice

Path choice is the assignment of the trip demands to the identified paths in the TDSP step, discussed in Section 2.3 above. This component results in the estimation of link flows by assigning the demands to the competing paths. At a high level, static assignment algorithms have been classified into assignments that do not consider the congestion effects on traffic behaviors (Non Congested Assignment) and those that consider these effects (Congested Assignment). The relevant assignment techniques to dynamic traffic assignment are those

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that consider the congestion effects and thus non-congested assignment will not be discussed in this document.

In DTA, the proportions of demands assigned to each path are calculated for each assignment time period. With DUE, the assignment in DTA is iterative to reach equilibrium among paths. However, non-iterative assignment is also possible in some tools and useful to be considered for certain applications, as discussed earlier.

In this section, a number of aspects of path choice are considered including disutility function formulation, the solution approaches, and convergence.

2.4.1 Generalized Cost Function Formulation

The problem formulation requires assumptions regarding traveler behaviors. Congested assignment methods are based on the premise that rational drivers select the paths to their destinations to minimize their generalized costs or disutility. The most widely used factor that is considered to impact traveler behaviors in assignment is travel time, and in some cases monetary costs such as tolls. However, other factors such as distances have also been used.
In the past few years, there has been an increasing interest in the inclusion of reliability as part of the objective functions of assignment. Recent projects conducted as part of the SHRP 2 reliability program and SHRP2 capacity program (SHRP2 C04, L04, and C10 projects) have investigated in details the inclusion of reliability as part of the assignment disutility function and the impacts of reliability on traveler's choices of tolled versus non-tolled facilities.

2.4.2 Assignment Solutions

As stated earlier, to find a solution to the equilibrium formulation in both static and dynamic assignment, an iterative solution is necessary. A number of approaches have been proposed to solve the assignment problem. Some of these approaches are heuristic approaches and others involve more rigorous mathematical programming (Ortúzar and Willumsen, 2001). The mathematical programming approaches express the assignment problem as an objective function subject to constraints representing traffic flow properties. The mathematical assignment methods

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generally allow the proof of optimality and uniqueness, and produce superior solutions to those obtained utilizing the heuristic approaches. For example, Citilabs recommends the Bi-Conjugate Frank-Wolf method as the preferred assignment method among those possible with their static traffic assignment.

However, due to the complexity of the dynamic network loading functions required for DTA, the traffic flow models in DTA problems are generally non-differentiable. Therefore, heuristic algorithms that do not require derivative information are used for simulation-based DTA of the type investigated in this study. Although with heuristic assignment, no formal convergence proof can be given. As is the case with mathematical solutions, measures of gap similar to those used in static equilibrium assignment can be used to assess the quality of a solution. Still, heuristic approaches with simulation-based DTA fail to guarantee optimality and convergence.

One of the simplest heuristic assignment methods is incremental assignment. Incremental assignment divides the total trip matrix into a number of fractional matrices by applying a set of proportional factors. The fractional matrices are then loaded incrementally onto the shortest paths using link costs based on accumulated flows. Although this assignment method is easy to program and use, often, it does not converge to an acceptable user-equilibrium solution. A problem found with this method is that once too much traffic is allocated to a link, it is not removed and loaded to another link (Ortúzar and Willumsen, 2001).

To overcome the above-mentioned problem, an iterative heuristic method referred to as the Method of Successive Averages (MSA) has been extensively used in both static and dynamic traffic assignment. In this method, the current flow on a link is calculated as a linear combination of the flow from the previous iteration and the flows resulting from the assignment in the current iteration. The MSA technique is one of easier and relatively effective heuristic solutions to be implemented in the field of simulation-based DTA. MSA became one of the most widely used methods to approximate user equilibrium in DTA for the above reasons and because it does not require finding the derivative as required with mathematical programming approaches.

Jacob et al., (1999) investigated the use of TRANSIMS in the Dallas-Fort Worth area, a relatively large network with 6,124 links. They found that the best performing method was similar to the MSA method. They started the rerouting fraction for each iteration at 30% of the total traffic, and slowly decreased this to 5% by the 20th iteration. The stopping criterion used was the vanishing of gridlocks in the microsimulation, which was realized by visualization.

In the past few years, a number of studies have questioned the convergence properties and computational efficiency of MSA, particularly for larger scale real-life networks and high congestion levels (Sbayti et al., 2007, Mahut et al., 2004, Chiu and Bustillos, 2009). MSA was found to suffer from two disadvantages. The first disadvantage is that it requires the explicit storage of the paths set and path assignments, which severely impacts the computational efficiency even for medium-sized networks. The other disadvantage is that the MSA, when shifting traffic from inferior paths to current optimal paths, does not consider the degrees of path inferiority with the slightly inferior paths are penalized as much as the most inferior path (Sbayti et al., 2007).

Sbayti et al., (2007) investigated improvements upon the performance of the MSA by exploiting local information made available from the simulation used as part of the DTA. To tackle the disadvantage of ineffective shifting between paths, a vehicle sorting algorithm in which for each origin-destination-trip time triplet, vehicles are sorted by their trip times and the only worst performing vehicles, the amount of which is determined by the MSA algorithms, are allowed to update their paths to optimal paths. The resulting implementation has been then tested and shows that they were able to consistently reduce the convergence gaps to below 5%. Sbayti et al., (2007) also reported that the Knoxville, TN network (consisting of 1347 nodes, 3004 links and 356 traffic analysis zones with 200,000 vehicles loaded onto the network in 2 hours) failed to work with the basic MSA implementation in Dynasmart. The proposed improvement combined with the TDSP memory saving using the Sbayti et al., (2007) approach discussed in Section 2.3, allows the network to run to convergence in eight hours achieving a gap of 1.72%.

Mahut et al., (2007) observed that, when using MSA, the assignment for a specific departure-time interval is further away from the equilibrium conditions with later departure times. Another

observation is that later departure-time intervals require more iterations before converging to a stable value of relative gap. The authors explained these observations in that the travel times of later-departing vehicles are affected by earlier-departing vehicles, and thus the convergence for later-departing intervals cannot be achieved until it has first been achieved for the prior intervals. This indicates that the higher values of relative gap in the later-departing intervals could be partially a result of the fact that the MSA step-size is the same for all departure-time intervals for a given iteration. This results in smaller gap sizes than are necessary to shift vehicles between paths at later time intervals. Another reason given for the higher values of the relative gap at later time intervals is that the later-departing vehicles normally have higher congestion, increasing the difficulty of reaching equilibrium conditions.

Mahut et al., (2007) compared two approaches for traffic assignment: one is an adaptation of MSA and the other, referred to as a quasi-gradient algorithm, is based on heuristic adaptations of the projected gradient search method used in solving the static network equilibrium model. In addition, a heuristic method that allows the maximum step size to increase with departure time, in both the MSA and quasi-gradient algorithms, was compared with using fixed step sizes. The best performance was consistently obtained with the combination of the quasi-gradient algorithm and the time-varying step-size adjustment heuristic. Compared to the MSA algorithm, this method provided considerably faster convergence, which for a typical network allowed the algorithm to achieve practical convergence in half as many iterations.

Chiu and Bustillos, (2009), recognizing the deficiencies in utilizing the MSA method, proposed a gap function vehicle-based (GFV) gradient-like procedure for solving the simulation-based DTA problem in a computationally efficient manner. For each iteration and each origin-destination-departure time triplet, the amount of vehicles allowed to update path depends on the gap function value. This proposed approach allows for faster convergence, compared with the MSA-based approach since each origin-destination-departure time triplet has an individual search direction and step size in the GFV method. The comparison in Figure 2-2 clearly shows the superior performance of the GFV method compared to the MSA-based method.
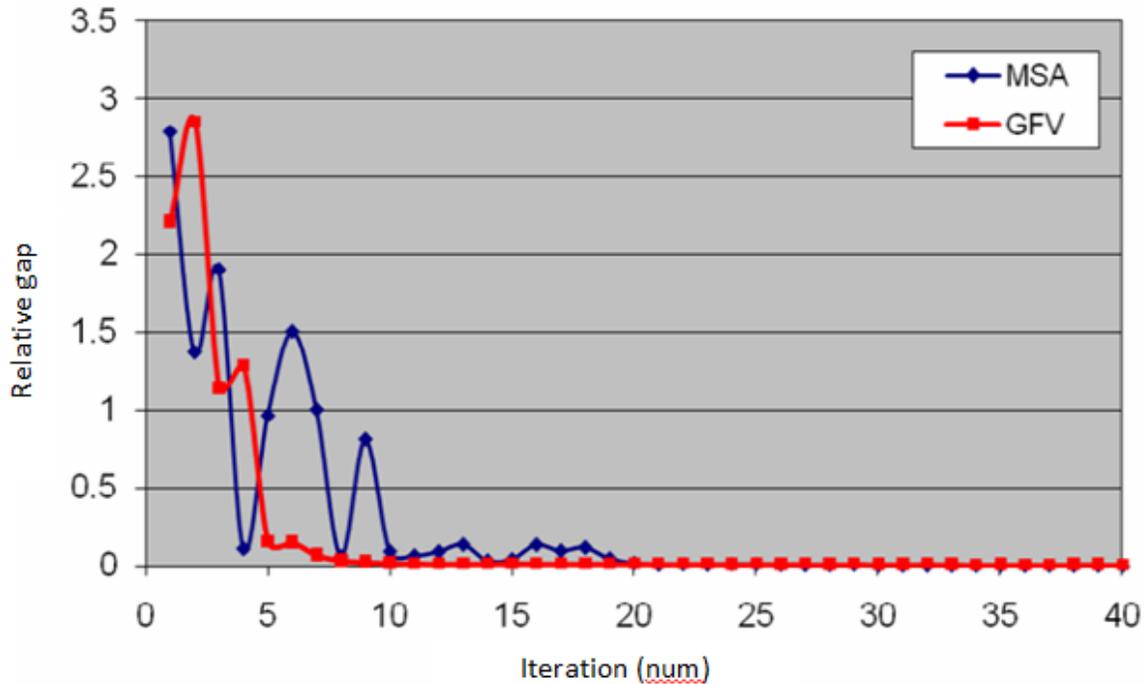
Figure 2-2 Comparison of MSA and GFV Assignment Method Convergence (Chiu and Bustillos, 2009)

Citilabs recognized the computational efficiency problem with the MSA application in Cube Avenue DTA assignment (Citilabs, 2011). As seen in Figure 2-3-a, with the original MSA implementation in Cube Avenue, in each iteration, a new best path is generated along with new packets and the traffic volume is equally distributed between all packets. Because this procedure generates new packets every iteration, its memory and computational demands are high, particularly as the network size increases. The packet allocation option introduced in the newer versions of Cube Avenue (Figure 2-3-b) addressed this problem. With this option, new best paths are still included in each iteration, but no additional packets are generated. The existing packets may instead 'switch' to the new best path, with a probability that is equal to the inverse of the iteration number. Because new packets are never introduced, the computational demands of this new MSA application, referred to as Packet Allocation (PA), are far lower than the original MSA application referred to as Packet Split (PS).

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| (a) under Successive Averages mode | (b) under Packet Allocation mode |
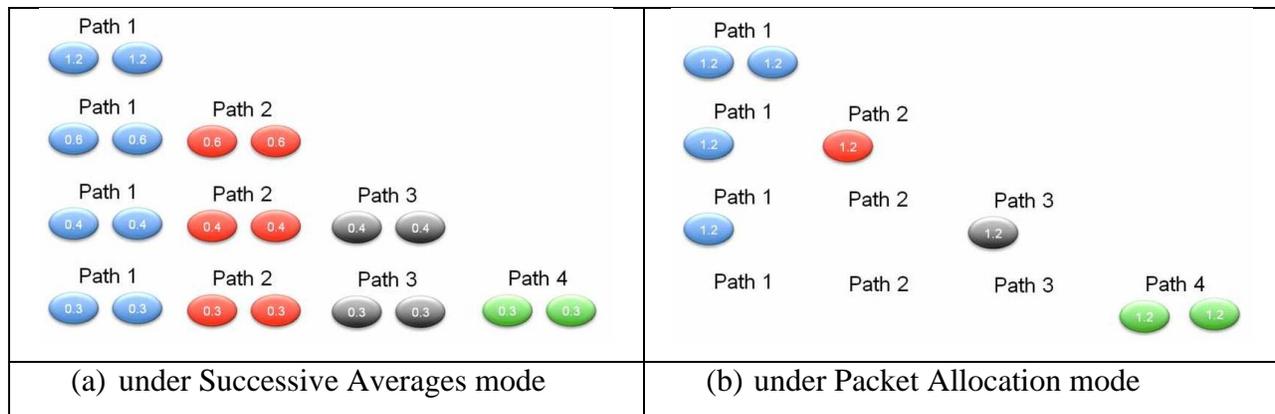
Figure 2-3 Packet volumes over four iterations (Citilabs, 2011)

The review of this section indicates that MSA has been the most widely used method in the application of DTA simulation-based assignment. However, increasingly researchers and DTA tool developers are developing more computationally efficient and better methods to achieve convergence than MSA.

2.4.3 Convergence

By definition, the equilibrium is said to be achieved when travelers cannot improve their travel times by selecting alternate paths, given their departure time (Chiu et al. 2011, RSG, 2010). This implies that every used path between an origin and destination is a minimum cost path and that there are no changes in flow pattern or experienced travel time between assignment iterations after the convergence is approached. Convergence of user equilibrium assignment is necessary to ensure the integrity of the resulting solution and to ensure that the model can be used in assessing alternative designs and operational strategies. Thus, the assessment of convergence is an important step in traffic assignment. There are still several issues that need to be investigated regarding convergence in DTA, as discussed below.

With simulation-based DTA, there are no guarantees of achieving a unique and optimal solution. In addition, there is no agreement on how low the values of the convergence criteria should be. Boyce et al., (2002), pointed out that a relative gap of 0.01% or ~0.0001 is required for static assignment, to ensure sufficient convergence to achieve link-flow stability. There is no good agreement on what represents an acceptable value of the relative gap in DTA. It is realized,

however, that it is much more difficult to achieve a small relative gap in simulation-based DTA compared to static assignment, particularly for congested conditions (Chiu et al., 2011).

Two categories of convergence criteria have been used: link-based and trip-based. A link–based criterion is based on the condition that that the solution link flows are stable and do not fluctuate with additional assignment iterations while a trip-based criterion is based on the stability of the flows assigned to the paths (or the travel times of the paths) between each O-D pairs. The utilization of a link-based criterion by itself may not be sufficient and thus path-based methods should also be used (as discussed next). In addition, path-based criteria allows utilizing heuristics targeting those trips, travelers, households or market segments that are most impeding convergence to achieve better solutions (RSG, 2010).

Chiu et al., 2011 indicates that convergence based on link flows may indicate convergence of path choices, but may also be due to how assignment methods like MSA work. MSA methods guarantee that links flow changes decrease over iterations due to how the utilized algorithms are set. Bar-Gera (2010) also pointed out that even if link flow reaches convergence, a main issue with route flows is that they are not uniquely determined by the UE conditions based on link flows. Reaching path flow convergence is particularly important for applications such as multi-class assignment, "Select Link" Analysis, estimation of origin-destination (O-D) flows from link flows, derivation of O-D flows for a subarea of a region, average travel time and average distance per O-D in a generalized cost assignment, and so on.

Lack of convergence can affect the consistency, stability, and proportionality of the resulting solutions. The proportionality requirement is defined by Bar Gera and Boyce (1999) and Bar-Gera (2010) as the proportions of travelers on each of the two alternative segments should be the same, regardless of their origin or their destination. They defined the consistency requirement as the contribution of all eligible routes in UE solution, which means all routes should be included in the UE solution, unless there is a good reason for not being considered, such as having a high generalized cost. Lu and Nie, (2010) defines stability as the solution's ability to appropriately respond to perturbation, meaning that if small changes in the network

or demand are made, the model should respond to them with small, not unreasonable changes. On the other hand, Chiu and Bustillos (2009) and Peeta et al.(2011), stability as steady link volume and the ability to respond appropriately to small perturbation is labeled consistency. This indicates that there is no general agreement on the definitions of these variables. Consistency, proportionality, and stability are needed for the evaluation of alternative treatments of the transportation system, and for applying methods such as select link analysis, select zone analysis, and subarea analysis. This is also very important to ensure unique solution of multi-class assignment, particularly in managed lane where preferential treatments of some of the classes are applied (Boyce et al., 2010).

Bar-Gera (2010) investigated the lack of uniqueness of UE and pointed out that not all UE route flow solutions are equally useful for the analysis. They stated that this issue can be resolved by testing for the condition of proportionality, which also ensures stability and consistency. Another option is to use the entropy measure, to decide on link flow (Rossi et al., 1989; Oppenheim, 1995; Bell and Iida, 1997; Larson et al., 2002). Lu and Nie, (2010) used the maximum entropy concept to address the uniqueness and optimality issues. This concept means that among all possible UE route set, there is just one that maximizes the entropy, which should be considered as the unique solution. It is proven that this route set also meets the proportionality condition described in Bar-Gera and Boyce (1999) and Bar-Gera, (2010).

2.5   Traffic Flow Models

Dynamic network loading, as a DTA component, provides estimates of the time-varying performance of a transportation network for a given traffic flow pattern (Lam and Xu, 1999). In DTA, network loading may be accomplished using analytical procedures or by simulating vehicles' movements to estimate path and link performance measures, resulting from the assignment of demand to the selected paths.

Analytical approaches to network loading have been extensively investigated in the literature utilizing a variety of approaches. Examples include those reported by Merchant and Nemhauser, (1978), Defermos, (1980), Friesz, (1989, 1993, 2001, 2006), and Ziliaskopoulos and Waller, (2000). Despite the advances in the analytical approaches mentioned above, it has been realized

since the early 1990s that the complexity of traffic flow and associated traffic control can be better represented using simulation-based DTA, if the network is to be modeled at the required levels of detail.

In general, the utilized simulation models in DTA tools are developed to accurately model traffic including bottlenecks and the impacts of queuing due to recurrent and non-recurrent congestion, shockwave propagation, and spillback effects (Chiu et al., 2011). Other features of simulation models are their ability to model signal control and managed lanes, and in some cases other advanced management strategies such as ramp metering, traveler information systems (DMS, pre-trip, and in-vehicle), pricing strategies (TOD and dynamics) and so on.

In general, simulation models have been categorized into macroscopic, mesoscopic and microscopic models. In this study, the microscopic category is further subdivided into low fidelity and high fidelity. Below is a description of these models.

- *Macroscopic simulation models*: Macroscopic simulation models are based on the relationships of flow, speed, and density parameters of the traffic stream combined with queuing and/or shockwave analysis. Macroscopic models simulate the impact of the traffic as a whole, on a section-by-section basis rather than by tracking individual vehicles. Macroscopic models are less complicated and have considerably lower computer requirements than microscopic models. They do not, however, have the ability to analyze transportation improvements in as much detail as microscopic models, although some of these models are able to model queuing, shockwaves, and spillbacks. FREEVAL, the computational engine of the HCM freeway facility procedure, is a good example of these types of models.

- *High Fidelity Microscopic simulation models:* In general, microscopic simulation tools simulate the movement of individual vehicles based on microscopic traffic flow models such as car-following, lane-changing, and gap acceptance. Vehicles are tracked through the network over small time intervals (e.g., 1 second or a fraction of a second). The modeling and computer requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that can be

completed. Examples of high-fidelity microscopic simulation models are VISSIM, PARAMICS, CORSIM, and AIMSUN. These models are normally used for operational analysis and are beyond the scope of this study.

- *Mesoscopic simulation models:* Mesoscopic simulation models combine the properties of both microscopic and macroscopic simulation models. As in microscopic models, the mesoscopic models consider the movements of individual vehicles but, in some cases, packets of vehicles. Their movement, however, follows the macroscopic approach of traffic flow, described above. Mesoscopic models provide less fidelity than microscopic simulation models. However, they provide much better computational efficiency, which is important for simulation-based DTA. Examples of mesoscopic simulation models are Dynasmart-P/DynusT and Cube Avenue.

- *Low Fidelity Microscopic Simulation Models:* The models in this category of models use vehicle-based rather than traffic-based models, however, at lower level of detail than microscopic simulation models. They use longer time steps or event-based rather than time-based simulation compared to high fidelity simulation, increasing the computational efficiency of the model but reducing the level of detail. Examples of such models are those implemented in TRANSIMS, Dynameq, and VISTA.

Most prevalent DTA models for larger scale modeling applications apply either mesoscopic or low-fidelity microscopic simulation approaches. These approaches provide much better computational efficiency allowing much faster simulation compared with high-fidelity microscopic simulation. However, they can provide different levels of details when modeling queuing and spillbacks. In addition, some low-fidelity simulation models can model lane-by-lane traffic flow, allowing better modeling, different turning movements on a link with different capacity restrictions, and in some cases spillover from a turning movement lane(s) to another movement lane(s).

2.6　Overview of Existing DTA Tools

This section presents an overview of some of the available DTA tools. More detailed discussions and assessment of a subset of these tools are presented later in this document.

2.6.1 Dynasmart

Dynamic Network Assignment Simulation Model for Advanced Road Telematics-Planning (Dynasmart-P) has been developed since the early 1990s by Dr. Mahmassani's group at the University of Texas at Austin and then at the University of Maryland with funding from FHWA. This development together with the development at the same time of DynaMIT by Massachusetts Institute of Technology, which was also funded by FHWA, formed a foundation for today's simulation-based DTA modeling.

New models and enhancements continue to be added to Dynasmart as part of the research conducted by Dr. Mahmassani group in Northwestern University. However, these new enhancements are not currently available commercially. The Center for Microcomputers in Transportation (McTrans) currently sells and supports an older version of Dynasmart-P, released in 2005. It costs $1,750 with technical assistance and $1,000 with no support.

Dynasmart-P's user manual reported that it is not limited by the size of the network, except for hardware-related constraints (memory) (Dynasmart-P user manual). Bergman and Gliebe, (2009) reported that the official version of Dynasmart is reported to accommodate 100,000 links, 35,000 nodes, with 1,000,000 vehicles simulated over several hours.

There are two methods for inputting demands in Dynasmart-P. The first method is to specify time-variant O-D matrices among origin-destination zones at different time intervals. The second vehicle loading method is to specify the origin and destination of all vehicles with or without their corresponding travel plans (paths). In this format, the users can model activity-based demands. The required inputs include the intermediate stops and the corresponding activity durations. Dynasmart-P can model intersection control such as no control, yield signs, stop signs, pre-timed signals, and actuated signals. It allows entering offsets that indicates that it allows modeling coordination.

Dynamic user equilibrium, system optimum, and non-iterative assignment can be selected to assign trips and combinations of these can be investigated. The official version of Dynasmart-P utilized the MSA method when performing iterative assignment, although research by the developers in recent years has explored enhancements to the assignment method.   Dynasmart-P recognizes four vehicle types: passenger cars (PC), trucks, high-occupancy vehicles (HOV), and buses. This limit on the number of vehicles/traveler types that can be coded is a constraint on the program flexibility.

Ten different facility types with different attributes can be modeled. The traffic flow model determines the speed based on speed/density functions for each link at a given simulation time step (default 6 seconds). Capacity constraints at the downstream node are considered resulting in queuing propagating upstream. For the non-queuing part of a link, the travel time is a function of density utilizing the modified Greenshields model. The travel time for the queuing vehicles is calculated by estimating queuing delay.

Dynasmart-P can model managed lanes, ramp metering, incidents, dynamic message signs (DMS), and rerouting using in-vehicle information systems.   Dynasmart-P recognizes five different user classes in terms of the availability of Advanced Traffic Information System (ATIS) equipment, drivers' knowledge of the network, and driver response to supplied routing information.   Dynasmart-P can assess the impact of different information dissemination strategies, including DMS, pre-trip information, and route guidance (for vehicles capable of receiving en-route information) on traveler behavior and overall network performance.

The shortest path calculations in Dynasmat-P are based on generalized link disutility (generalized cost) that combines travel time and cost. The tool is also capable of modeling dynamic congestion pricing.

Dynasmart-P has a graphical user interface referred to as DSPEd. The interface allows displaying static and animated simulation results. Dynasmart-P produces various time-variant performance

measures such as speeds, densities, queues etc. It also produces the trajectory for each vehicle as it travels through the network.

2.6.2 DynusT

DYNamic Urban Systems for Transportation (DynusT) (Chiu et al., 2012) was developed at the University of Arizona by Dr. Yi-Chang Chiu's research team based on Dynasmart. DynusT is based on the Dynasmart-P program, described in the previous section. As DynusT is being used in a number of projects funded by FHWA and the Transportation Research Board (TRB) SHRP 2 program, enhancements continue to be introduced to it. DynusT is an open source program that can be obtained free of charge by downloading from the web. The developers of the program reported that there are more than 250 users worldwide and more than 1,000 downloads in one year since the open source web site was set up.

One of the first enhancements introduced in DynusT is to improve the Dynasmart mesoscopic traffic simulation model by introducing what is referred to as the Anisotropic Mesoscopic Simulation (AMS) (Chiu et al., 2010). With this model, a vehicle's prevailing speed is not assumed to be the same over all segments of a link but influenced only by the vehicles in front of it, in a region referred to as the Speed Influencing Region (SIR) area. The influence of traffic downstream of a vehicle speed decreases with increased distance. The developers showed that this model produces more realistic representation of traffic flow compared to the original Dynasmart model (Chiu et al., 2010). They also pointed out that the main advantage of this model compared to cell-based simulation used in other software such as TRANSIMS and VISTA, is its time/memory efficiency.

In a recent version of DynusT, a gap-based assignment has been introduced as the default assignment replacing the MSA assignment, although MSA assignment can still be requested. The gap-based method has been shown to produce much better convergence behavior and computational efficiency compared to MSA (Chiu and Bustillos, 2009).

DynusT's GUI has been created using the Network Explorer for Traffic Analysis (NEXTA). This interface allows users to create and modify DynusT input files and execute DynusT. Recently,

DynaStudio, a more powerful editor developed by a private developer (RST International Inc.) has been released and can be purchased from the mentioned company.

A new version of DynusT (DynusT, 2012) is planned. This version has several improvements in modeling features and computational efficiencies. With respect to improved computational efficiency, the following has been reported:

- DynusT 2012 has been fully parallelized in simulation, time-dependent shortest path and assignment algorithms. These made the computational speed 3-4 times faster than the 2011 version. The memory usage for simulation remains unchanged, while the memory usage for assignment is reduced to half of the 2011 version.
- The much-improved computational efficiencies allow DynusT to model large 24-hour regional models within a reasonable run time. The developers reported that for the Sacramento regional model, it takes about 50 minutes per iteration for 6.2 Million trips in a 24-hour simulation on a network with 1,500 zones, 10,000 nodes and 21,000 links. It has been reported that most peak hour models takes less than 10 minutes per iteration, and most models reach convergence in less than 20 iterations.
- The run time will not increase in the case of multi-class assignment, in which different attributes, such as value-of-time, are assigned to different user (traveler) classes.

With respect to modeling enhancements, DynusT 2012 has an improved congestion pricing modeling. In addition to fixed and time-of-day tolls, DynusT is able to model congestion responsive tolling in which the price in the managed lane is dynamically updated considering (1) congestion in the generalized-purpose lane, and (2) user-specified minimal required speed in the managed lane.

Several additional features that have been in development are expected to be incorporated into the official release of DynusT in 2013. These include the following features:

1. *Integration with EPA MOVES model:* DynusT will produce the operating mode distribution and output it to .csv files that can be used as input to MOVES.

2. ***Incorporating reliability measures***: These measures will be used as part of the assignment and produced as outputs of the model.

3. ***Incorporating heterogeneous attributes in the assignment.*** This enhancement will improve the fidelity of analysis by incorporating heterogeneous attributes of travelers in the assignment process such as the value-of-time and reliability perception.

4. ***Integration with dynamic transit assignment***. DynusT is being integrated with FAST-TrIPS, which is a simulation-based dynamic transit assignment model developed by University of Arizona. In the DynusT-FAST-TrIPS model, transit assignment procedure considers stop wait time, transit vehicle capacity, transfer, choice of stops, walk and bike access, and intermodal (e.g., park-and-ride, kiss-and-ride) assignment.

In addition, DynusT developers are currently collaborating with other researchers to produce system-wide signal re-optimization for future year model and diurnal curve/peak spreading model for future year analysis.

Some of the issues with the open source software versus propriety software that are supported by vendors are the level of technical support provided to the customers, adequate documentation of software enhancements, and ensuring continuity in the support of the software in future years. These are very important issues that need to be confirmed before the use of open source software in large-scale projects. The DynusT developers have recognized this and thus a new fully supported arrangement referred to as the DynusT Plus membership program has been recently started. The program provides technical support and value-added content such as training videos and various pre-and post-processing utilities to speed up the project delivery process.

Table 2-1 provides the additional features available with the DynusT Plus license. The technical and the additional tools provided by the program are very useful when using DynusT, particularly for large-scale time-sensitive projects.

Table 2-1 Comparison of standard DynusT and DynusT Plus

	DynusT Standard	DynusT Plus
Source Code	√	√
Online Manual	√	√
User Forums	√	√
Technical Support	✕	√
Programmer`s Guide	✕	√
Training Videos	✕	√
Course Materials	✕	√
Online Videos	✕	√
Example Datasets	✕	√
DynusT Utilities	✕	√

2.6.3 TRANSIMS

TRansportation ANalysis and SIMulation System (TRANSIMS) was developed in the 1990s by Los Alamos National Laboratory, as part of the Travel Model Improvement Program (TMIP) sponsored by the U.S. Department of Transportation, the Environmental Protection Agency (EPA), and the Department of Energy. It is currently an open source tool (free online downloading and updating). Later versions were developed by AECOM and were made significantly more user friendly.

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TRANSIMS was designed to be modular and the original version included an activity-based model. Recent efforts such as those of the SHRP2 C10A project, integrate TRANSIMS assignment and traffic flow models with external activity based demand models like DAYSIM.

The traffic flow model used in conjunction with the assignment can be based on an analytical equation (the BPR-Bureau of Public Roads curve) or on simulation. TRANSIMS based on BPR incorporates some of the features desired in DTA modeling, such as using experienced travel times. However, it does not represent traffic controls and does not capture traffic dynamics such as queues and spillbacks.

The simulation in TRANSIMS is a second-by-second low-fidelity simulation based on cellular automata that considers car following and lane changing. Various road types can be modeled including local streets, collectors, ramps, freeways, expressways, primary arterials, secondary arterials, light rails, heavy rails, ferries, and walkways. Traffic control including signals (both fixed timing and demand-actuated signals), ramp metering, and signs can also be modeled. Bus lines can be also simulated including loading and unloading. A roadway section is divided into grid cells, each is one lane wide and 7.5 meters long (approximately the size of one passenger car) but the user can change this length. The position and speed of vehicles are measured and incremented by cells. The lane-changing maneuver of a vehicle in TRANSIMS Microsimulator can be performed to pass a slower vehicle immediately ahead or to make turns at intersections following its current plan. Merging is handled by using the same lane-change logic. The microsimulator can model separate queues for different turning movements on the link.

The Route Planner module in TRANSIMS generates routes for each individual travel plan from a trip file. The router can process both trips resulting from activities as well as simple trip tables, or both at the same time. An important feature of TRANSIMS is that it deals with the trips at the person level rather than the vehicle level. Modes include walking, passenger car, bus, train, or combinations of the above are considered. However, in TRANSIMS, travelers choose a mode of transportation according to user inputs based on travel surveys. Therefore, the original TRANSIMS process typically iterates between the router and microsimulator. External demand models (such as DAYSIM in SHRP2 C10A project) were used to estimate traveler choices in response to changes in network performance estimated using the TRANSIMS micro-simulator.

During the first iteration, when link delays are not yet available, the router can optionally calculate link delays on the fly based on BPR formulas. In subsequent iterations, either the simulator or the BPR formulas can be used.

The algorithm adopted in TRANSIMS to calculate the TDSP is a variant of Dijkstra's procedure for finding shortest paths, modified to accommodate time-dependent link delays.

To assign vehicles to these paths, TRANSIMS chooses a fraction of travelers to switch between paths, based on user-defined criteria or utilizing a random selection process. The selection criteria can include a large difference in estimated and actual arrival times (re-route travelers whose trip duration in the Plan file is significantly different from the travel time calculated from the path), trips that pass through specific nodes and links that meet certain criteria (e.g., trips get selected if they go through a link at a time when the V/C ratio is greater than 1.3), or trips at specific times of the day. The convergence criteria could be based on any of the following; the travel times on the links, the volumes on each of the links, the paths of travelers, or the travel times on the different paths between each origin-destination pair.

It has been reported that TRANSIMS can handle large road and transit networks (more than 100,000 links) and large population (more than 30 million travelers), subject to the utilized hardware limitations. Parallelization of TRANSIMS for standalone multi-core machines, as well as high performance cluster environments, is currently being implemented.

TRANSIMS is traditionally a console-based program that uses the TRANSIMS Output Visualizer (software) or ArcGIS for temporally and spatially dynamic visualization. As of April 2009, a network editor has been introduced utilizing the NEXTA platform. Without NEXTA, network editing is done in ArcGIS and converted back to TRANSIMS' own shapefile formats using internal utility programs. TRANSIMS is able to make use of some common GIS tools and formats with regards to network editing and cutting. Tools are available to convert TRANSIMS network components into GIS shapefiles for effective visualization and editing.

2.6.4 Cube Avenue

Cube Avenue is the DTA/mesoscopic model that is an add-on to the Cube Voyager HIGHWAY assignment module and shares similar structure, commands, and keywords as the static assignment of Cube Voyager but with additional required commands (Citilabs 2011). With Cube Avenue, vehicles are grouped into homogenous "packets" and simulated as they move through the network. The performance of the resulting traffic stream on each link is still evaluated using aggregate macroscopic speed-flow relationships, with the default being the BPR relationships. Movement from one link to another is regulated by "gates" allowing the estimation of traffic

queues in the network due to capacity at specific locations (lane drops, intersections, ramps, etc) and downstream link queuing capacity constraints using deterministic queuing analysis. Packets can be in one of two states: moving on a link or in queue (waiting on a link). A vehicle may have to wait if: cars leaving a link exceed its exit flow capacity (capacity constraints), cars entering a link exceed its entrance flow capacity (capacity constraints), or there is no room for it on the next link (storage constraints). The simulator tracks average time spent in queue, referred to as "excess" time above the "expected" time estimated using the speed-flow relationship. The excess (queue) time is added to estimated time in flow stream. If junction modeling of signalized intersections are included as input, then additional queuing delays at intersections are calculated using a junction delay model (e.g., highway capacity manual equations)

The disutility function used in the assignment is a generalized cost function that can include any variable with its own weight. The assignment in Avenue is user equilibrium that utilizes the MSA method, whereby at any given iteration, the probability that a packet switches to the newly generated path is 1/n, where n is the iteration number.

The convergence testing is done based on one of the following criteria:

- GAPk Ratio of difference between successive iterations travel cost divided by the shortest path cost
- RGAPk Ratio of difference between current travel cost and shortest path cost divided by the shortest path cost
- AAD Average Absolute Volume Difference: based upon successive iterations
- RAAD Relative AAD: DiffV/V
- Pdiff Percent of links whose change in V between iterations is less than a set value.
- RMSE Root Mean Squared Error of the differences in V between iterations.
- MAXITERS Sets a fixed maximum number of iterations for convergence

2.6.5 TransModeler

TransModeler is a simulation-based traffic assignment tool offered by Caliper. One of the important features of TransModeller is that it allows modeling parts of the network in microscopic and parts of the network in mesoscopic and/or macroscopic simulation in the same run.

TransModeler exploits affordable computing resources to evolve efficient algorithms suitable for large-scale traffic microsimulation and DTA. Emergent CPU architectures and the low cost of memory are optimized via multi-threading to deliver rapid time-dependent shortest path and route choice calculations geared towards the simulation of large scale geographic scope and demand levels. TransModeler's developers reported that the micro-simulation based DTA as implemented in DTA can handle large-scale DTA. Caliper has calibrated a 500-square-mile network with two million trips in the peak period for the Maricopa Association of Governments. Such detailed modeling can be an attractive option in cases that require micro-level precision for accurate estimations of performance measures. Micro-level simulation also has the most accurate representation of signal operations.

A computationally efficient route choice algorithm is fundamental to large-scale DTA models, since paths must be independently calculated for different trip starting times. Stochasticity, imperfect network knowledge and behavioral heterogeneity may cause drivers between the same origin and destination to select very different routes. TransModeler's algorithms operate under the assumption that a few paths will dominate the individual selections, with the possible addition of other competitive alternative routes. Probabilistic models capturing the effects of perceived path overlaps are also available.

When used as a microscopic simulator, TransModeler simulates the behavior of each vehicle every one-tenth of a second. Vehicles can vary in terms of their physical and performance characteristics, and can be custom defined by users. Acceleration, deceleration, car following, lane changing, merging/yielding, and movements at intersections are simulated in detail and are affected by driver aggressiveness, vehicle characteristics, and road geometry. This option, however, is not suitable for very larger networks. Thus, TransModeler includes mesoscopic and

macroscopic simulators in addition to its microscopic simulator. The mesoscopic simulator is cell-based with traffic movements that are based on capacities and speed-density functions.

The definition of cells in the TransModeler's meso platform is not the traditional one associated with the cell transmission model. Rather than divide the roadway links into cells of pre-defined size (length), TransModele groups vehicles into cells when they are moving close to each other. Cells fuse with, and detach from, other cells when they get close to (or too far from) each other. Speeds within a cell still vary according to the traffic density within the cell. When a cell approaches an intersection, it splits into streams by turning movement. Although individual vehicles are represented in the meso model, their movements are based on macroscopic speed-density functions rather than microscopic car-following and lane-changing logic as in microscopic simulation.

TransModeler provides the option of a hybrid simulation capability; in which microscopic, mesoscopic, and macroscopic simulation can be combined to model different portions of the network. The portions of the network of the highest interest can be simulated using microscopic simulation while other portions can be simulated using mesoscopic or macroscopic simulation. TransModeler's meso and hybrid options are intended for very large regional models.

Another advanced feature of TransModeler is that it provides an integrated database management subsystem for storing traffic data such as traffic counts, lanes, and speeds. It also has a tool that generates time-variant trip tables that are consistent with counts using a trip table estimator. Another interesting feature is that the model can dispatch new trips from anywhere in the network or divert trips en-route to alternate destinations for modeling incident and hazard response or evacuation scenarios. The tool also has a powerful user interface, displays, and visualization capabilities.

Recent enhancements to TransModeler have included improved driver behavior algorithms in the presence of incidents and DMS information, additional calibration tools for visualizing and analyzing route choices, expanded compatibility with Synchro signal optimization tool, and faster running times for route choice and dynamic traffic assignment computations.

2.6.6 Dynameq

Dynameq is a DTA tool, offered by INRO, the vendor of the EMME demand forecasting modeling environment. One of the important features of Dynameq is its traffic flow model that can be considered as a low-fidelity microscopic simulation model, allowing more detailed lane-by-lane modeling of transportation systems compared to mesoscopic simulation models used in other tools but with higher computational requirements. This simulation model is an event-based simulation that model car-following, lane changing, and gap acceptance Compared to time-interval based simulation, event-based simulation is much more computationally efficient but with a lower fidelity, since it only updates the simulated network when changes occur to the network conditions. The propagation of traffic delays are modeled in Dynameq through a simplified car following model that implies triangular flow-density traffic flow relationship.

In user equilibrium assignment, Dynameq provides the user with the choice of using the regular MSA or the flow-balancing MSA (flow-balancing is the default). With flow balancing, the amount of flow added or removed from a path in each iteration is proportional to the difference between the average travel time and the path travel time. Dynameq also has the "path pruning" option that sets a path's flows to zero if it drops below a predefined value as a fraction of total demand for an origin-destination pair and redistributes it proportionally to other paths. The "dynamic path search" option looks for new shortest paths to add to the past set during the second part of the DTA, when normally no new paths are being added, to replace paths with zero flow.

Dynameq can simulate fixed time signal timing plans but not actuated controllers. It is also possible to run a Dynameq simulation without signal timing, in which case default traffic movement rules are applied with vehicles taking turns going through intersections and lower volume roads yielding to higher-volume roads.

The size limitations have been reported to be 20,000 links, 6,250 nodes and 1,250 zones.. Dynameq has an internal network editing GUI and the input file is in binary format. Various model outputs can be visualized.

2.6.7 VISTA

Visual Interactive System for Transportation Algorithms (VISTA), originally developed at Northwestern University, is a DTA tool that is marketed by the Vista Transport Group. VISTA was developed based on the Dynasmart tool described earlier. However, it has involved significant research and development effort to improve many components of the software. The traffic simulator in Dynasmart was replaced by a simulator that propagates traffic according to the cell transmission model. In a preprocessing step, it divides the network links into a number of cells based on their length and free-flow speed and transmits vehicles between cells according to the cell's density, the downstream cell's density and jam density, and the saturation flow rate. This model is computationally efficient in that allows fast computation of very large networks. The simulator has been designed to update the vehicle movements at varying time intervals, depending on how frequent the queue evolution needs to be monitored. The simulator also includes an enhanced cell-transmission model and a car-following model for microscopic simulation. Portions of the network may be marked as microscopic, allowing greater detail to be captured in the movements of traffic.

In addition, the path assignment module and time-dependent shortest path module were reengineered into a more efficient module that can handle large data sets. With traffic assignment, the traditional MSA approach is used for early iterations, but gap function-based methods are used to obtain meaningful convergence in later iterations. Convergence is usually assessed based on the difference in the number of vehicles assigned to various paths over successive iterations. VISTA allows both dynamic user equilibrium and system optimal assignment. Although travel time is the most commonly used cost, other cost metrics may be used. The assignment module recognizes multiple vehicles classes, class-based roadway restrictions, closures, and controls. Currently, all vehicles are departure-time based.

All network, control, and demand data is stored within an integrated database. The outputs of some modules and reports are also stored in the database, making it possible for the user to construct a variety of queries to inspect or analyze the results directly.

VISTA is accessible over the Internet. A typical VISTA installation is hosted and run on computers accessible by any authorized user where Internet access is available. Thus, there is no

need for having new software installed on individual computers. Any authorized user can modify their model, run the model, and obtain the results using a typical web browser. VISTA runs on a cluster of UNIX/Linux machines. It follows the Sun Microsystems paradigm. The interface works as a client exclusively, and communicates only with the Management and Database Modules. VISTA also utilizes GIS functionality to graphically represent the network, vehicle loading, and performance measures. The VISTA Editor supports typical GIS operations such as zooming, panning, and styling of individual data layers.

VISTA allows modeling different types of traffic management features including traffic signals, ramp meters, stop and yield signs, DMS, traffic detectors, and incident management. Traffic signals may be pre-timed and actuated. Signal priority and signal optimization can be requested. Ongoing development will add arrival-time based trips, multi-destination trips, and intermodal trips.

The developers of VISTA reported that VISTA is scalable to model small to very large roadway networks involving thousands of traffic analysis nodes and that the 1,877-zone northeastern Illinois roadway network has been coded in VISTA.

3. Further Identification of Issues Associated with DTA

Chapter 2 identified a number of issues associated with DTA. Additional DTA issues were identified in this study using a combination of tasks including a detailed review of DTA research and documentations available about DTA methods and tools, a survey of the modeling community in Florida, a user needs workshop, and phone interviews with agencies that have experiences with DTA applications. This chapter discusses the results of these tasks.

3.1 Review Committee and DTA Subcommittee

At the beginning of the project, a DTA subcommittee to the Modeling Advancement Committee of the Florida Model Task force (MTF) was formed to provide advice on the project activities. The MTF establishes policy directions and procedural guidelines for transportation modeling in Florida using the Florida Standard Urban Transportation Model Structure (FSUTMS). Later the DTA subcommittee was merged with the Toll Modeling Subcommittee to form the Advanced Traffic Assignment Subcommittee. The memberships of the committee before and after the merge are included in Appendix A. The research team coordinated the project activities with the subcommittee, making presentations about project progress and getting input regarding project activities from the subcommittee members.

In addition, the FDOT project manager formed a review group that consisted of a number of FDOT contractors, the chair of the Modeling Advancement Committee of the Florida Model Task Force, and the chair of the DTA subcommittee of the Modeling Advancement Committee. This group participated in phone calls with the project team and reviewed project deliverables.

3.2 DTA User Survey

The next step was to conduct a survey of the transportation planning modeling community in Florida. The purpose of this survey was to gather inputs from the Florida modeling community related to their views of DTA applications. The survey addressed issues such as how DTA will be most useful as part of the modeling process, the main technical and institutional constraints to DTA applications, the maximum size of the network that the DTA must be able to handle, the

needed temporal model resolution (the assignment period), the required details of modeling, and the needed support of the modeling community.

The survey was conducted in two stages. In Stage 1, a preliminary version of the survey was distributed to the members of the MTF DTA subcommittee, who were asked to answer the survey questions and to comment on them. Significant input was provided by the DTA subcommittee regarding the content and format of the survey. The survey was then updated based on the received comments and the lessons learned from Stage 1. The distributed survey is included in Appendix B.

In Stage 2, the updated survey was distributed to the modeling community in a modeling task force meeting conducted in December 2010 and attended by modelers from around the state and by a number of modelers from out-of-the-state. A total of 47 responses to the survey were received with 54% of the responses from the private sector, 22% from metropolitan planning organizations (MPOs), 18% from state agencies, and 4% from academia. The rest of this subsection presents a summary of some of the responses received from the survey:

When asked how do they think that the DTA will be most useful as part of the modeling process, 13% of the responders specified replacing static assignment in regional demand forecasting models, 35% specified subarea or corridor planning studies, 27% specified traffic operation analyses, and 21% specified the support of activity based models (**Error! Reference source not found.**1). Other specified applications included modeling evacuation, transit, freight, and ITS, in addition to the use as a public involvement tool. It is interesting to note that only 13% of the respondents believed that DTA should be used to replace static assignment and that a relatively large proportion (21%) believe that it should be used with activity-based modeling (ABM) reflecting the increasing awareness of ABM in the state.
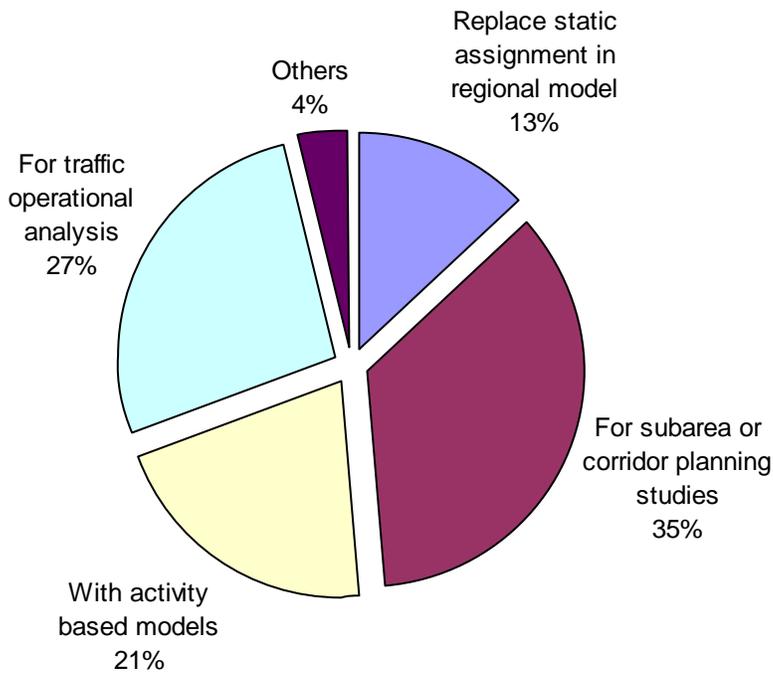
Figure 3-1 Potential use of DTA modeling

The main technical and institutional constraints to DTA applications were identified to be the lack of data (36% of responses), lack of experience (24%), calibration and validation requirements (22%), computational time (21%), parameter assumptions for future years (21%), complexity of process (18%), need for training (15%), and cost of software (11%), as shown in **Error! Reference source not found.**.
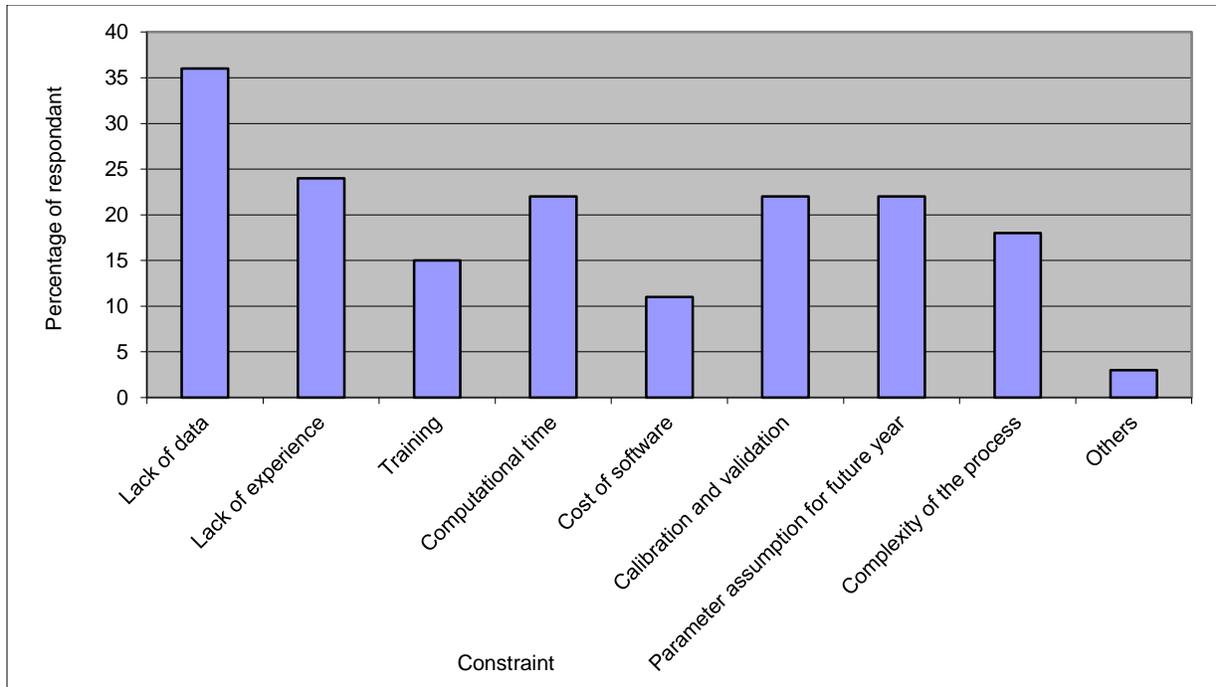
Figure 3-2 Identified technical and institutional constraints

With regard to the maximum size of the network that the DTA must be able to handle, 37% of the respondents said that it should be able to handle the largest size network in Florida (e.g., the Southeast Florida network that includes Miami, Fort Lauderdale, and Palm Beach including 4,283 zones, 19,349 nodes and 26,718 links), 27% specified a medium size network (e.g., the Jacksonville network including 2,578 zones, 73,260 nodes and 177,735 links), and 25% specified a small size network such as Gainesville. Some respondents also specified that DTA should also be able to handle the Florida statewide model network, which is a large statewide network in geographic size but is modeled at a much lower level of spatial details compared to regional urban models.

With respect to the needed temporal model resolution (the assignment period); 32%, 35%, and 23% of the respondents specified 15 minutes, 30 minutes, and one hour, respectively. Few respondents specified five minutes. Others said that the period should be changeable depending on the application with 15-30 minutes required for congested urban networks and one hour being sufficient for statewide or regional evacuation analyses.

The most needed supports by the modeling community were specified as the provisions of training (25%), standards/guidelines (15%), case studies (13%), assistance in DTA tool selection (13%), long-term support (13%), knowledge center (11%), and peer review (8%) as shown in **Error! Reference source not found.**3. Other specified needs included documentation of DTA methods.
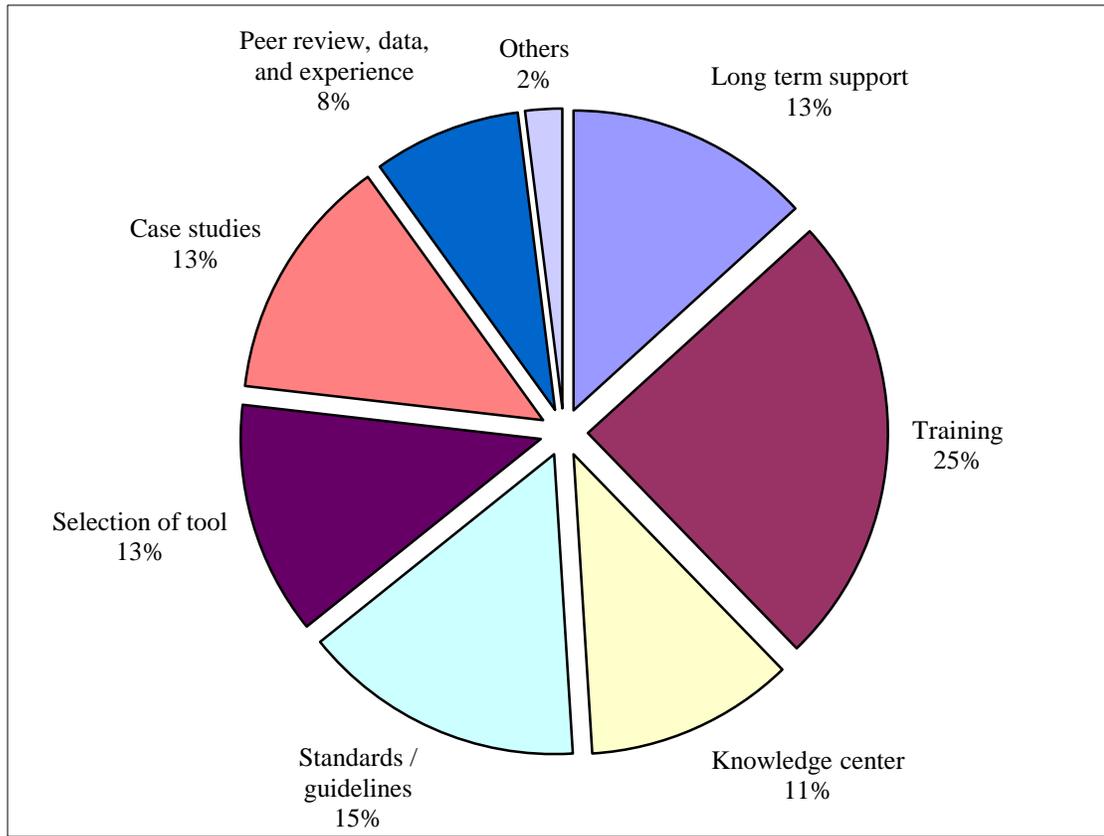
Figure 3-3 Types of assistance needed by the modeling community

When asked about a reasonable increase in the computation time, a majority of the responders accepted a 45% increase in computational time for models that require two hours to run using static assignment as presented in Figure 3-4. For longer run-time models, the accepted increase in computational time was specified to be around 20%. However, further examination of this issue in the stakeholder workshop described next indicated that the modelers might be willing to accept significantly higher increases in run time, depending on the application under consideration. In reality, DTA requires much longer running time than what was indicated to be acceptable in the responses.
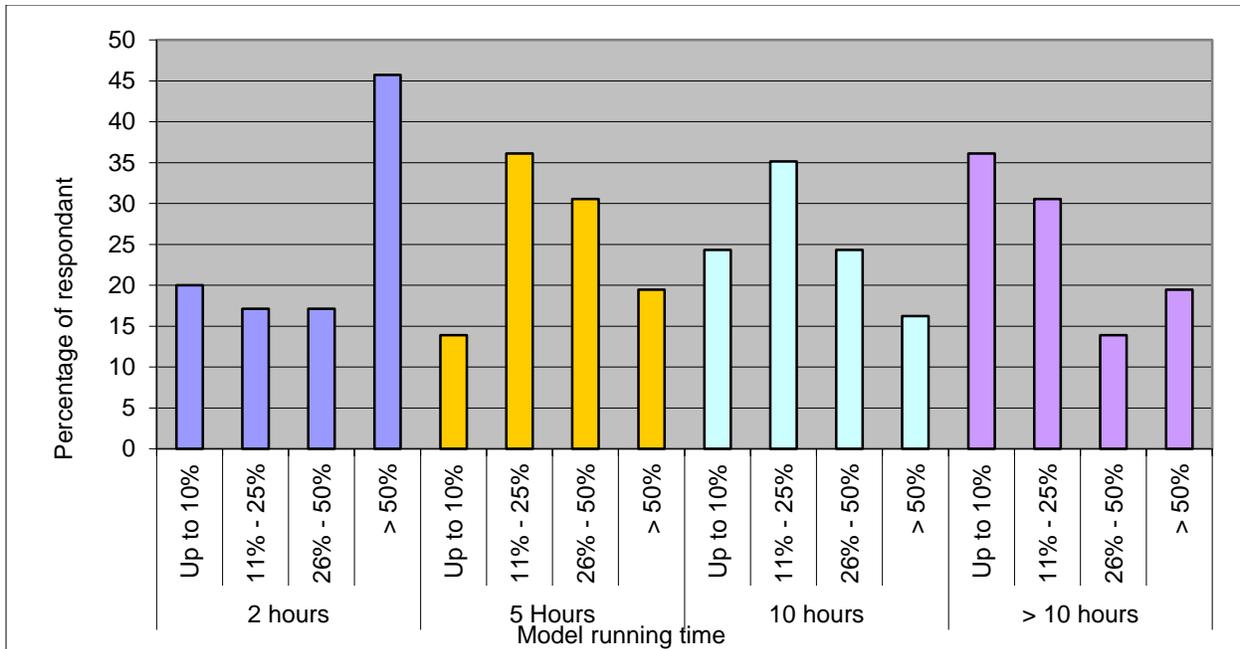
Figure 3-4 Reasonable increase in computation time regarding static model computation time

Other inputs from the responses included:

- 58% of the respondents indicate that the DTA assignment should include person-based modeling, in addition or in lieu of vehicle-based modeling.
- Methods should be developed to evaluate existing DTA solutions and platforms in a thorough and objective manner.
- The DTA platform must be capable of accurately replicating real-world phenomena.
- The DTA must be able to model advanced ITS, pricing, and managed lane strategies.
- There is a need to identify data requirements and sources.
- There is a concern about the level of knowledge and experience required for DTA applications; DTA tools should not be too complex to learn, understand, and use.
- DTA should be an additional process and should not replace the existing assignment methods in the demand forecasting models, at least in the short term.

3.3   User Need Workshop

A DTA user need workshop was conducted December 2010 in Orlando, FL and was attended by approximately 50 modelers from Florida, although there were several modelers from outside the

state among the attendees. The research team made a presentation of the state-of-the-art in DTA modeling, applications and associated issues, which were based in part on the review of literature conducted in this study. The presentation was meant to deliver information to the attendees and more importantly to induce interactive discussion of DTA modeling needs in Florida. The areas covered in the discussion included DTA model alternatives, hardware/software issues, calibration requirements, convergence, data requirements, intersection modeling, relationship to traditional four-step models, and integration with activity-based models.

An example of the discussion in the workshop is presented herein to illustrate the types of the feedback gathered in the workshop. This example is related to the generalized cost function as applied to different traveler (user) types in the DTA process. There was extensive discussion of this issue in the workshop. Workshop attendees emphasized the need to make the generalized cost function as flexible as possible to include additional parameters other than travel time and monetary costs. The additional parameters could include reliability, number of signals, arterial versus freeways preference, number of turns, a discomfort/safety index, and so on. Of course, including more parameters would require the accurate estimation of the weights of these parameters in the generalized cost function, which may not be easy to do. In addition, the attendees wanted the DTA to allow the modelers to have the maximum flexibility in specifying various types of users with different generalized cost functions, assignment behaviors, access to information, familiarity with the network, and link/facility access constraints.

Some of the existing DTA tools severely limit the number of parameters that can be used in the generalized cost functions and the types of users that can be modeled. Many examples were given by the participants of why it is important to overcome these limitations. These examples include the modeling of tourists versus commuters, modeling different trip purposes, modeling the value of time and reliability of commercial vehicles versus passenger cars, modeling of the higher willingness of drivers with electronic toll tags to pay tolls, and so on. There was also a mention that there may be a need to model the parameters of the cost function for each user category as a distribution rather than as an average value.

3.4 Tool User Interviews

This section presents interviews with users that have applied DTA in their analyses. The users were selected from those that have utilized Cube Avenue, DynusT, and TRANSIMS, as examples of DTA software users. The discussions involve issues related to both general DTA applications and issues related to the utilized DTA software.

3.4.1 Interview Setup

The users were identified from recommendations by the software developers. The following were the persons interviewed by phone.

- Hubert Ley, Argonne National Laboratory
- John Kerenyi, P.E., Senior Traffic Engineer, City of Moreno Valley
- Scott Higgins, Oregon MPO
- Brian Wolshon, Professor, LSU
- Guy Rousseau, Travel Surveys & Transportation Model Development Manager, Atlanta Regional Commission
- Lei Zhang, University of Maryland
- Shi-Chiang Li, System Planning Manager, FDOT District 4
- Roberto O. Miquel, Planner, CDM Smith
- Jim Hicks, PB America

The users were asked a pre-prepared set of questions, as follows:

1. What is the purpose of the modeling assignment? What are the issues to be addressed?
2. What is the size of the network (zones, links, nodes, and number of trips)?
3. What are the main issues that you faced with the DTA modeling process in general and the specific tool in particular?
4. Compared to static assignment, where the obtained results more accurate? Provide information that could not be achieved with static? Produce any unexpected results?
5. How easy was getting technical support for the software?
6. How easy was it to convert from your demand model to the DTA tool model?

7. Would you do the DTA modeling again? Would you do anything different, if you start over?

8. Do you have any other comments?

3.4.2 TRANSIMS Chicago Implementation

This project has focused on the evacuation of the Chicago area. It includes the investigation of traffic routing, lane closures, and barriers at strategic entrances during evacuation, which need very dynamic network modeling. Due to limited resources for emergency responders, practical strategies such as barriers at strategic entrances, and a staff informed by projection, the advantages of this DTA model is that it can consider regional abnormal traffic patterns resulting from evacuation that are quite different from the normal demand. It can also model the evacuation plan down to the person level.

The network is 25,000 links, 40,000 nodes, 10,000 square miles, with 27,000,000 auto trips, 3,000,000 transit trips (total is 30,000,000). One-second time step is used for simulation. TRANSIMS version 5 has considerable enhancement compared to TRANSIMS version 4 including modifications of car-following model and queuing approach. The demand is obtained from Chicago MPO model and 12-15 user groups were modeled.

One of the issues identified with the model is the steep learning curve but users reported that use of the model is now easier. Another issue identified is the additional network details required such as signals, stop signs, left-turn lanes, lane restrictions etc. An additional issue is that the assignment starts with high demand on some paths and finds difficultly to converge by shifting to alternative paths. Finally, an additional issue is that the signal model does not work well with the simple signal timing calculated internally by the software. The exact signal timings were obtained for about 600-700 intersections. Utilizing transit as part of the assignment process makes achieving equilibrium more difficult. Most of the above problems were identified as associated with DTA generally, and are not specific to TRANSIMS.

It was found that DTA results are statistically comparable to the static assignment results but it was difficult to get reasonable validation data. The main benefit to the DTA is that results

include more detailed time-variant network and link performance, allowing the identification of trouble spots.

Argonne National Laboratory, who was responsible for the application, after gaining experience provided training on TRANSIMS identified certain things that could have been done differently. It was mentioned that that may be an assessment of the software choice. However, it should be noted that they did not have choices other than using TRANSIMS when the project started due to it being the only package available (at the time) capable of handling large scale networks and doing transit assignment. Transit assignment is critical for evacuation in the Chicago area.

3.4.3 Use of Cube Avenue to Model Evacuation

This project (conducted between 2008 and 2010) uses Cube Avenue to address evacuation problem in Florida, specifically, to estimate clearance time for emergency management. The study area is the whole state. However, due to the large size of the network, it was subdivided into 11 regions. Given the size of the used data sets, such division may be necessary for all simulation-based DTA tools.   The total number of zones is about 10,000-11,000 and the numbers of zones for subareas range 200-900 depending on the area analyzed. The southeast Florida region is the largest subarea,. it covers the area from Key West to central Florida.

The network was extracted from the Florida Statewide Model with the 2005 base year. The number of evacuation trips in a sub-network can exceed one million. Thus, some scenarios were not possible due to the large number of trips.   The packet size was 1 in this project. Initially, the packet split method was used since it was the only method available. This resulted in the total number of modeled trips increasing dramatically during the assignment, which caused the model to crash. Then, the enhanced Avenue MSA method that utilizes packet allocation rather than split was introduced after communicating with the Cube Avenue developers. This method solved the problem.

One issue encountered is the need for good time variant trip matrices of the loadings. Another problem was that to avoid coding background traffic (that do not evacuate), which would have resulted in unacceptable increase in the size of the problem.   When these cases were discovered,

they were dealt with by refining the model network capacities to provide for more reasonable evacuation traffic flow and to account for the background traffic. Another issue faced was that the queuing model in Avenue did not isolate correctly the impacts of the queues of left and right turning movements (or exit ramps in case of freeways) with respect to its use of link queuing capacity (by lane). These queues were allowed to fill the whole link, and thus totally block upstream movements. Citilabs responded that one way around this is to use the junction modeling to model different lanes for different movements. It should be mentioned, however, that while it is possible that the junction modeling would have corrected this issue, the vast geographic scale of the modeling scope of this project made it unfeasible to implement the junction modeling. During the course of this project when the problem became known and was discussed with Citilabs, the solution proposed by their staff was to consolidate links to reduce micro-links and to prohibit unnecessary turning movements. These solutions were implemented and the problems were resolved. Finally, due to the large size of the network, the assignment had difficulty avoiding congestion on long distance paths, although alternative routes were present in some cases. It should be noted that long distance paths in the evacuation model are hundreds of miles long in some cases, far in excess of what is expected in simulation-based DTA applications.

The intersection signalization was not included, which made the application easier. It was found that the DTA results are comparable to the static assignment with no abnormal results. However, due to the lack of data, it is difficult to compare. The queuing information, queue location, and clearance time can be obtained from DTA but not from static assignment. One realistic finding that may seem counterintuitive at first, is that when Collier County is evacuated before Dade County it reduces the clearance time of Dade County due to the elimination of background traffic in Collier County.

Regarding the ease of support, the support from the vendor was very good. Users found that documentation needs to be improved. In some cases, even though things are documented, the user can easily overlook them. The Cube Avenue log file was found very useful for debugging.

The reason that the Cube Avenue was used was because the Cube software is the selected environment for the state, thus there is no extra costs for state agencies. In addition, Cube Avenue is able to model larger networks compared to what can be achieved with models that are based on lane-by-lane simulation.

3.4.4 Atlanta Implementations of TRANSIMS and Cube Avenue

Atlanta has implemented both TRANSIMS and Cube Avenue DTA. In the past, they have also tried to use VISTA as part of I-285 project modeling. TRANSIMS was used to model express bus routing system and transit in the downtown area, however, they did not use transit assignment. The TRANSIMS network includes 15 million trips per day.

Cube Avenue was used as part of a macro-meso-micro multi-level simulation with Avenue providing the mesoscopic component at 15-minute time-slice resolution and VISSIM providing the microscopic component. It was used at the corridor level focusing on major corridors in the region to estimate queues and delays.

The main advantage of Cube Avenue is its seamless integration with the regional model. It is also considered much more user friendly than TRANSIMS. However, it was found not to be detailed enough to assess corridor performance. However, because it is combined with microscopic modeling, this is not a big issue. Cube Avenue also appears to be suitable for smaller areas compared to TRANSIMS that can be used for large-scale networks. Respondents found that a few years ago, Cube Avenue was not ready for implementation, but consider it now much better and ready for implementation, particularly with the new packet allocation model. Because of the long running time for the two tools, the Atlanta team had to limit the number of alternatives studied.

With regard to technical support, having AECOM the developer of TRANSIMS, as part of the consultant team helped a lot. The team also experienced good technical support for Cube Avenue.

With regard to conversion from macro to meso models, the team noted that the transition may not be straightforward for congested networks where V/C more than 1 is allowed in the macro

models. Transit modeling is still difficult since DTA is still mainly for highway modeling. DTA can give detailed project level performance measures such as bottlenecks, queues, and delays by time and location. Complex geometry can be correctly assessed including reversible lanes and collectors/distributers design. However, DTA seemed to be more appropriate for corridor-level analysis. In the future, the team's plan is to continue with the use of both TRANSIMS and Avenue. The goal is to have a number of tools used as needed for a specific application.

3.4.5 DynusT Application for Tolled Facilities in the Washington D.C. Area

This project was to combine behavioral models with DTA to determine what users will use tool facilities, revenue levels, shifts in occupancy, and time shifts. At this stage, the project is at a regional level with detail signal control not coded. In the future, corridor level and intersection level details will be coded and used in more detailed analysis. Portions of the area in Washington D.C. were coded, which was estimated to be 23 miles by 20 miles for the AM, PM, and midday (900 zones, number of signalized intersections is 1,100 signals). Currently, the traffic for the 6 AM to 9 AM was coded with the total number of users at 400,000. The plan is to combine the mesoscopic model with a microscopic model for further detailed analysis.

One of the important issues is the required input matrices. The modelers looked at an existing module to calculate the time-variant O-D matrix by the DynusT developers but decided to develop and use their own tool. The team asserted that a good initial O-D matrix is important and that coding the network details can also be time consuming. Converting from static to dynamic and estimating subarea network O-Ds still needs additional research. In addition, there is a need for set of utilities (e.g., interfacing to signal optimization software, etc.) to support modeling.

With respect to coding signal timing, it was found that DynusT internally calculated timing is not adequate and coding of the actual timing may be necessary, particularly since the team is feeding the results to a microscopic simulation tool. In addition, their experience is that previously suggested automated calibration/validation procedures are not usable for large complex networks. They finally achieved volume accuracy of 10% on freeways and 15% overall. The travel time on major corridors and between major O-D pairs was within 20%-25%.

The complexity of their modeling that included DTA routing combined with time shift required iteration between the behavior model and the DTA in DynusT. The modification of the source code of DynusT was difficult due to the lack of documentation and the team recommended caution to avoid impacting existing modules in DynusT.

The benefits of DTA modeling includes providing time-variant queues, delays, stops section-by-section and also estimate time-shift (peak spreading) in addition to routing. It also allows accounting for signals (although at this stage, the actual signal timings are not coded) and active management strategies. Mesoscopic modeling provide much more efficient modeling compared to microscopic modeling.

In general, the team found the technical support to be adequate.

3.4.6 DynusT and Dynameq Applications in Oregon

In Portland, both DynusT and Dynameq were selected for modeling the network. DynusT was selected to model at the regional level and Dynameq to model specific subnetworks. The reason for selecting DynusT is that it is open source, has a good reputation, and has been used in SHRP2 and FHWA projects. There are 2200 zones, 12500 nodes and 33000 links in the regional network with six million daily trips, although the modeled period is limited to between 2:00 PM and 7:00 PM.

The reason for using DTA is that as congestion increases and managed strategies increasingly are utilized; there is a need for more advanced ABM and DTA modeling. At the current stage, there is no transit modeling integrated with the DTA application, although the new version of DynusT is expected to have some transit capabilities, as discussed in Section 2.

Incorporation of correct signal timing and coordination was important to produce reliable results. The required level of details was an issue. The Portland team hired three temporary staff to code network details. These details can also be inputted into the static network.

Dynameq simulation provided more detailed lane-by-lane simulation than DynusT, and allows the modeling of turning movement queuing correctly. However, it cannot be used for the whole region from both memory and run time points of view.

Open-source software, like DynusT, may have the disadvantage of not having adequate technical support and untested/undocumented features. Also, the Portland modelers expressed concern with the continuity of the product support in the long-term.

For this team, the DynusT regional network has not been fully calibrated. The calibrations of the Dynameq network are further along and started to produce good results for calibrated freeway segments. Portland team found that signal timing calculated internally does not seem to be good because it does not consider signal coordination, which has an important impact on congestion. Initial examination of the results indicated that the queues are not reasonable, but this is most likely due to the need for improved O-D matrix and signal timing. The visualization of results is important with DTA. DynusT GUI is not sufficient for this, and it is hard to see the results. DynusT Studio, a newly released commercial software, provides this functionality and is being purchased by the team.

The region will complete this exercise again, if given the chance. Region staff found that DTA provides much more detail than demand models. This functionality cannot be provided by microscopic simulation, due to computational demands. In the future, the team would investigate and do a more careful review of the different packages to evaluate their qualities. The issue of link-based versus lane-based simulation should also be investigated further.

3.4.7 Application of TRANSIMS in the City of Moreno Valley in California

TRANSIMS was applied to model a regional network with 48,000 links and 40 million trips in the base year and 50 million trips in the future year. The BPR curve was used in conjunction with the router at this level. This provided a time-of-day trip table, which was then further disaggregated for the subarea. In addition, a subarea with 1200 links (one million trips in the base year and two million trips in 2030) was extracted and assessed in TRANSIMS simulation. Transit was not included as part of the modeling. An important part of the model was truck

movements. The demands were converted from the production/attraction stage to retain the trip purpose.

An important issue with DTA is the conversion from the four-period regional trip matrices to time-variant trip matrices. Initially, the team had a mistake in specifying the probability of trips at any given period that was later caught by the peer-review of their model. Also, they found that the additional details required in TRANSIMS modeling required additional efforts, compared to the static demand forecasting model. They also found a steep learning curve, particularly for those not familiar with scripting. The scripting language (Python) is currently being used, which may be difficult to use and code. One of the current modifications that this team is investigating is to constrain the trips by their arrival times, thus resulting in time shifts in response to congestion.

One interesting result that was initially unexpected is that the demand in the PM peak was lower in TRANSIMS compared to the regional model. It was determined that the difference was because some of the trips that were included in the PM peak in static assignment actually spilled over into the post-peak (6-7 PM). Another was that a corridor showed an unexpected increase in density due to change in land use. The reason was later found to be that there was less opportunity for carpool with the change that reduced the opportunity of using high occupancy lanes. In further review these results were found to be correct and an improvement over static models.

The advantage of using DTA is the high fidelity of the model and the ability to focus on a small area. The city did some three-way comparison and found that whenever there is a significant deviation between the TRANSIMS and the regional model, the TRANSIMS model was found to produce better results.

With regard to technical support, the person in the city responsible for the modeling can be considered as an advanced user that was able to answer many of the questions on his own. However, he also found good support from FHWA and AECOM. AECOM fixed bugs that were found in the software on occasions. Version 4 of TRANSIMS is reported to be much more

stable. The user group list was found to have been very helpful to users of the software, in general. The team stresses that training is important and the modeler should at least take the one-week training course of TRANSIMS.

The team found that initial conversion to TRANSIMS took a considerable amount of time but with the previous experience this could be done much faster in the future. If given the opportunity to go back and do it again, the different developed modules should be restructured and organized to make the structure of the model more "elegant".

The interviewee generally likes using TRANSIMS and has participated in the TRANSIMS user community. He is also providing training and technical support on TRANSIMS to other jurisdictions in the area.

3.4.8 Application of TRANSIMS to Evacuation in Louisiana

Louisiana State University (LSU) utilized TRANSIMS to model the evacuation of the New Orleans network, which is a large regional area. The model is demanding because of the large size of the network, long modeling period, and the individual vehicle modeling. There was a need to determine the clearance time for different user groups requiring a micro-level look at the issues. The modeled area is about 100 miles by 50 miles. The model is currently being extended to a mega model, that extends from Houston to New Orleans, using the TRANSCD network as a starting point. Simulation rather than BPR functions were used in the assignment. Transit modeling was also used at a later stage. Contra-flow lanes operations were also modeled.

Some of the challenges experienced by the LSU team are the usability of the program (coding, processing output, difficulty in visualization, etc.) and the documentation. The models appear to be very good but the ease of use appears to be a problem at the beginning. Technical support was provided by AECOM and Argonne National Lab and the open source user community list serv. The team found version 5 of TRANSIMS appears to be much faster than version 4. They also found a general problem with DTA is that it is a new field with still not enough deployments and understanding of the different issues, and a need for training.

The team found the accuracy compared to static models difficult to assess. However, the assessment is that the reasonableness of the results for 3.5 million people over 24 hours period is impressive and very realistic. They had difficulty in a part of the network to shift trips to obvious alternative routes. They ended up having to reduce the free-flow speed to 30 mph on the heavily loaded corridor to shift people out of it.

If given the chance, the project manager said he would use DTA again, and would try as much as possible to understand better the model technical details.

3.4.9 Cube Avenue Application in FDOT District 4

As a start, it should be noted that Citilabs mentioned that many of the reported issues in this section have been corrected in later versions of the model developed for the area. FDOT District 4 has used Cube Avenue in one project about two years ago to determine its capabilities in better analyze traffic performance. The project was for a small network in West Palm Beach between two I-95 interchanges and the arterials east of these interchanges with a total of 30 zones. The effort took three to four months. The actual signal timings and turning movement volumes were obtained and used in the development and calibration of the model. Some of the faced issues were the required learning curve, what street delay function to use, and the difficulty in obtaining realistic queuing on short links. Also, the calibration requirements and criteria were not clear. These seems to be general problems to DTA utilization and not specific to Cube Avenue.

After all the effort, the network was not sufficiently calibrated. A consultant is currently revisiting the network calibration. In many cases, it was not clear if bottlenecks identified in the system by the model are due to problem in the model or actual results to consider. The short links in the FSUTMS model created a lot of problems and it took time to increase the lengths of the links or to join them to adjacent links to make them work adequately.

The interviewee expressed his belief that DTA should not replace demand models, since the demand models based on the BPR curves are still needed to predict the actual demands because they allow v/c ratios higher than 1.0. However, DTA may be available for multi-resolution

analysis, in which DTA tools can be used in between the demand forecasting models and the microscopic simulation models.

When using DTA, the team recommended that the analyst should be cautious about the level of details and efforts required. This extra effort should be justifiable from analysis benefits point-of-view. In addition, modelers should not use DTA for analyzing networks that are more than 6-7 year in the projects because of uncertainties in the demands. As more advanced data becomes available in the future, they can be used for better calibration of the models.

3.4.10 Application of DynusT to Assess Diversion due to Freeway Closures in Michigan

This project applied DynusT to Assess diversion due to the closures of I-96 in Detroit, Michigan. It involved modeling large subarea of the region. The modelers initially explored modeling the full region in DynusT and ran it for one iteration. The iteration for 24 hour modeling took about three hours, so a decision was made to model a subarea. It should be recognized that the software is being modified to make it much more efficient. The modeled subarea included 1,700 zones and 22,000 links. The AM and PM peak were modeled with 2 Million and 3 Million trips, respectively. The commercially available tool that became available recently was very useful in visualization important measures that would have been very difficult without the tool.

An important challenge was obtaining the signal timings, which were not available. The modelers obtained the signal timings from previous studies and utilized the DynusT calculated plans. This was considered acceptable since the main purpose of the study was to compare alternatives rather than obtaining absolute values. Another challenge was that the coding of intersections was not correct in the regional demand forecasting model and had to be revised in the DTA subnetwork. A problem was found with extracting subareas from a full area in DynusT. Another limitation of DynusT is the maximum number of O-D matrices allowed (three).

The method used to predict the demand was to first use time-variant factors (fixed for all O-D pairs) to multiply the peak period O-D matrices to obtain initial 30 minute O-D matrices. The factors were obtained from the MPO travel survey. The matrices were assigned to the network

and the vehicle trajectories resulting from the assignment were analyzed to determine if there is a need to make adjustment in specific O-D pair demands. Two to three iterations were required to achieve reasonable demands. The network was calibrated for demands but not for travel times.

The modelers believe that the diversion results were reasonable. 15 videos were made based on DynusT visualization showing the base and alternative solutions for use in outreach activities with project stakeholders. This type of analysis is a major advantage of DTA versus static assignment.

3.4.11 Summary of Findings from the Interviews

Interviews with the users of three DTA tools (TRANSIMS, DynusT, and Cube Avenue) revealed that the experience with real-world applications is still limited, although agencies are increasingly considering and willing to invest in the use of DTA tool for the assessment of recurrent, incident, and evacuation conditions. These agencies recognize the abilities of agencies to provide time-variant measures not available from static demand models (such as queues, delays, and bottleneck locations) and the ability to model advanced management strategies such as pricing, reversible lanes, and intelligent transportation systems (ITS). Only few applications were identified where DTA has been applied or are being attempted on a regional scale and some modelers found difficulty when applying specific tools to large size networks. Thus, the analyst should be mindful of the amount of effort required for such an exercise and in the selection of the DTA platform for regional applications.

Coding the additional details of the network for DTA tools is time consuming. An important finding from the interviews is that coding good signal timing plans that ensure realistic coordination between adjacent signals is important (though time consuming) and that in many cases the simple plans calculated internally by the tools are not adequate enough to provide good results.

It appears that most of the issues related to converting to DTA involve the greater level of network and demand details required and are not associated with particular software packages. Another finding is that the ability of tools to simulate the interaction between queues of different

movements on the same link and the spillback to above links are critical to DTA analysis and need to be considered when selecting the DTA tools. Utilizing transit and time of trip choices in conjunction with the assignment process makes achieving equilibrium more difficult. Some agencies have started utilizing DTA as part of multi-resolution (macro-meso-micro) analysis, which is an attractive option for certain types of applications.

It should be recognized that the interviews present a snapshot at a particular point in time. All of the packages are evolving including the commercial packages. It appears that all three tools addressed in the interviews have been improving as new releases come to the market. Further, improvements in computer technology are likely to significantly decrease runtime in the future.

4.   Catalog of Assignment Assessment Criteria

This section presents a catalog of assessment criteria for an advanced assignment environment (AE) in Florida. The main purpose of writing these criteria is to allow the comparison and testing of various assignment methods and tools including static and dynamic assignment, as part of this project and future projects. Thresholds for acceptable limits and performances of the assignment environment vary as a function of the modeling purpose and scope, agency, region size, and other considerations for the specific projects under considerations. This became clear during the requirement workshop and surveys, conducted as part of this project. Thus, this study avoids specifying exact thresholds but rather present guidance on the factors to be considered when comparing the performance of static and dynamic assignment models and tools. Later in this project, testing of existing tools will indicate what can be expected with regard to the performance of these tools.

It should be recognized that the "assignment environment" in this document does not reference the utilized core assignment tool but also the tools and modules that need to be developed to support the use, calibration, and utilization of the core tool.

These criteria are based on a review of literature, the requirement workshop of this project, and a survey of the modeling community conducted as part of this project. It should be recognized that some of the criteria are not expected to be satisfied by any existing methods and tools. The criteria are written based on the needs rather than the existing capabilities of assignment methods.

For each of the identified criteria, a statement will be given specifying if the criterion is general and applied to all applications (All), applicable to long range plan (LRP) modeling, short range plan (SRP) modeling, planning for operation/ITS (PO), and/or corridor/impact studies (CS).

The next steps in utilizing the requirements presented in this section include:

- An assessment of how examples of existing static and dynamic assignment tools can meet these requirements.
- An assessment of what additional supporting tools and modules are needed to accomplish the requirements.

It should be recognized that the purpose of developing the assessment criteria and the testing of example tools based on the criteria is not to select a specific assignment tool for use in Florida but to provide a mechanism for the assessment of different tools relative to the criteria for use in a specific application. The final decision about the selection of a tool will have to be made by the agency based on various considerations related to the specific application.

4.1   General Hardware and Software Criteria

In general, DTA should be able to run on computers commonly available to the public and private sectors. However, it is recognized that for large regional networks and computationally intensive modeling, it is acceptable that specialized equipment such as 64 bit computers, parallel computing on multi-processors, and/or distributed computing are needed as long as this is made clear ahead of time to the users. In terms of run time, 16 hours has been identified as possible upper limit in the requirement workshop of this project for large networks. However, it was also stated that this limit depends on the modeled system attributes and some workshop attendees mentioned that ideally they should be able to leave the model running overnight and obtain the results when they come to their offices in the morning. Also, computer technology is rapidly evolving. A 16-hour runtime on today's computer will likely take eight hours in two years and four hours a year after that. The current 16-hour runtime should be regarded as a temporary limitation on performance.

Some of the identified general software requirements include the ease of interfacing with the existing demand forecasting modeling environment in the state, microscopic simulation models, emission models, activity-based models, and geographic information systems. The core DTA tool or developed supporting tools must provide the visualization and analysis of the outputs utilizing various performance measures obtained from the tool and in line with the Highway Capacity Manual recommendation that the output measures from alternative analysis tools

should be trajectory based. The requirements also emphasize the cost, training opportunities, and previous practical experiences with the software.

Below are the detailed hardware and software criteria:

Applicability: All requirements presented in this section are general requirements that are applicable to all four levels of requirements (All).

1   The assignment environment (AE) shall be able to run on computers commonly available to the public and private sectors for the specific application under consideration, with different congestion levels and multiple user class specifications.

    1.1   For corridor studies, the AE shall run using commonly available 32-bit computers with a memory of 2 GB of RAM. For regional network and computationally intensive components, it is acceptable that 64-bit computers are needed as long as this is made clear ahead of time to the users.

    1.2   The AE shall run in a reasonable time on commonly available public and private sector computers considering the size and attributes of the model network and demands.

        Note: 16 hours has been identified as possible upper limit in previous studies and in the requirement workshop of this project. However, this limit depends on the modeled system attributes. Reasonable time should be decided on by the agencies. This project will provide the time required by typical AE tools as guidance.

    1.3   For large problems, it is acceptable that more powerful computers are needed to reduce the computational time, as long as the analyst is made aware of this need in advance.

        1.3.1 The AE computational performance shall improve with the use of computational capabilities such as distributed (allocation of processing workload to available processors on a local area network) or parallel computing (use of multiple computer processors), if such capabilities are implemented and required.

        Note: There may be tradeoffs between communications overheads and computational savings that are a function of the number of processors. There may be an optimal

number of processors for best computational performance. The AE results shall be the same on computers with different number of utilized cores, in the case of parallel processing, and different number of computers, in case of distributed processing, if such capabilities are implemented and required. This shall be applicable for both deterministic AE procedures and for stochastic procedures. Stochastic procedures shall allow specifying fixed seed numbers and ensuring that the results are the same, as long as the seed numbers are not changed.

1.3.2 The AE results shall be the same when running the software with the same inputs different times on the same computer and different computers. This shall be applicable for both deterministic AE procedures and for stochastic procedures. Stochastic procedures shall allow specifying fixed seed numbers and ensuring that the results are the same, as long as the seed numbers are not changed.

2   The AE shall be installable on Florida agency local computers or internal networks. Internet-based software solutions are not acceptable.

3   The tools/software used in the AE shall have acceptable initial and annual recurrent costs.

4   The AE shall provide the flexibility of updating core modules within the AE environment.

Note: This could include having an open source software or an application programming interface (API) type facility to allow the interface with internal assignment/traffic flow modules.

5   The AE shall have a proven customer support.

6   The vendor of the assignment tool shall provide contact information of agencies that successfully used the tool in at least one project of similar size to the size of the system to be modeled using the tool.

Note: Vendors will have to be asked to specify for such information the size of the largest network modeled by their software.

7   It shall be possible to integrate the AE with other modeling components as outlined below either directly or indirectly by using data conversion tool.

7.1   The AE shall be able to be run from and exchange all needed AE input data and AE output data with the FSUTMS modeling environment.

7.2   The AE shall be able to exchange or can be extended to allow exchanging all needed AE input and AE output data with microscopic traffic simulation tools that use text input and output files.

7.3   The AE shall provide sufficient data to support integration with the EPA emission modeling procedures that require travel model inputs.

7.4   The AE shall allow importing data from GIS files.

8   The AE shall provide a Graphical User Interface (GUI) that allows editing inputs.

9   The AE shall output text files with model outputs including global, facility, and link measures of performance including but not limited to volume, speed, travel time, density, queue length, and delays.

9.1 The AE shall include graphical displays of performance measures.

9.2 AE shall display the results in text list format.

9.3 It shall be possible to reconstruct the vehicle trajectories from model output files.

9.4 In addition to outputing vehicle trajectories, the software should be capable of outputting a table of link flows and a table of link travel times, averaged over a user selectable time interval. The combination of this output with the experienced trajectories would allow an analyst to self-report the final convergence measure to verify that equilibrium was achieved and that the reported values by the software are consistent. This is important, as it ensures transparency of model results rather than masking them as would be the case without such information.

9.5 The AE shall allow dynamic animation of traffic movements and the animation link-based performance measures. The scale of the animation (geographic and temporal) shall be such that it is sufficient to allow the modeler to calibrate and assess network performance.

Note: A qualitative assessment of the ability of typical tools to meet this requirement will be made in this study.

10 Training shall be provided to the Florida modeling community with focus on the principle and use of AE.

4.2 Shortest Path and Path Choice Modeling

The shortest path and path choice modeling requirements specify the needs for efficient algorithms and implementations of these algorithms. Flexibility should be given to the modelers to have different parameters in the generalized cost functions and also to have different user types with different generalized cost functions, assignment behavior, access to information, familiarity with the network, and link/facility access constraints. Another path choice requirement is to allow the modeler to specify fixed paths between origins and destinations for use by specified proportions of travelers by traveler types. Dynamic user equilibrium based on experienced travel time is needed to simulate the behaviors of commuters who are familiar with the network during recurrent congestion. In addition, non-iterative or no feedback assignment (also called one-shot assignment in some tools) of some of the travelers is also needed for some applications such as advanced traveler information system (ATIS) modeling.

The user equilibrium shall support a proof of convergence for each assignment time interval. The assignment environment including the supporting tools must support the computation of the relative gap and use it as the convergence criterion, based on user specified values for each departure (assignment) time interval. The analysts shall be able to achieve DTA solutions of high quality to allow their use in applications that required stable, consistent, and proportional route flows such as select link analysis, subarea analysis, and impact analysis. To improve the computational efficiency, the assignment should ideally be able to re-compute a new equilibrium from a prior solution (warm start), even if the demands or network attributes have significantly changed.

1 The AE shall identify all the routes used by each origin-destination pair, the volumes associated with them, and the performance of each path in terms of the components of the disutility function used in the assignment.

Applicability: LPR, SPR, PO, and CS.

2 The utilized tool(s) within AE shall provide documentation and/or an explanation of the method used to ensure an efficient identification of the optimal sets of shortest path and path choice. This should include the documentation of basic algorithms, methods for improving computation memory and time efficiency, data structure improvement, and other techniques.

Applicability: LPR, SPR, PO, and CS.

3 The AE shall allow the user to specify different driver groups for use in the assignment.

Applicability: LPR and SPR (3.1, 3.4, 3.5), PO (all), and CS (all).

   3.1 The AE shall allow differentiation between different vehicle types (e.g., automobile, truck sizes, and truck types).

   3.2 The AE shall allow differentiation between different types of demands in the assignment process to reflect the fact that the disutility function parameters, network constraints, and tolls are different for different traveler types (e.g., commuters, non-commuters, tourists, etc.), toll payment methods, trip types, and vehicle occupancy levels.

   3.3 The AE shall allow differentiation between different demand and vehicle types on managed lanes and toll facilities, allowing tolls to charge different rates to vehicles belonging to these types.

4 The shortest paths and path choice computation shall be made for specified user groups (demand and vehicle types) to take into consideration the different disutility function parameters, link use constraints, and tolls for different groups.

4.1 Utilization of additional user groups shall not result in AE performance not meeting the other requirements presented in this document, including for example, computational time, consistency, and convergence.

5 The identified shortest paths and path choice shall take into consideration various factors that affect traveler choices that can be specified in a disutility function for use in the assignment. The weights of the different factors in the disutility function shall be modifiable by the analyst for different demand and vehicle types.

Applicability: LPR (5.1-5.5), SPR (5.1-5.6), PO (all), and CS (all).

5.1 The disutility function shall allow consideration of the cost of travel in dollars.

5.2 The disutility function shall allow consideration of the average travel time.

5.3 The AE shall allow consideration of the difference in the perceived travel times between different facilities such as freeways and arterial streets.

5.4 The disutility function shall allow accounting for the number of turning movements in the disutility function.

5.5 The disutility function shall allow accounting for the number of signals in the disutility function.

5.6 The AE shall allow accounting for measures of reliability.

5.7 The disutility function shall allow accounting for the additional disutility resulting from accounting for calming measures.

6 The assignment interval (the interval between the time of path updates and assigning traffic to the updated paths) shall be user selectable. The length of the interval over which travel times are averaged for the purpose of computing time-dependent shortest paths, network performance, and equilibrium convergence should be user selectable (5 minute, 15, minute, 60 minute, etc).

7 The modeler shall be able to identify fixed paths to be used for all traffic or for specified user groups between O-D pairs.

Applicability: PO

8 The selected paths shall consider access restrictions/prohibitions for specified vehicles or demand types on individual links.

Applicability: ALL

8.1 The AE shall be able to assign traffic using different assignment options.

8.2 Non-iterative or no feedback assignment (also called one-shot assignment in some tools), in which vehicles are assigned paths based on free-flow travel time without feedback to the assignment, shall be supported to allow simulating users unfamiliar with the network.

   Applicability: All but more for SRP, PO, and CS.

8.3 Non-iterative or no feedback assignment (also called one-shot assignment in some tools), in which vehicles are assigned paths based on instantaneous travel time without feedback to the assignment, shall be supported to allow simulating drivers receiving pre-trip real-time information and deciding to divert based on the information.

   Applicability: PO.

8.4 It shall be possible to have user equilibrium based on experienced travel time to simulate users familiar with the network during recurrent congestion (day-to-day learning).

   Applicability: All

8.5 It shall be possible to have a single run with different user groups assigned using different assignment options (e.g., unfamiliar drivers using non-iterative assignment based on free-flow travel time, user equilibrium for commuters, etc.).

Applicability: All but more for SRP, PO, and CS.

9 The user equilibrium shall support a proof of convergence for each assignment time interval.

Applicability: All

9.1 The AE shall support the computation of the relative gap and use it as the convergence criterion, based on user specified values.

9.2 The used relative gap measure shall be reported for each departure (assignment) time interval.

9.3 The AE shall allow the ability to specify the maximum number of iterations as a criterion for the assignment.

9.4 It shall be possible for the user to ensure that the AE will converge to an acceptable relative gap. It shall be possible to plot of relative gap by departure interval over all iterations to show convergence to stable values.

Note: A typical trend that has been found with AE is to see increasing values of relative gap with increasing departure time, partially due to the increasing congestion levels encountered by drivers.

Note: For static assignment, the relative gap found to be acceptable by research is (10^{-4}). It has been found that dynamic traffic assignment models typically have significantly higher values of relative gap in the final calibrated solution. The level of convergence achieved by an algorithm in a given time period is highly dependent on the size of the network including the trip tables, the level of congestion, and the number of zones.

9.5 AE shall provide sufficient information to allow the external computation of the total relative gap (see Requirement 9.4 in Section 4.1).

10 The results from the AE shall be of high quality to allow their use in applications that required stable and proportional route flows such as select link analysis, subarea analysis, and impact analysis.

Applicability: All.

10.1 AE shall ensure route flow proportionality in relation to the demands between origins and destinations.

10.2 AE shall respond logically to changes in input and shall not produce unexplained results, such as significant changes in vehicle mile traveled (VMT) and or changes in links that should not be impacted by minor changes in the modeled network.

10.3 Division of a link into sub-links while maintaining network geometry shall not result in change in the assignment results.

11 The assignment shall be able re-compute a new equilibrium from a prior solution (warm start), even if the demands or network attributes have significantly changed.

Applicability: All.

11.1 Warm start shall significantly improve the computational efficiency of AE.

12 It shall be possible to extract zone-to-zone path skims for the variables used in the disutility function (travel time, cost, distance, etc.) for any time interval within the modeling period and with a user selectable aggregation interval over which time-dependent shortest paths are computed for the purpose of skimming. .

Applicability: All

13 The AE shall allow the user to perform en-route assignment to emulate in-vehicle traffic information provision using different options.

13.1 Non-iterative or no feedback en-route assignment (also called one-shot assignment in some models), in which vehicles are assigned paths based on instantaneous travel time while traveling on the network to simulate traffic diversion, based on information while en-route.

13.2 The en-route assignment shall consider the percentage of travelers with in-vehicle information and the proportions of travelers that change route under different conditions in response to the received information.

14 The AE shall allow the modeling of the impact of dynamic message sign/highway advisory radio implementations on traffic diversion under incident conditions.

Applicability: PO

14.1 The AE shall allow the user to change input parameters to impact the proportions of travelers that change routes under different conditions in response to the received information.

14.2 The AE shall have the option to allow the user to specify the paths used by travelers diverting in response to incident conditions.

15 The AE shall allow the specification of monetary user costs of travel (tolls).

Applicability: All

15.1 The AE shall allow specifying entrance, exit, and mainline tolls by user groups.

15.2 The AE shall allow specifying distance-based tolls by user group.

15.3 The AE shall allow specifying tolls that are calculated dynamically as a function of congestion (dynamic pricing) or are inputs as time variant tolls.

4.3   Traffic Flow Modeling (TFM)

1   The AE shall include a traffic flow modeling components that satisfy traffic flow theory principles.

Applicability: All

2   TFM shall be able to simulate different traffic conditions from free-flow conditions to congested conditions at an acceptable level of accuracy for the considered application.

Applicability: All

   2.1   TFM shall estimate the change in travel time with the increase in demand.

   2.2   TFM shall simulate the building, propagation, and dissipation of queues.

   2.3   TFM shall model queue spillbacks to upstream links.

   2.4   TFM shall model the blocking of left and right turning movements without causing the through movements to be blocked (unless the TFM is able to accurately account for turning bay queuing capacity and account for the spillover to adjacent lanes).

   2.5   TFM shall account for the blocking of a lane due to back off from an exit ramp.

   2.6   TFM shall account for limited capacity at merging points by distributing the flow correctly between the two merging traffic streams.

   2.7   The software shall process all the demands inputted to the model without eliminating portions of the demand due to congestion.

3   TFM parameters that affect capacity and performance measures shall be changeable by the users.

Applicability: All.

4   TFM shall not allow link V/C ratios greater than 1.0, other than due to rounding errors.

Applicability: All

5   TFM shall be able to simulate non-recurrent congestion.

Applicability: OP

5.1   The modeler shall be able to model and assess the impacts of incidents and work zones with specified capacity drops, beginning time, and ending time.

6   TFM shall be able to assess signal control impacts on approach travel time/delays.

Applicability: 6.1 (All), 6.2 and 6.3 (SRP, OP, CS), 6.4 (OP and CS), 6.5 (OP)

6.1   The analyst shall be able to specify a simplified method of assessing the impacts of signals on traffic flow travel time/delay for large scale networks without requiring detailed modeling of signal control attributes and intersection geometry.

6.2   TFM shall optionally automatically calculate the signal timing, using an acceptable methodology.

6.3   TFM shall allow the user to input signal timings.

6.4   The effect of cycle length and green split on intersection delay shall have the same trend as those produced by commonly used and accepted traffic signal analysis tools.

6.5   TFM shall be able to account for the effect of coordination between traffic signals.

7   TFM shall be able to simulate the impacts of stop signs and yield signs on traffic operations.

Applicability: OP and CS.

8   TFM shall be able to model the impacts of ramp metering on freeway mainline and on-ramp traffic using time-of-day rates and/or traffic responsive rates.

Applicability: OP.

9   TFM shall be able to simulate time-variant speed limits on links, at least at the time-of-day level, to simulate applications, such as dynamic speed limit and school zoning.

Applicability: OP and CS.

10 TFM shall be able to simulate the impacts of bus priority on signal operations on transit and passenger car traffic, at least at a macroscopic level.

Applicability: OP.

11 TFM shall be able to model the operations of bus-only lanes and bus congestion bypass lanes.

Applicability: CS and OP.

12 TFM shall be able to model managed lane with different number of lanes and different capacity per lane compared to general use lane.

Applicability: All.

13 TFM shall allow the modeling of reversed/contra-flow lanes.

Applicability: CS and OP.

14 TFM shall allow the inclusion of warm-up and cooling periods that are not considered when reporting the statistics of the system in the outputs.

Applicability: All.

Note: Modeling traffic flow by lane is desirable but not required. In addition, modeling merging, diverging, and weaving explicitly is desirable but not required.

15 The TFM shall be able to take into account non-motorized travel activity on adjacent segments and cross-streets to represent interactions between simulated vehicles and significant pedestrian/bicycle movements.

Applicability: Applications that require assessing pedestrian/bicycle impacts.

4.4   Network Geometry (Supply)

1   AE shall allow the simulation of a network that include links belonging to different facility types including freeway facilities, arterial facilities, on and off ramps, two-way two-lane highways, HOV/HOT lanes, truck-only lanes, and user-defined link types.

Applicability: All.

2   The provided AE tool shall meet network size requirements of different applications of the AE tool including the number of zones, nodes, links, and vehicles.

Applicability: All.

Note: The size depends of the application being considered by an agency. However, this study will provide estimates of the ability of example AE tools to deal with various network sizes.

3   The modeler shall have the flexibility of specifying connection to the network for the trips to enter and leave the network with as many connections per zones as needed.

Applicability: All.

3.1   The AE shall have an acceptable method to divide the generated trips from a given zone between the different connections between the zone and the network.

3.2   The AE shall allow the modeler to specify the distribution of the generated trips from a given zone between the different connections between the zone and the network.

4   The AE shall be able to correctly simulate networks with short and long links.

Applicability: All.

5   The modeler shall be able to model detailed intersection geometry and control including the number of lanes and lengths of left and right turn bays.

Applicability: CS and OP.

6   The AE shall be able to model specified link and node attributes.

Applicability: All.

   6.1   AE shall allow specifying capacity or fine-tuning parameters to produce capacity for network links.

   6.2   AE shall allow specifying free-flow speed and/or speed limit per link and per facility type.

   6.3   AE shall allow specifying the permission and restriction of different turn types from a link including thru, right, left, diagonal, and U-turn.

   6.4   AE shall modify link capacity based on heavy vehicle proportion (trucks, transit, and RVs) and grade.

   6.5   AE shall allow the modeler to specify turn penalties of network links.

7   AE shall allow specifying transit line information including transit paths, stop stations, terminals, park and ride, and schedule.

Applicability: All.

8   The AE shall support specifying time-dependent link variations, such as posted speed, number of lanes, capacities, based on start/end schedules.

4.5   Network Demand

1   AE shall allow the specification and modeling of different types of demands.

   1.1   It shall be possible to specify different vehicle types (e.g., passenger cars, truck types, truck sizes)

 Applicability: All.

1.2 It shall be possible to specify different demand types (e.g., commuters, non-commuters, tourists, etc.) to model socioeconomic classifications or value-of-time classifications

Applicability: CS and PO.

1.3 It shall be possible to specify vehicles with different equipment (e.g., electronic toll transponders, dynamic guidance/in-vehicle information)

Applicability: PO.

2 AE shall allow the inputs of demands in a fine-grained origin-destination matrix format at a user specified interval length.

Applicability: All. Note that coarser interval lengths may be acceptable for long range plans.

2.1 The user shall be able to specify trips at modeling interval lengths of as low as 15 minutes.

2.2 The modeler shall be able either to specify the demands at each modeling interval or the proportions of the total demands for the intervals.

3 AE shall include a dynamic (time-dependent) trip matrix estimation process.

4 The AE shall allow the inputs of demands as an activity list.

Applicability: All.

4.1 The AE environment shall allow the use of activity-based model outputs as input to the assignment process.

4.1.1 It shall be possible to load individual trips in the activity list on the network at the time that the activity is estimated to start.

4.2   It shall be possible to have a feedback of assignment results to the activity-based model to re-estimate the demands based on the network performance.

4.6   Transit Modeling

Applicability: Networks with significant transit services.

1   AE shall allow the consideration of various types of public transportation including bus, paratransit, express bus, bus rapid transit, and rail.

2   AE shall allow trips that utilize a mixture of modes (transit, auto, and walk).

2.1 The AE shall allow the specification of the accessibility of transit to walk and auto.

Note: Modelers normally use distance-based or time-based criteria to identify zones that can access a bus stop or station by walk. The availability of park and ride facilities is used to determine the availability of auto access to a bus stop or station.

3   AE shall support the identification of optimal transit routes and assigning demands to these routes. A route is defined as a sequence of links and nodes used by transit riders including the transit vehicle portion, in addition to the walk and auto (park-and ride) access and egress portions of the trip.

3.1 AE shall include a route enumeration process to identify sets of routes between origin-destination pairs, which have a reasonable probability of being used to travel between the zones.

3.2 AE shall allow analysts to request multi-path routing between origin-destination pairs, in which multiple potential routes are identified with the probabilities of using these paths. AE shall also allow performing best-path assignment, in which a single "best path" route for each origin destination pair is identified.

3.3 AE shall utilize the travel time for each particular transit run scheduled time in the assignment. The results from the highway assignment process shall be used as

needed to produce the performance of the enumerated potential routes by the period of the assignment.

3.4 The transit speed used in calculating transit travel time in the assignment shall be a function of highway speed resulting from the highway assignment process but shall also consider the difference between highway and transit speed, which may be a function of parameters such as the number of stops, number of boarding/alighting, facility type, and area type.

3.5 It shall be possible to adjust the transit speed based on signal priority availability.

3.6 AE shall allow the estimation of the wait time, transfer time, and number of transfer for use in the assignment process.

Note: Examples of this are the wait curves used to compute initial and transfer wait times based on the frequency of services in Cube. In Cube, the user can assign at each stop node, two wait curves: one for the first boarding point and the other for transfer points.

3.7 AE shall allow for accounting for the impact on highway performance of the extra auto traffic generated due to driving to park-and-ride facility, as specified by the analyst.

4   AE shall support the estimation of mode choice by providing the in-vehicle travel time data required for the mode choice estimation process.

5   The mode choice, route enumeration, and demand assignment shall be based on a generalized cost (disutility function) that can include fare, in-vehicle time, transfer/boarding penalty, waiting time, and walk time.

5.1 It shall be possible to specify the relative weights of different components of the generalized cost function that are different for different user groups to reflect the importance of each of the generated cost components.

5.2 The analyst may select to use different components for the route enumeration step compared to the demand estimation step.

5.3 The AE shall select between walking, transit mode/line, boarding/alighting, and transfer choices.

5.4 The analyst shall be able to specify that transit line choice based on service frequency and/or generalized cost of travel to account for users with different information levels of the travel time to destination.

6 AE shall account for variations of transit fares strategies including complex fare systems such as fare-zones, peak/off-peak fares, transfer fares, monthly pass discounts etc.

6.1 It shall be possible to specify different fares for different traveler classes.

6.2 It shall be possible to specify the fares as a function of a number of measures including trip distance, number of fare zones crossed, and boarding/alighting fare zones.

6.3 It shall be possible to specify different fares for initial boarding compared to subsequent transfers.

7 The AE shall allow the modeler to put limits on the parameters of the selected transit options including:

7.1 Maximum number of transfers.

7.2 Wait time limits.

7.3 Transfer walk limits.

7.4 Maximum trip time.

7.5 Minimum in-vehicle trip time.

8 The user shall be able to specify a "must-use-mode," which must be used during at least one leg of a public transport route.

9 AE shall account for transit capacity constraints/crowding effects. The estimated average wait time shall include the estimated additional wait time due to passengers not able to board (and must wait for a later service). The link travel time adjustment shall account for rider's perception that travel time has higher disutility when standing compared to sitting, for example.

10 AE shall account for the impact of the presence of transit vehicles on the capacity of highway links.

11 AE shall allow the modeling of bus lanes, bus-toll lanes, and bus-on-shoulder.

12 AE shall produce detailed reports from the assignment/passenger loading including:

    12.1 Link based outputs.

        12.1.1 Number of buses on links (individual lines and total).

        12.1.2 Number of riders on link (input and output).

        12.1.3 Average in-vehicle travel time and total travel time (included dwelling time at bus stops) on the link.

    12.2 Bus stop level information.

        12.2.1 Aggregated and disaggregated (by line) numbers of boarding and alighting.

        12.2.2 Aggregated and disaggregated (by line) average dwelling, waiting and transfer times.

    12.3 Network based outputs.

        12.3.1 Number of transfers, average waiting time, and transfer time.

        12.3.2 Total trip and in-vehicle travel times for auto and transit vehicle.

12.3.3 Total vehicle and walking distances for passenger and transit vehicle.

12.3.4 Average speeds for passenger and transit vehicle.

12.4 Line based outputs.

12.4.1 Total distance.

12.4.2 Total boarding and alighting.

12.4.3 Average in-vehicle and total travel time.

12.4.4 Total revenue.

12.4.5 Maximum number of standing and sitting riders.

12.5 Transit system skim matrices.

4.7 Calibration and Validation

Applicability: All requirements presented in this section are general requirements that are applicable to all four levels (All).

1 The AE shall allow model calibration by adjusting parameters related to capacity, demands, assignment, and traffic flow model parameters.

2 AE shall allow the changing of global and local parameters to produce link capacities/throughputs, travel times/speeds, volumes, density, queue lengths, and other measures comparable to those observed in real world.

3 AE shall allow the importing and use of data from multiple sources (coded in standard formats) to support model calibration.

3.1 It shall be possible to import link-level ITS data at different time aggregation levels including volume, speed, travel time, and density measurements.

3.2 It shall be possible to import FDOT statistics office data including volume and classification.

3.3 It shall be possible to import turning movement data.

3.4 It shall be possible to import signal-timing data.

4 AE shall allow the modeler to modify the configuration of the links on which the traffic enter or exit the network.

5 Tools shall be provided to assist the modeler in the calibration process based on qualitative assessment.

5.1 The tools shall allow the identification of overestimation/underestimation, underutilized versus over-utilized paths between O-D pairs, and inaccurate estimation of demand profiles (time-of departure) based on visual examination of time-series plots of link and path measures such as volume and travel time.

5.2 The tools shall provide time-series plots of link and path measures such as volume, travel time, and density.

5.3 The tools shall provide time-series plots of the number of vehicles in the network by user group at each simulation interval.

5.4 The tools shall provide time-series plots the number of vehicles waiting to enter the network by user group at each simulation interval.

5.5 The tools shall provide time-series plots of time-varying, spatially averaged network speed.

6 Tools shall be developed to assist the modeler in the calibration process by calculating measures to assess the degrees of deviation between model estimates and real-world measurements for each time interval.

5. Utilization of Criteria Catalog to Assess Assignment Tools

As stated in the previous chapter, one of the most important reasons to develop the assessment criteria catalog is to be used, possibly as a starting point, to support the assessment of existing DTA tools to determine if they meet state, regional, local and/or project requirements. This section presents a demonstration of how such assessments can be made based on the developed criteria. For this demonstration, an assessment is made of the ability of the static Cube assignment currently included in the FSUTMS models and three existing DTA tools to meet the criteria presented in Chapter 4 of this document. These three DTA tools are two open source tools originally developed with support of the USDOT (DynusT and TRANSIMS) and a DTA tool (Cube Avenue) from the developer of Cube, the modeling engine of the FSUTMS. A number of agencies in Florida have started using or considering the use of Cube Avenue since this tool is available to them and there is no conversion effort involved. DynusT (and its parent Dynasmart) have been used in research projects in Florida. TRANSIMS has been used as part of the SHRP2 C10A project for the Jacksonville region. Other assignment tools can also be assessed using the assessment criteria presented in the previous section and the assessment procedure presented in this section. It should be mentioned again that, when utilized, the assessment criteria could be amended and modified to meet the requirements of the specific applications. The subsections below include the assessment results for corresponding subsections of the assessment criteria in the previous chapter.

The assessments were conducted utilizing a number of simple hypothetical networks and three real-world networks, depending on the test under consideration. The real-world test networks are shown in Table 5-2. For each assessed criterion, one or more hypothetical and/or real-world networks were selected as needed for the testing. As shown in Table 5-2, two different Jacksonville networks were used in the assessment. The first is extracted from the statewide model with coarse representation of the Jacksonville network. The second is extracted from the (NERPM) model and represents a detailed representation of the network. The third network used in the assessment I-95 to NW 27th Avenue in Miami-Dade County. Although, this network represents a much smaller geographic area than the Jacksonville statewide network, it is expected to require more computer resources due to the higher number of zones and the longer modeling

period, although the numbers of nodes and links in the two networks are almost equal. Table 5-3 includes the hypothetical networks used for testing different parts of this study.

5.1   Hardware/Computational Efficiency Assessment

To test the hardware requirements, the four tested tools were run on commonly available 32-bit and 64 bit computers with a memory of 2 GB of RAM, details of computer features are given in Table 5-2.

Table 5-1 The attributes of two computers

Attribute	First Computer	Second Computer
Processor	Intel Core 2 Quad	Intel Core 2 Duo
CPU	3.0 GHz	2.66 GHz
RAM	8.0 GB	2.0 GB
System Type	64 bit	32 bit
Operation System	Windows 7	Windows XP
Graphic Card	NVIDIA Geforce 310	NVIDIA Geforce 9800 GT
Graphic Card Memory	4 GB	1 GB

Table 5-2 presents testing networks from different models, which are SERPM I-95, Statewide Jacksonville, and NERPM Jacksonville. Table 5-3 shows hypothetical networks that are used to assess different criteria. The base trip matrices utilized in this study were extracted from the demand forecasting models. However, different levels of demands were tested representing different percentages of the peak hour demand in the FSUTMS model since the demand level is expected to affect the running time and 100% demand was found to produce highly congested conditions for the non-calibrated networks.

Table 5-2 Test networks

#	Network	Characteristics
1	NW 27th Ave. I-95 Subarea Network (SERPM Model) 	247 zones 1196 nodes 2640 links - Model period is 180 minutes, divided into six 30 minutes intervals - This subarea is derived from SERPM 2010 model
2	Statewide Model Jacksonville Subarea Network 	143 zones 1294 nodes 2805 links - Model period is 90 minutes, divided into eight 15 minutes intervals, including 2 cooling periods.
3	Jacksonville from NERPM Zones 	1815 zones 26812 nodes 54279 links - Model period is 180 minutes, divided into six 30 minutes intervals, including 60 minutes cooling periods.
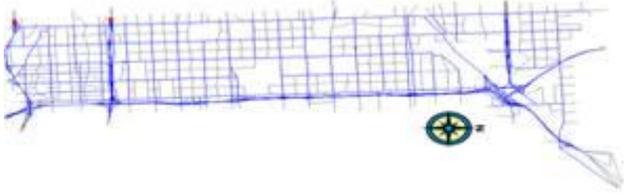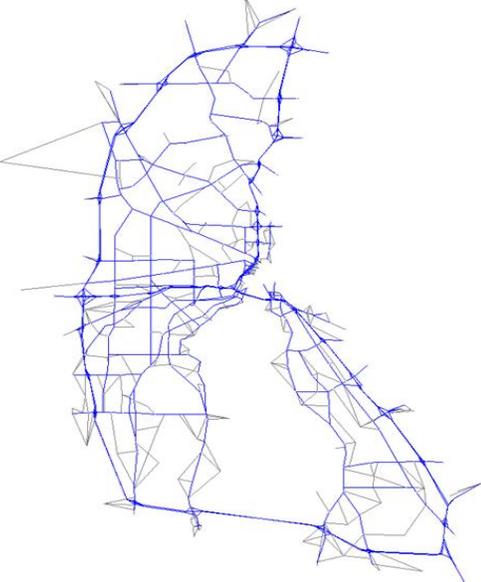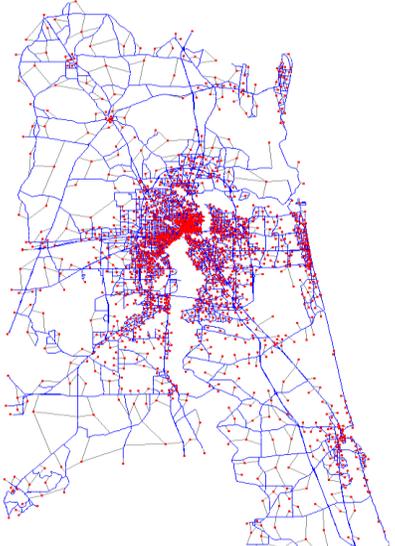
Table 5-3 Hypothetical networks

1		Free-flow speed: 60 mph. Jam density::295/120 veh/mi/ln (Avenue/DynusT) Capacity:1800 vph/ln/hr Link length: 0.5 mile.
2		Free-flow speed: 40 mph. Jam density:295/120 veh/mi/ln (Avenue/DynusT) Capacity: 1800 vph/ln/hr. Link length: 0.5 mile.
3		Free-flow speed: 60 mph. Jam density:295/120 veh/mi/ln (Avenue/DynusT) Capacity: 1800 vph/ln/hr. Link length: 1 mile.
4		Free-flow speed: 60 mph. Jam density:295/120 veh/mi/ln (Avenue/DynusT) Capacity: 1800 vph/ln/hr. Link length: 1 mile.

Table 5-3, continued
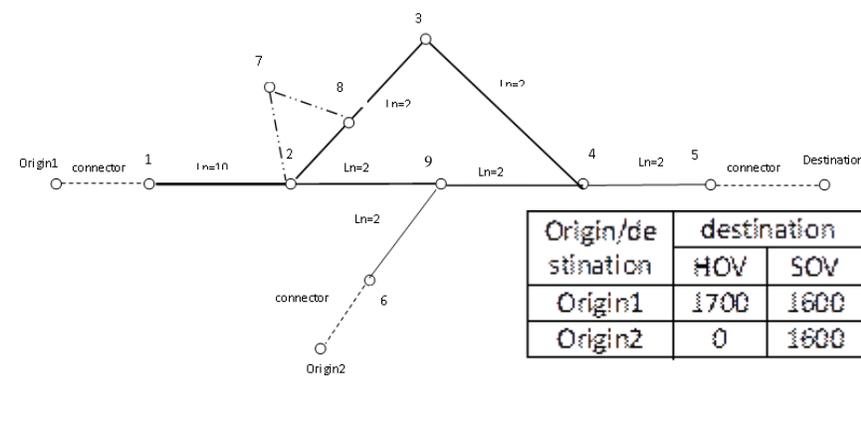
5		Free-flow speed: 60 mph. Jam density:295/120 veh/mi/ln (Avenue/DynusT) Capacity: 1800 vph/ln/hr. Link length: 5 miles, except 1-2& 4-5 with 1 mile *Links 2-7&7-8 are dummy link by distance & free-flow travel time close to 0&large capacity and storage
6		Free-flow speed: 60 mph. Jam density:295/120 veh/mi/ln (Avenue/DynusT) Capacity: 1800 vph/ln/hr. Link length: 5 miles, except 1-2& 4-5 with 1 mile

The total numbers of trips for different levels of demands for the three networks are given in Table 5-4. Initially, all tools were run specifying for 80 iterations. Then, the tools were run for the number of iterations that produced close to the minimum relative gap that could be achieved by the software (13 iterations).

Table 5-4 Testing networks demands (number of trips for model period)

Networks / Demand Level	20%	50%	65%	80%
NERPM Jacksonville	267,924	669,814	870,760	1,071,704
Statewide Jacksonville	22,730	56,826	73,874	90,922
I-95 NW 27th Ave	34,536	86,340	112,242	138,145

With Cube Avenue, the testing was conducted utilizing the Packet Allocation (PA), introduced in the new version of Cube Avenue and the Packet Split (PS) method, which the original method

utilized in the software. With DynusT, the comparison was done utilizing the MSA method originally implemented in DynusT/Dynasmart and the Gap-Function Vehicle (GFV) based traffic assignment algorithm implemented in the latest version of the program. The review of literature section presents reviews of the tested methods mentioned above.

Figure 5-1 compares computational time for different testing networks in Cube Voyager on different computers. This figure confirms the computational efficiency of static assignment, even for the larger size networks.
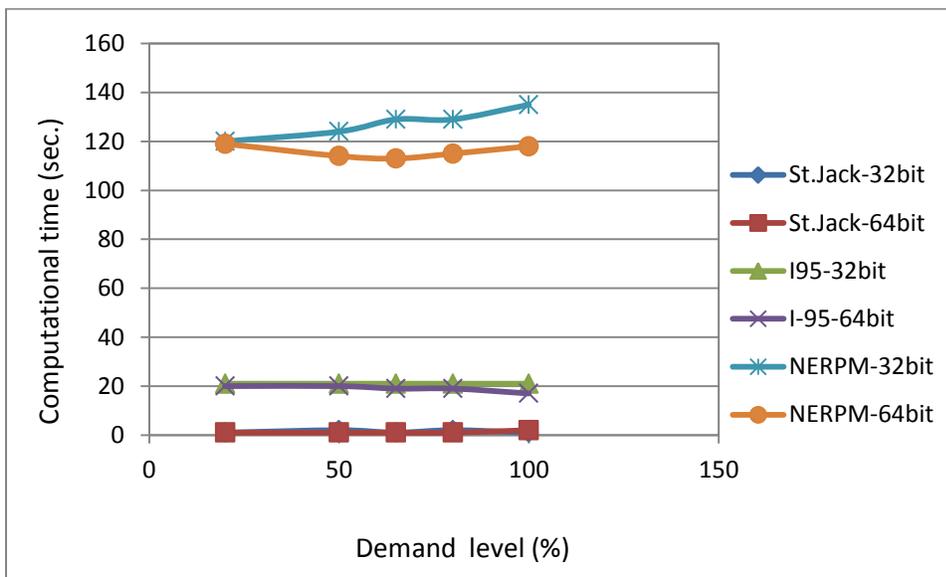
Figure 5-1 Computational time when utilizing Cube Voyager static assignment

The computational time for different levels of demands and computers are given in Figure 5-3 for Statewide Jacksonville network with PA mode. Figure 5-3 and Figure 5-4 presents computational time for different levels of demand in PS mode for Statewide Jacksonville and I-95 networks. Figure 5-5 depicts the I-95 network model for PA mode with different packet sizes in Cube Avenue. The demand level significantly affects the running time for both networks, particularly for the I-95 network and high demands. The PA mode computational time is significantly less than that of the PS mode for both networks. Also, increasing packet size from 1 to 5 decreases the running time significantly, particularly at high demand levels (more than 2.5 times decrease for the 80% demand level as shown in Figure 5-5). Utilizing 64 bit computers

with additional computation power did not improve the computational time, indicating that Cube Avenue does not take advantage of these additional computational capabilities.
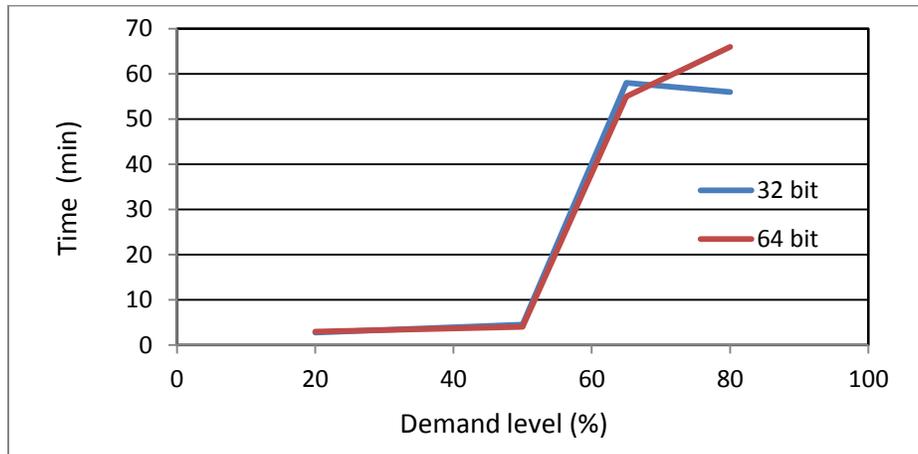
Figure 5-2 Computational time when utilizing Cube Avenue for the Statewide Model Jacksonville Network for PA mode
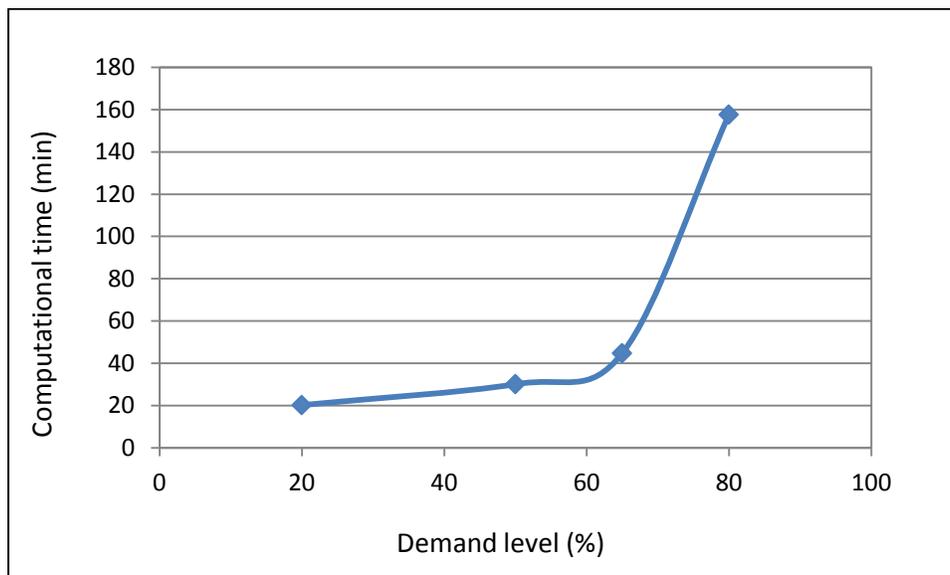
Figure 5-3 Computational time when utilizing Cube Avenue for the Statewide Model Jacksonville Network for PS mode
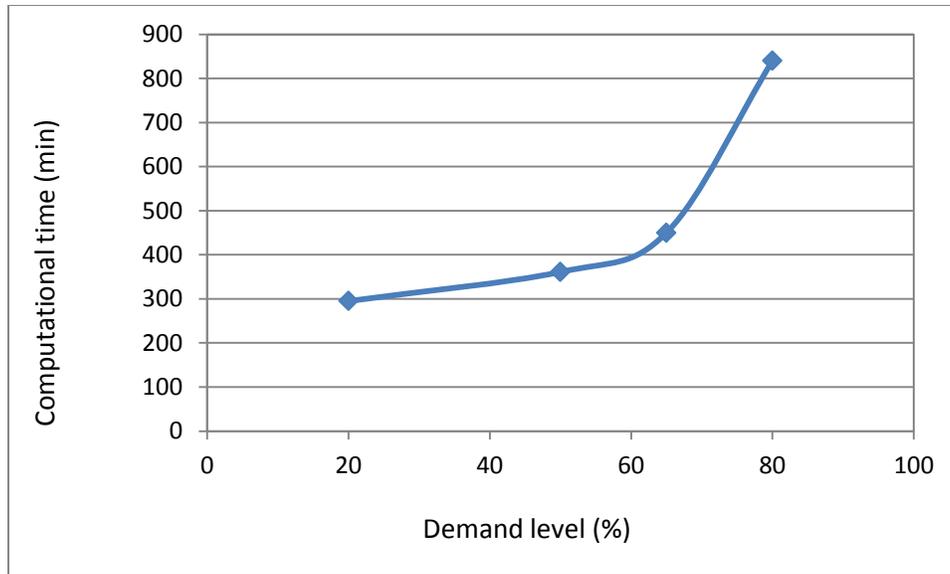
Figure 5-4 Computational time when utilizing Cube Avenue for the I-95 Network for PS
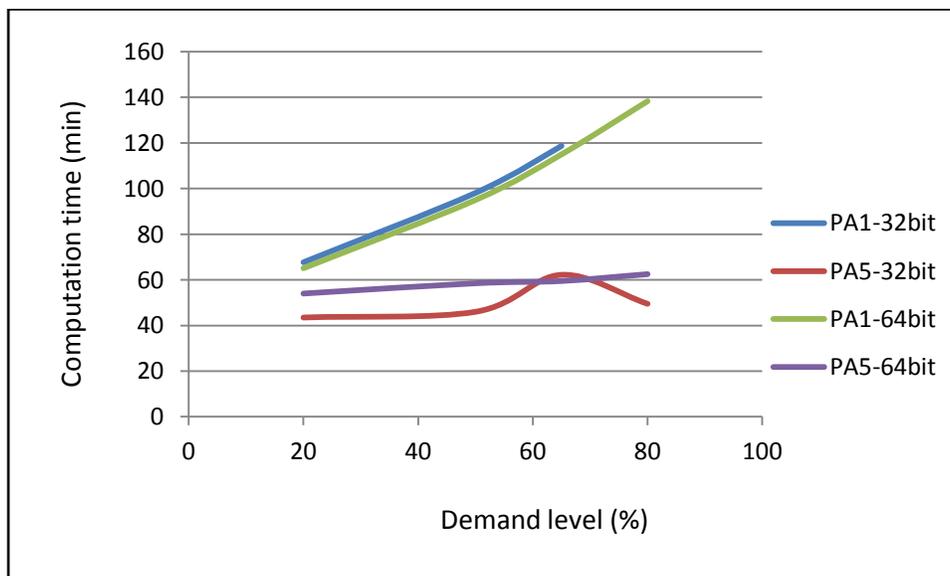
Figure 5-5 Computational time when utilizing Cube Avenue for the I-95 Network for PA packet size 1 and 5

Figure 5-6 to Figure 5-9 show the results of the testing with 80 assignment iterations for DynusT. DynusT is the only software among the three tested that has a 64-bit version. The models run 12% faster for the I-95 network on the 64-bit computer. The Gap-Function Based (GFV) assignment produced about 15% to 35% improvement in computation time depending on the

demand level and the network. In general, the Cube Avenue PA method is significantly more computationally efficient than both methods implemented in DynusT. The PS method of Avenue is slower than both DynusT assignment methods.
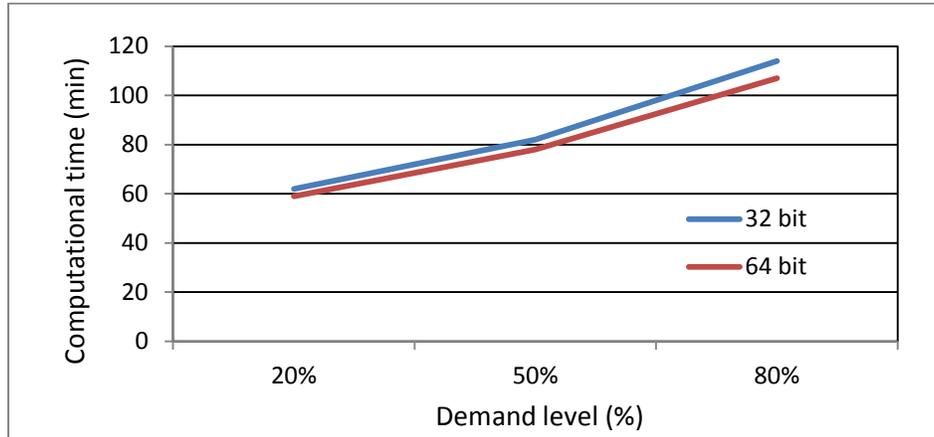
Figure 5-6 Computational time when utilizing DynusT with 32 and 64 bit computers for Statewide Jacksonville
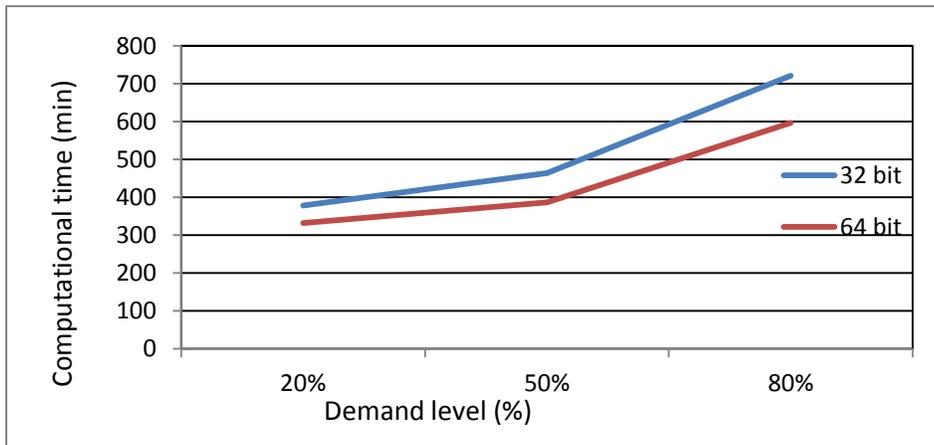
Figure 5-7 Computational time when utilizing DynusT with 32 and 64 bit computers for I-95 Network
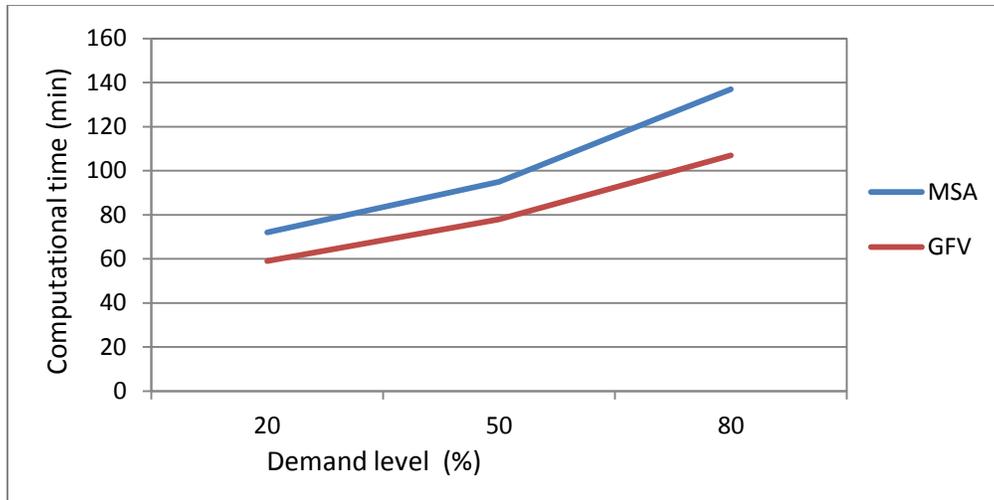
Figure 5-8 Computational time when utilizing DynusT with MSA and GFV Methods utilizing 64 bit Computer for Statewide Jacksonville
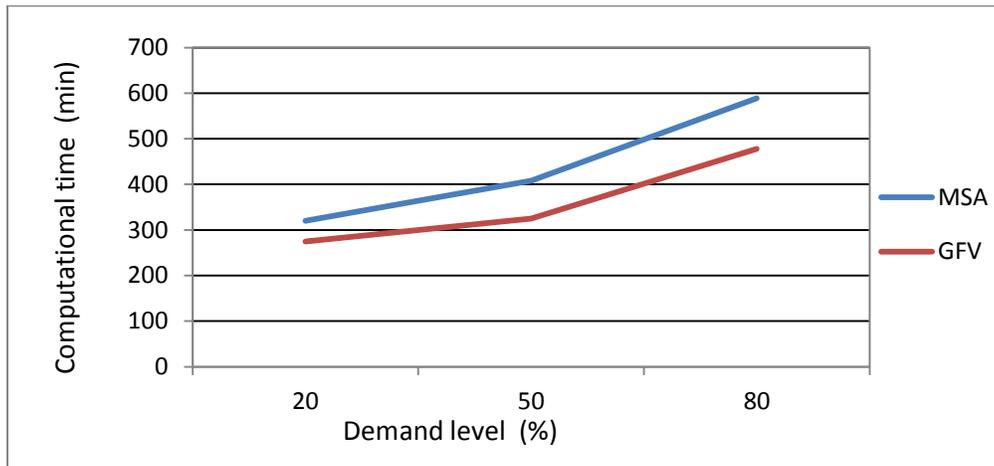
Figure 5-9 Computational time when utilizing DynusT with MSA and GFV Methods utilizing 64 bit Computer I-95 network

The computational time for TRANSIMS is presented in Figure 5-10 for the Statewide Model Jacksonville and I-95. The computational time is only presented for the 32-bit computer since running the software on a 64-bit computer did not make a difference. TRANSIMS is slower than DynusT, depending on the tested case study and whether the 64-bit version of DynusT is used.
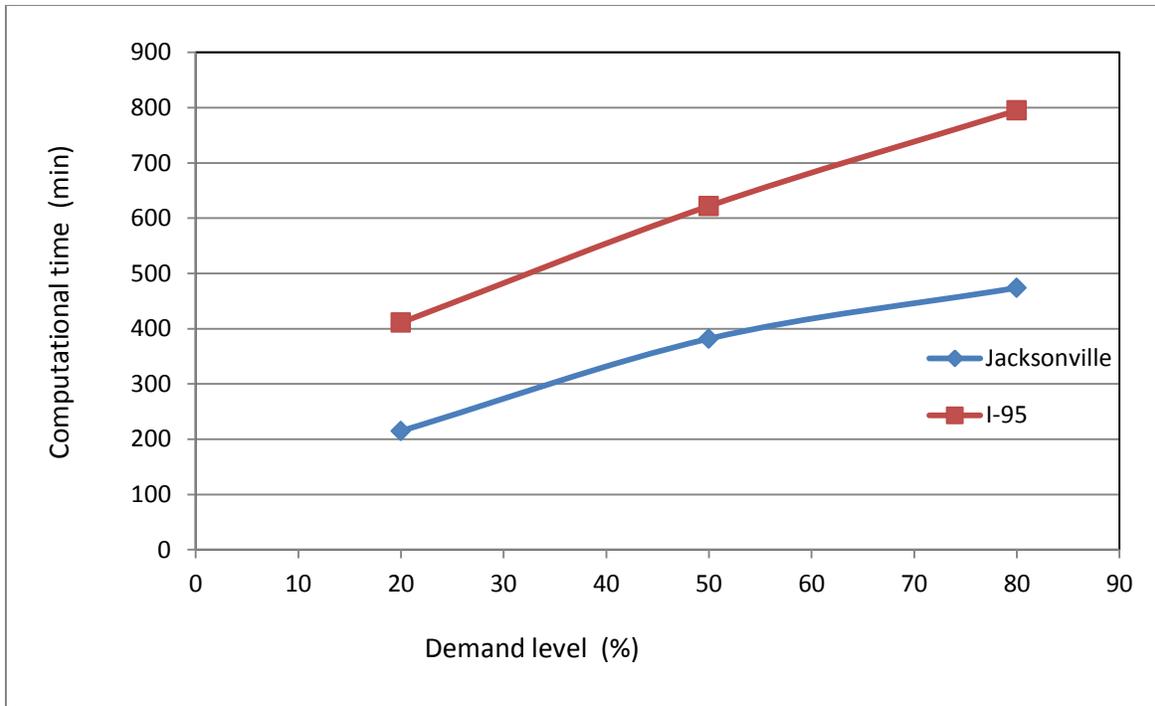
Figure 5-10 Computational time when utilizing TRANSIMS for the Statewide Model Jacksonville and I-95 network

The Jacksonville NERPM model could only be run utilizing Cube Avenue PA. This may be due to conversion problem when converting the network to TRANSIMS and DynusT. This issue is being investigated. Table 5-5 presents Cube Avenue with PA computational time and relative gap for NERPM network. As shown in this table, even when using the PA method, the network with 80% demands requires more than 68 hours for running 40 iterations.

Table 5-5 Cube Avenue Computational Time for different demand levels for the NERPM Jacksonville Network

Demand level	Number of Iteration			
	1	10	20	40
20%	11	111	286	NA
50%	24	235	-	2540
80%	36	378	1156	4099

In Table 5-6, the computational time is summarized for different demand levels and networks for 13 iterations. Table 5-7 illustrates the computational time for NERPM Jacksonville model for

one iteration since it was not possible to run the DynusT and TRANSIMS for more iterations with this network.

Table 5-6 Computational time (min unless specified) for Statewide Model Jacksonville and I-95 network on different tools for fixed 13 iterations

DTA Tool	Demand Level			
	20%	50%	65%	80%
Statewide model Jacksonville Network				
Cube Voyager	2 (sec.)	1 (sec.)	1 (sec.)	1 (sec.)
Cube Avenue (PA)	2	3.2	4	5
Cube Avenue (PS)	13	19	24.5	40.5
DynusT (MSA)	10.2	13.4	15.7	19
DynusT (GFV)	7.6	10.5	12.2	15.6
TRANSIMS	26	57	62	73
SERPM I-95 Network				
Cube Voyager	6 (sec.)	5 (sec.)	5 (sec.)	5 (sec.)
Cube Avenue (PA)	3.5	4.5	5	6
Cube Avenue (PS)	13.5	22.5	30.5	42.5
DynusT (MSA)	8.8	11.7	13.4	16.2
DynusT (GFV)	6.5	8.6	10.2	13.1
TRANSIMS	38.6	47.8	60.1	89.4
NERPM				
Cube Voyager	2	2.1	2.1	2.25
Cube Avenue (PA)	158	347	-	574

Table 5-7 Computational time (min) for NERPM Jacksonville network for one iteration

DTA Tool	Demand Level			
	20%	50%	80%	100%
Cube Voyager	2	2.1	2.1	2.25
Cube Avenue (PA)	11	24	36	46
DynusT (MSA)	85	152	183	247
DynusT (GFV)	72	124	142	198
TRANSIMS	NA	NA	NA	NA
Note: TRANSIMS did not run with the network and DynusT was able to run for only one run with this network. This issue is being investigated.				

It should be mentioned that due to the required computation time, the user should try to minimize the applications that share any of the computational powers of the computer. During our tests, on different dates, the computational time for the same on the same computer was different when utilizing Cube Avenue due to additional applications on the computer (e.g., 20% demand for I-95 sub-network on 32 bit computer, 43min vs. 56min).

Comparison of run times is very fluid at best. The run times shown above for TRANSIMS are based on version 4.0. Version 5.0 runs at least four times faster. Similar improvements are beginning to be made to DynusT. Run times also depend on the computer configuration. Finally, hardware speed continues to increase and, if historic trends continue, will double every 18 months. Run times can only be regarded as a snapshot at a particular point in time and not a permanent factor.

To improve the computational performance, the DTA software has implemented computational capabilities such as distributed (allocation of processing workload to available processors on a local area network) or parallel computing (use of multiple computer processors). A computer cluster is a group of loosely coupled computers that work together closely so that in many respects they can be viewed as though they are a single computer. Cube Cluster is an add-on to Cube Voyager that enables intra-step and multi-step distributed processing of highway assignment on multiple CPU cores. Cube Cluster allows the user to completely control the allocation of the processing workload to available processors on a local area network. However, Cube Avenue does not make use of the Cube Cluster capabilities, and such use is highly recommended. As stated in Chapter 2, the upcoming version of DynusT has been fully parallelized in simulation, time-dependent shortest path and assignment algorithms. Similar improvements have been made in TRANSIMS version 5.

Initially, the results from DynusT were different when running the software with the same inputs different times on the same computer and different computers. This problem was not observed with other software. It was later determined that this could be fixed by changing a specific input parameter to DynusT (by using No. of threads = 1 and specifying a seed number other than zero). This is important to recognize that since getting different results in different runs will not allow meaningful comparison of alternatives, unless multiple runs are performed, the results are averaged, and a proof of adequate sample size is conducted.

5.2   General Software Attributes Assessment

All four tools can be installable on Florida agency local computers, as required by the General Software criteria presented in Chapter 4. The open source software (DynusT and TRANSIMS) provides understanding of how the tool module works through publications in the literature.

They also include advanced capabilities as of the result of national research and development in these tools. In addition, they provide the flexibility of the user to be able to update the core modules and parameters by accessing the source code. TRANSIMS also provides the flexibility of using scripting to update software module parameters. However, modifying the codes of these tools is a difficult task that requires familiarity with the coding of the tool modules. Care must be taken not to introduce bugs in the program when updating the code. Another issue with open source software is the lack of detailed documentation of upgrades and new features. In addition, there is a concern with the provision of technical support with open source tools, although there are user community support groups that are supported by the open source user community for both TRANSIMS and DynusT, that have been reported to work relatively well in answering user questions. Recently, DynusT developers introduced the DynusT Plus program (see Chapter 3) to address this issue.

Modifying the Core modules of Cube Avenue requires the involvement of Citilabs. However, the script language of Cube can be used to allow for flexibility in selecting modeling parameters. It should be mentioned, however, that the Cube environment provides the user the access to internal "built-in" software variables, allowing additional significant flexibility. The definitions of these variables are also well documented to facilitate their use. However, the access to built-in variables is not the available for Cube Avenue, which limits the flexibility of the analysis. An example of built-in variables that are well documented for the static but not dynamic assignment in Cube are current and final assignment iteration link volumes. It is recommended that Citilabs facilitate the access to these variables.

TRANSIMS and DynusT are open source tools and free of charge. However, it should be mentioned that if a user wants to make a change to these software, they need to purchase a license of a complier for the language used in their coding. Both TRANSIMS and DynusT are written in Fortran.

One of the criteria that should be examined when starting a project is to determine the level of past experience with the tool in applications similar to that of the project at hand. If not known, the vendors should be asked to provide an example of such an application and possibly contact information of agencies that successfully used the tool in this application. In this study, users of

the three assessed tools were interviewed about their experience with the tools. The results from the interviews are presented in Chapter 3.

An advantage of Cube Avenue is that it works within the Cube modeling environment and has the same input and output format, allowing seamless modeling. However, pre-processors and post-processors can be written to exchange data between Cube and other software such as TRANSIMS and DynusT, Similar processors can also be written to exchange data between these tools and microscopic simulation tools, EPA emission tools such as MOVE, and Geographic Information Systems (GIS).

Although a graphical user interface (GUI) is provided for each of the three tools, the usefulness and user-friendliness of these interfaces vary among the three tools. As a general rule, tools developed and/or marketed by the private sector generally have much better user interfaces than the open source tools. For example, Cube Avenue can take a full advantage of the powerful and very flexible user interface and visualization of the Cube environment and is the user interface is familiar and easy to deal with for FSUTMS modelers. It has to be stated, however, that modelers with a traffic operation background who are not familiar with demand forecasting tools and Cube may find the DynusT user interface easier to learn. The TRANSIMS interface is harder to learn and use compared to the other two tools. A large proportion of input parameters have to be input using scripts rather than a GUI, as in the other two tools. The GUI in TRANSIMS allows only inputting and selection of some high level parameters. Figure 5-11 shows screen captures of the three tool user interfaces. The open source DynusT and TRANSIMS user interfaces were developed using a tool called NEXTA. However, the testing conducted in this study indicates that latest version of both software are not fully compatible with the users interfaces created using NEXTA. It should also be mentioned that NEXTA is a 32 bit application and thus has a real limit on the size of the network and number of vehicles that can be visualized. The original visualization of both tools is not high quality. However, tools have been recently developed by Argonne National Lab that provides powerful visualization of TRANSIMS network. In addition, recently a user-friendly GUI environment referred to as DynusT Studio became available on the market, as discussed in Chapter 2.

(a) Cube Avenue	**(b) DynusT**	**(c) TRANSIMS**
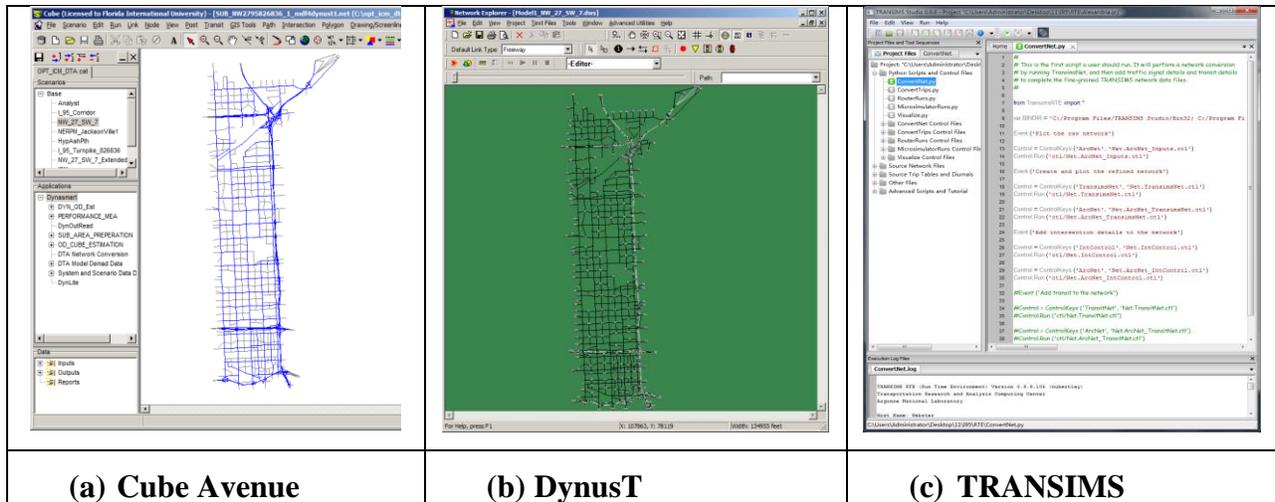
Figure 5-11 Screen Shots of the GUI of DTA tools

All three tools include graphical displays of performance measures. Cube Voyager has powerful performance measurement display capabilities that can be used for Cube Avenue, as shown in Figure 5-12. The three DTA tools allow dynamic animation of traffic movements and the animation link-based performance measures. The research team conducted a qualitative assessment of the dynamic animations of these tools. According to this assessment, TRANSIMS is best in dynamic animation. The performance visualization is the best in Cube. This assessment however, does not include the recently released DynusT Studio, which has to be purchased for a cost, and the TRANSIMS tools.

(a) Cube Avenue	**(b) DynusT**	**(c) TRANSIMS**
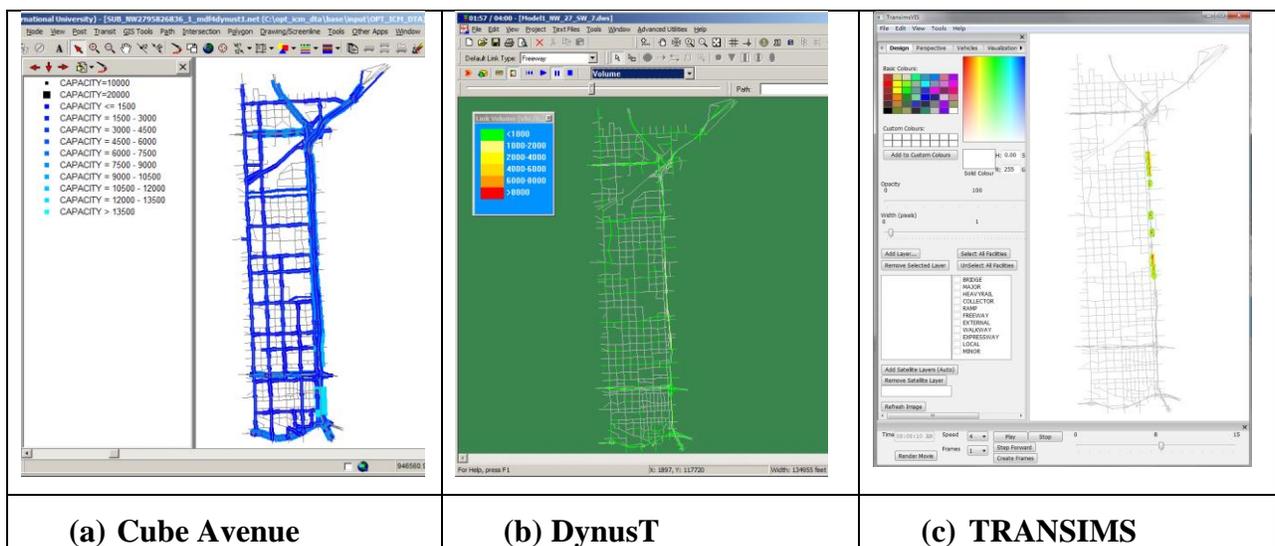
Figure 5-12 Visualizations of link performance in DTA tools

All three DTA tools output text files with model outputs including global, facility, and link measures of performance. Examples of these measures are volume, speed, travel time, density, queue length, and delays for each period of the analysis. Cube Avenue gives the user the flexibility of requesting subsets of the output measures, the formats of these measures (tab delimited, comma delimited), and the output file types (text, CSV, or dbf). Cube also includes a powerful data manager that can be used for input and output data management. TRANSIMS also gives flexibility for the users to define the output measures and format.

The three DTA tools output test files with vehicle trajectories (see Figure 5-130), which can be used to calculate various performance measures.

| (a) Cube Avenue | (b)DynusT | (c)TRANSIMS |
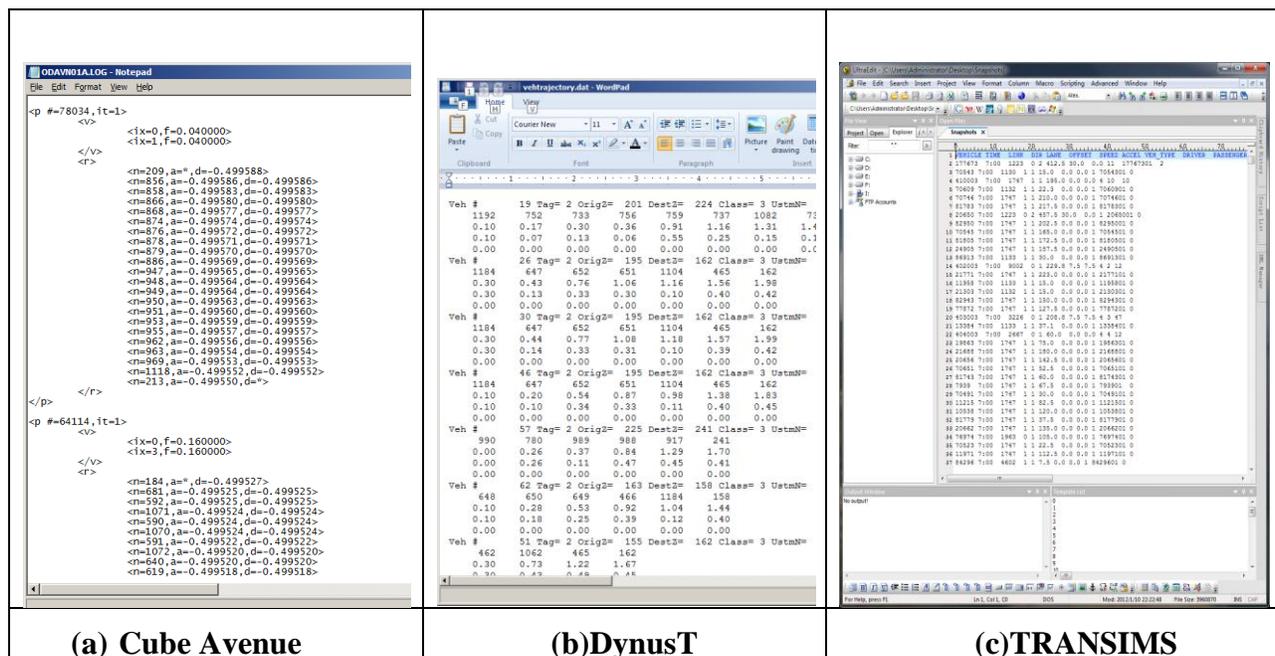
Figure 5-13 Trajectory output files from DTA tools

Citilabs has provided training to the Florida modeling community with focus on the principle and use of AE. TRANSIMS training courses have been also offered in the past. Providing adequate multiple day trainings is essential for using DTA tools.

5.3 Shortest Path and Path Choice

This section presents an assessment of the three tools with respect to the shortest path and path choice criteria presented in Chapter 4.

5.3.1 Assignment Objective Function

One of the assessment criteria specifies that the disutility function used in the assignment should include parameters representing various factors that affect traveler choices. The weights of these parameters should be changeable by the traveler/vehicle type. This criterion is only needed to be met if the assignment process is to include factors other than travel time. The tested version of DynusT allows specifying only travel time and monetary cost (toll) in the disutility function used in the assignment. The test conducted in this study indicated that specifying toll cost does not affect the assignment in the tested version (Version 3.1). The version of DynusT used as part of the SHRP2 C10B program was used to model the impacts of travel time, reliability, and toll cost. The reliability measures are used in route assignment and are also fed back to an activity based model, as part of the generalized cost to influence many dimension of choices.

The disutility function in TRANSIMS router is based on travel time, toll and distance. In TRANSIMS, the traveler selection of toll versus no-toll facilities can be made outside the assignment step (utilizing a logit choice model provided by the user). TRANSIMS can represent tolls in a variety of ways. Tolls can be assigned by lane, by link, by vehicle type, traveler type, by time of day and by route. The impact of tolls can be assessed in the routing phase or as a pre-routing mode choice method.

Cube static assignment and Cube Avenue provide the maximum flexibility in specifying any function of traffic parameters and tolls. They allow the tolls to be included as part of the assignment or outside the assignment, either in the mode split stage or utilizing a logit model in combination with the assignment.

The inclusion of reliability as part of the disutility function is currently being addressed as part of the C4 and L4 SHRP2 research projects. The inclusion of the consideration of reliability based on the above two project results has been investigated as part of the C10A project utilizing TRANSIMS in Jacksonville and C10B utilizing DynusT in Sacramento.

All four software allow the user to specify a bias to freeway versus signalized arterial choice. In addition, the impacts of calming measures and number of signals on a path can be coded in Cube Avenue, DynusT, and TRANSIMS by using an additional facility bias or a toll (when coding a toll is allowed). However, user-specified turning penalties can only be specified in Cube Avenue. The challenge, of course, is to come up with appropriate values for the basis values and penalties not only to replicate existing conditions but to predict future demands.

An important desired attribute of DTA tools is the use of experienced travel time rather than the instantaneous travel time. Experienced travel time is more appropriate for route selection based on traveler's assessments of their routes from day to day. The three DTA tools used in this study (DynusT, TRANSIMS, and Cube Avenue) base their assignment on experienced travel time. Experienced travel time cannot be estimated using a static assignment in software such as Cube Voyager.

5.3.2 Traveler Groups

As specified in Chapter 4, DTA tools should allow the user to specify different traveler groups to provide maximum flexibility in modeling different vehicle and driver types in the assignment. Cube static and dynamic assignment allow the specification of up to 20 different types of demand matrices that can be used to model any combination of vehicle types, trip types, traveler types (e.g., commuter, non-commuter, and tourists), vehicle occupancy level, vehicles with different toll pricing, and so on. However, the user needs to write a script to implement the assignment strategy and parameters for each user.

TRANSIMS allows coding ten different types of vehicles including auto, truck, taxi, bus, trolley, streetcar, light rail, rapid rail, and regional rail. Each driver is assigned a vehicle in the assignment. TRANSIMS maintains all detailed trip information, including the identities and attributes of individual travelers and of the vehicles used. Each of these attributes can potentially be used in the routing process. Unlimited number of traveler's types can be coded.

A major limitation of the tested version of DynusT (and Dynasmart) is that it allows the coding of only three types of demand matrices, including Single Occupancy Vehicles (SOV), High Occupancy Vehicles (HOV), and trucks; although it allows coding different proportions of this responding to information delivered using in-vehicle navigation systems and dynamic message

signs. The users can use these three matrices for purposes other than what they are intended for (e.g., to model more than one type of traveler behavior) with the limit of a total of three demand types. However, the HOV matrix is not assigned to the network in the tested version (Version 3.1) but has been fixed in the newer version that will become available soon. To code higher numbers of users than the three allowed utilizing O-D matrices, the user can load O-D matrices combined with trip rosters (individual travel records) to increase the number of user types. This approach was used in the SHRP2 C10B project. The input O-D trips were for airport, external, and freight trips. The trip/tour roster was used to capture activity patterns from Activity Based Models. Transit vehicles are also loaded as route file and schedules. Trip roster and O-D matrices are used simultaneously to generate vehicles.

One important criterion is that the selected paths must consider access restrictions/prohibitions for specified vehicles or demand types on individual links. This is very important, for example, for coding managed lanes. All four tested tools allow this restriction.

Networks 5 and 6 in Table 5-3 are used for the test of the ability of Cube static and dynamic assignment to deal with tolled managed lanes. The O-D table can be found in Table 5-3 for a modeling period of 90 minutes, divided to six 15 minutes interval. The network is loaded in the first 60 minutes and 30 minutes, is used as a cooling period. The test is run for congested and uncongested conditions by reducing link capacity. In this test, two matrices representing SOV and HOV demands are loaded to the network, with SOV having to pay the toll rate to use a managed lane, while HOV can use it for free. There is no specific function for modeling managed lanes in Cube, therefore, additional scripting is needed to model such lanes. There are different ways to model managed lanes. In this study, separate generalized cost functions are defined for SOV and HOV users such that SOV users have to pay the toll rate for using the managed lane.

Figure 5-14 and Figure 5-15 show the results from testing of the ability of Cube dynamic and static assignment to model the impact of toll cost, as part of the assignment process, as described above. The static assignment results indicate that a toll rate equivalent to 0.1 minutes and 0.3 minutes user times, respectively, are sufficient to drop the SOV volume that uses the managed lane to zero in uncongested and congested conditions. 0.1, and 0.3 minutes are equivalent to 3

cents and 10 cents, assuming a value of time of $15 per hour. Cube Avenue shows that toll rate ranges from 1 minute for uncongested network to 10 minute for congested network. Considering $15 per hour as time value, it would be 25 cents and $2.5 for uncongested and congested conditions respectively.
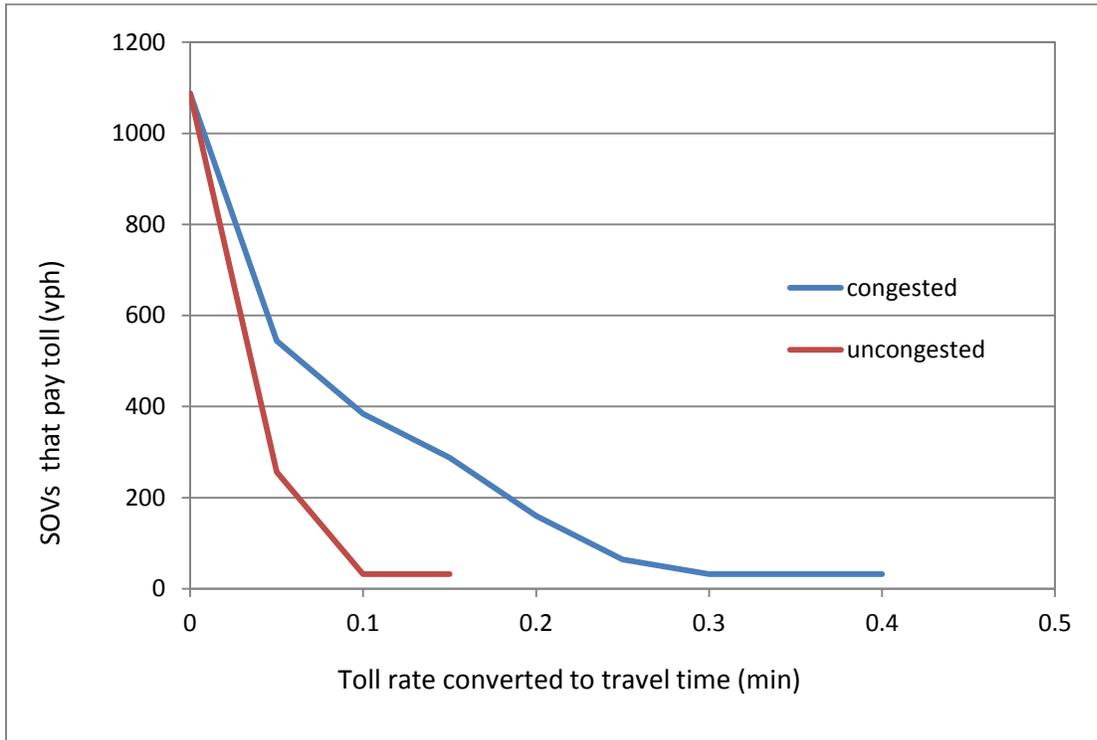
Figure 5-14 Cube Voyager static assignment sensitivity to toll specification
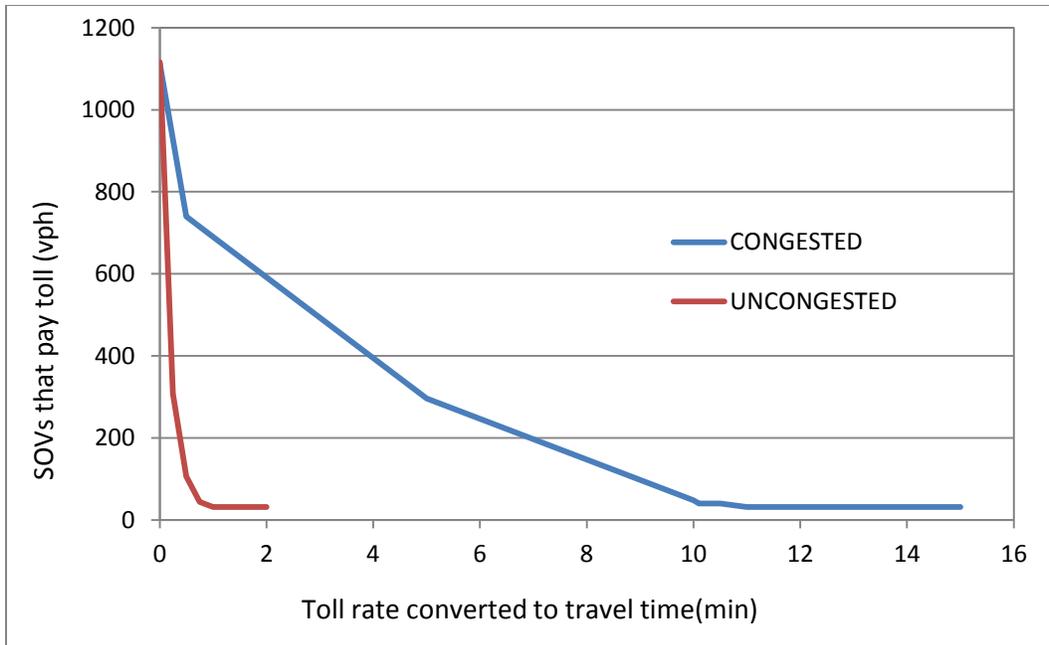
Figure 5-15 Cube Avenue dynamic assignment sensitivity to toll specification

5.3.3 Assignment Interval

One of the advantages of DTA over static assignment such as Cube Voyager is the ability to model multi-intervals. All three tested DTA tools allow the user to specify the length of the assignment interval as short as one minute. There are no clear guidelines currently available about the appropriate interval length to be used in the analysis. The most widely used length is 15-30 minutes. The interval length selection should consider factors such as the purpose of the analysis and the temporal variations in the network demands based on count data.

5.3.4 Assignment Methods

Because of the variations in DTA assignment methods, it is essential that the DTA tool provide adequate documentation of the utilized methodologies and algorithms for selecting the shortest paths, path choice, and convergence calculation, as specified in Chapter 4's criteria. All three tools provide documentations of the methods used, however all three tools can improve their documentation capabilities and the additional features incorporated in these tools. Additional complication with the open source software such as DynusT and TRANSIMS is that some of the new features that have been introduced in recent research and development are not documented yet due to the limited resources. As stated earlier, however, the theories of open source tools are in general better documented either in user manuals or journal publications.

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All four tools allow the analyst to request utilizing UE assignment to simulate user familiarity with the network during recurrent congestion (day-to-day learning). The UE assignment includes two major components: shortest path identification and assigning traffic to these paths.

For shortest path identification, assignment tools have utilized algorithms, data handling, and parallelization of computation to ensure reduction in computational requirements. It is critical to ensure efficient and effective identification of the shortest paths. In TRANSIMS, the paths are generated by the "Route Planner" module based on a modified Dijkstra's shortest path algorithm and this algorithm has been modified to ensure efficiency. In addition, a more rigorous version of the algorithm can be used for transit assignment, since transit schedules and transfers complicate the assignment process. DynusT uses the A* algorithm and the latest version to be released includes parallelization of the computation. Cube Avenue uses Dijkstra's shortest path algorithm.

The method used to assign traffic to these paths is very important since it determines the ability to converge to a stable and consistent solution, in addition to affecting computation time. Not being able to reach such a user equilibrium solution can affect the reliability of travel demand modeling analyses such as select link, select zone, subarea network extraction, and comparison of alternatives, as described in the review of literature section.

Cube Voyager static assignment allows the analyst to select from a number of user equilibrium methods that vary in their ability to produce a mathematical traceable unique solution. The recommended assignment method in Cube is the Bi-Conjugate Frank-Wolf method. Previous studies show that the Frank-Wolf algorithms provide results that are close to unique solution and achieve convergence in fewer numbers of iterations. Bi-Conjugate performs better than Conjugate Frank-Wolf based on tests conducted by Citilabs utilizing a network in Florida. The method is recommended by Citilabs as the best method for achieving high precision user equilibrium assignments without loss of the desired properties of the solution. The static assignment in Cube can also be performed using a path-based gradient projection assignment algorithm that converges fast to a low relative gap value, but has not been recommended due to the non-uniqueness of the resulting solution. This issue relates to the zone-based incremental loading process used in the algorithm, which makes the results highly dependent on the size, structure, and numerical order of the zone system.

Frank-Wolf type assignment cannot be used for a simulation-based DTA, as stated in Chapter 2. Thus, less rigorous mathematical approaches have been used for these types of assignment. A heuristic method that has been used widely for simulation-based assignment is the method of successive averages (MSA). As stated in the literature review, in this method, the flow of a path is calculated as a linear combination of the current flow on the previous iteration and the flows resulting from the assignment in the current iteration. The MSA method is the method used in the original version of Dynamart (the parent of DynusT), DynusT and is being used Cube Avenue and other DTA tools. As described in the review of literature, recent work by Sbayti et al. (2007), Mahut et al. (2007), and Chiu and Bustillos (2009) clearly indicates that the MSA has problems in converging to a good solution. For this reason, the current version of DynusT and Dynasmart utilizes other assignment methods that have been shown to perform much better than MSA (see the discussion in the review of literature). It should be mentioned here that both Dynameq and VISTA have also incorporates additional assignment methods, as alternatives to MSA.

As stated in Chapter 2, to assign vehicles to the selected paths, TRANSIMS chooses a fraction of travelers to switch between paths, based on user-defined criteria. The mostly widely used selection criterion by the users of the software is to shift traffic from congested paths. This method has been criticized, as it is not aligned with the UE assignment concept. However, TRANSIMS allows the coding of different assignment methods. For example, in the SHRP2 C10A project, two equilibrium network assignment processes were compared. The first is consistent with current DTA theory, in which the method of successive averages was used to randomly select a share of the new shortest paths to replace those in the current set of paths – for example, in the second iteration 50% of vehicles replaced paths, in the third iteration 33% of paths were replaced. In the second process, an equilibrium-seeking network assignment process inconsistent with current DTA theory, but which has been shown to converge more quickly, was implemented. In this process, the Router was used to develop a new set of shortest paths using the time-varying averaged Microsimulator-based network costs. The method of successive averages was used to determine the weighting used in the averaging the time period link costs. The second approach was found to reach a better equilibrium.

As specified in Chapter 4, one shot (non-iterative assignment) is needed to model specific conditions such as unfamiliar drivers (if the assignment is based on free-flow speed) or driver with traveler information (if the assignment is based on current information). In addition, one shot assignment has been proposed for evacuation modeling since user equilibrium is not appropriate for such modeling. In some cases, some travelers need to be assigned based on equilibrium and others based on non-iterative assignment to model realistically combinations of traveler types. Non-iterative assignment can be modeled in all tools. However, only DynusT allows travelers to change route based on dynamic information while they are on their routes.

Another feature that is very useful in modeling various travelers' behavior is to allow the user to fix the paths and optionally the proportions that use these paths for portions of specific traveler types. For example, a user may want to fix the route of travelers with no travel time and knowledge of the network to predefined paths and allow others to reroute themselves during incident conditions. All tools allow this flexibility.

5.3.5 Convergence

Ensuring convergence is required to achieve a stable, consistent, and proportional solution that is useful for analysis, as discussed in Chapter 2 and specified in Chapter 4. Each of the four evaluated tools compute what it calls a "relative gap" and allows the user to utilize it the convergence criterion by specifying target values for convergence. The analyst can also specify a maximum number of iterations, beyond which the assignment process stops.

The relative gap is defined differently in the three tested tools. The relative gaps in Cube, Cube Avenue, and TRANSIMS are "link-based," while the relative gap in DynusT is path-based. The user can select from five different built-in convergence criteria in Cube. However, all these functions are link-based. Recent literature has recommended the use of a path-based method to assess convergence. For example, Chiu et al. (2011) mentioned that the use of link-based convergence criteria could be problematic. This issue is discussed in Chapter 2 of this document. Thus, path-based criteria are preferred. Path-based criteria also allow analysis and convergence strategies targeting those trips with the highest contribution to the lack of convergence. The utilization of both approaches is recommended since it will reveal if the links are reaching stable performance, at the time that the paths are also reaching acceptable performance. Table 5-8

shows the default gaps in the four software tools and the path-based gap added in C10A project to assess TRANSIMS Convergence.

Table 5-8 Convergence criteria for the asessed models

DTA Tool	Convergence Criteria	
Cube Highway/Avenue	GAPk	ABS(SUML(VEk*COSTEk) – SUML(Vk-1*COSTEk-1))/ SUML(Vk-1*COSTEk-1) Where k is the current iteration and SUML denotes summation over the links and, if appropriate, the turning movements in the network, VEk is the equilibrium weighted volumes for iteration k and COSTEk is the cost based on the equilibrium volumes VEk.
	RGAPk	(SUML(VEk-1*COSTEk-1) - SUML(VAk*COSTEk-1))/ SUML(VEk-1*COSTEk-1) Where VAk is the link volume from an all or nothing assignment to the minimum cost paths based on COSTEk-1.
	AAD	Average absolute volume difference: based upon successive iterations
	RAAD	DiffVE/VE
	Pdiff	Percent of links whose change in VE between iterations is less than a set value.
	RMSE	Root mean squared error of the differences in VE between iterations.
DynusT	$$RG_{l,\tau} = \frac{\sum_{n\in k}\left(T_n - T^*\right)}{\sum_{n\in k}T^*} \quad \forall k \in K^l(o,d,\tau)$$	
	RG	Relative gap
	T_n	Total travel time for all vehicles **n**
	T^*	Shortest path travel time
	l	Iteration
	o	Origin
	d	Destination
	τ	Departure time
	k	Path
TRANSIMS	$$RelativeGap = \frac{\sum VE_n xCE_n - \sum VA_n xCE_n}{\sum VE_n xCE_n}$$	
	n	Current iteration
	VE_n	Volume for iteration **n**
	CE_n	Cost associated with volume VE_n
	VA_n	Link volume from a shortest path assignment based on CE_n

It is recommended that Cube Avenue allow the user to examine both path-based and link-based convergence criteria. In addition, one of the identified criteria is to allow better testing of the convergence and the quality of the solution by providing sufficient information to the users to calculate their own convergence criteria, if needed. It is recommended that the users will have access to internal built-in variables to allow them to write their own convergence criterion through scripting.

The relative gap in TRANSIMS is link-based but other gap functions can be coded by the user including link-based gaps. As stated in the review of literature, the SHRP2 C10A team has tested different convergence criteria, implemented through iterations within the many applications and modification of the data between iterations. DynusT does not allow the changing of the convergence criterion.

It is not clear if all tested DTA tools calculate the gap for each departure interval and whether they base their convergence decision on each interval convergence or on a convergence measure that is calculated based on data for the whole simulation interval. Only TRANSIMS reports the gap for each period, which gives the analyst a much better way of assessing the convergence. It appears that the stopping criteria in the four software tools is based on the gap at the end of the iterations, with no consideration of the convergence of individual periods. This is not desirable, as discussed in the review of literature section, the convergence of early intervals is much more difficult than the convergence of later intervals. Thus, basing the convergence on a single measure for the whole iteration will result in diluting the value of the measure. To make this point clear, the user can simulate ten non-congested periods and one congested period at the end and the network will look like it is converging based on the convergence criteria even if the last period is totally not converging. In Cube Avenue, the gaps are calculated for each iteration rather than for each interval. For DynusT, the developer mentioned that the relative gaps are calculated internally for each interval and utilized to calculate an overall relative gap but the interval relative gaps are never reported to the users.

Below, the relative gaps achieved for the solutions produced by the four software for the tested real-world networks at different levels of congestion are shown. It was not possible to plot the gap by departure interval since this is not reported by the tools, as stated previously except for

TRANSIMS. SERPM I-95, Statewide Jacksonville and NERPM Jacksonville networks (Table 5-2) are used in this test, with one user group and different levels of demand (20%, 50%, and 80% of the demand from the travel demand model). The stopping criteria were set to a relative gap of 0.0005 and a maximum number of iteration of 80.

The convergence results of the Cube Voyager static model run are shown in Figure 5-16 for SERPM I-95, and Figure 5-17 for Statewide Jacksonville and Figure 5-18 for NERPM Jacksonville networks. Figure 5-16 shows that the achieved relative gap was 0.0068 for the I-95 network and the demand levels do not affect the gap. Figure 5-17 shows that the achieved relative gap was 0.00016 to 0.00057 for the statewide Jacksonville depending on the demand levels. For the NERPM Jacksonville network, Figure 5-18 shows that the achieved relative gap is less than 0.006 for all cases investigated after 40 iterations.
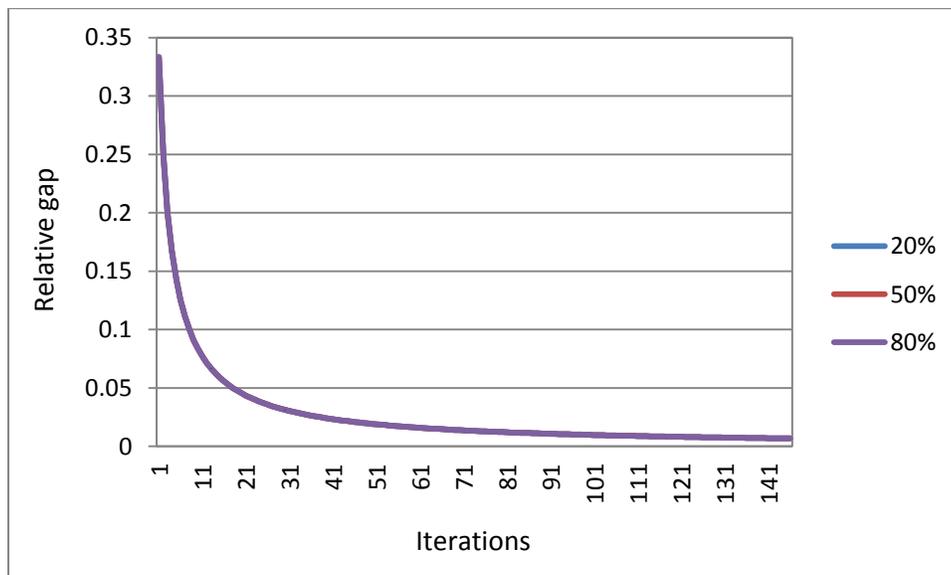
Figure 5-16 Cube Voyager, Network 1(I-95), relative gap vs. iteration
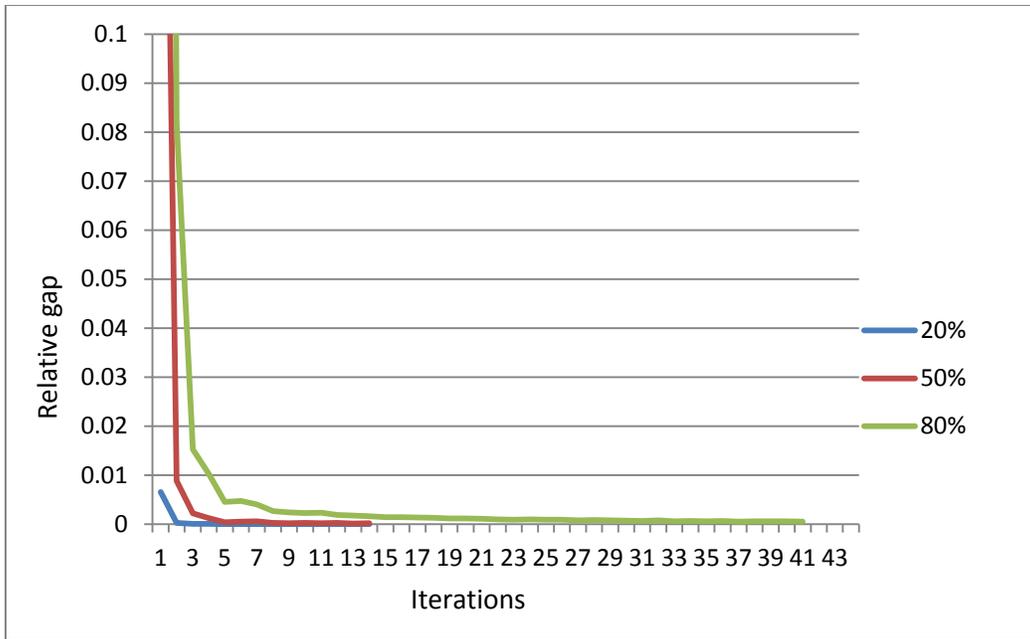
Figure 5-17 Cube Voyager, Network 2 (Statewide Jacksonville), relative gap vs. iteration
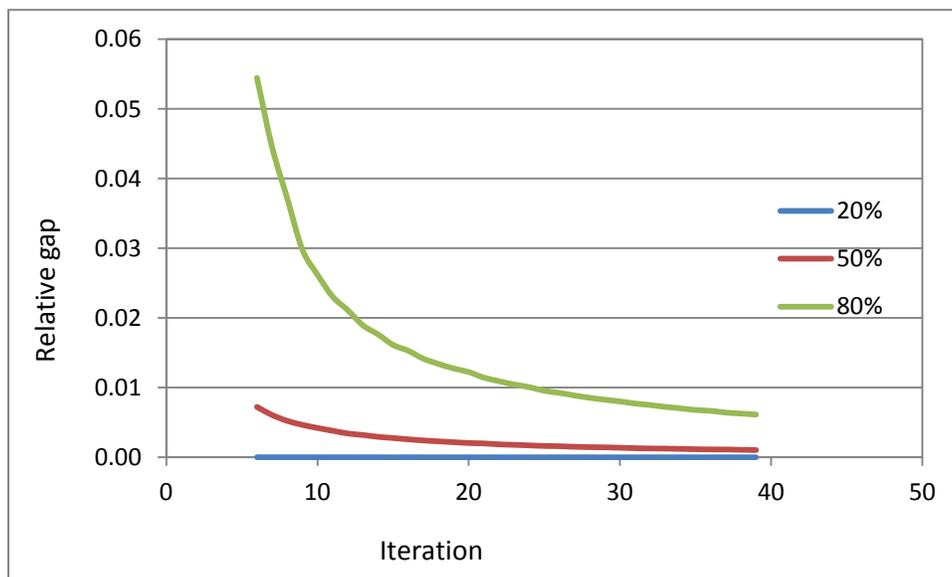
Figure 5-18 Cube Voyager convergence for NERPM Jacksonville network for different demand levels.

As stated earlier, Cube Avenue has two modes for assignment (referred to as PA and PS assignments). The results are plotted in Figure 5-19 and Figure 5-20 for the I-95 network. For PS simulation, the Jacksonville network reaches a good level of convergence for the investigated demand (at 0.0006). For the PA method, the relative gap reached low values but continued going

up and down (oscillating) producing up to a 0.035 gap value after 60 iterations, depending on the demand level.
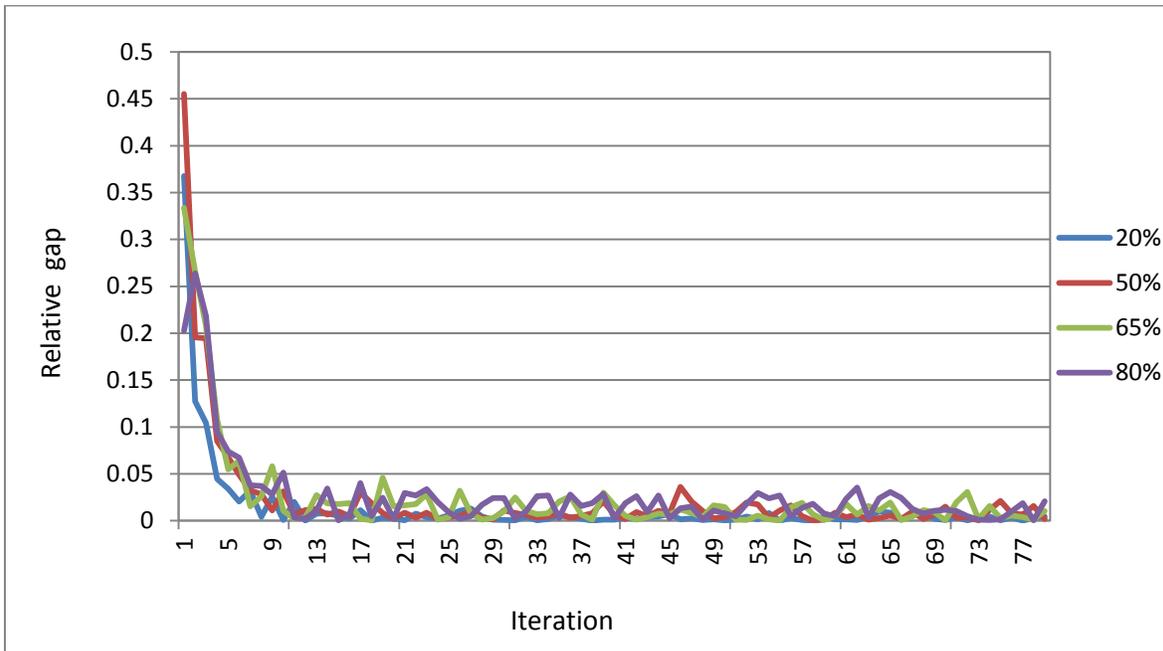
Figure 5-19 Cube Avenue PA method convergence for the I-95 network
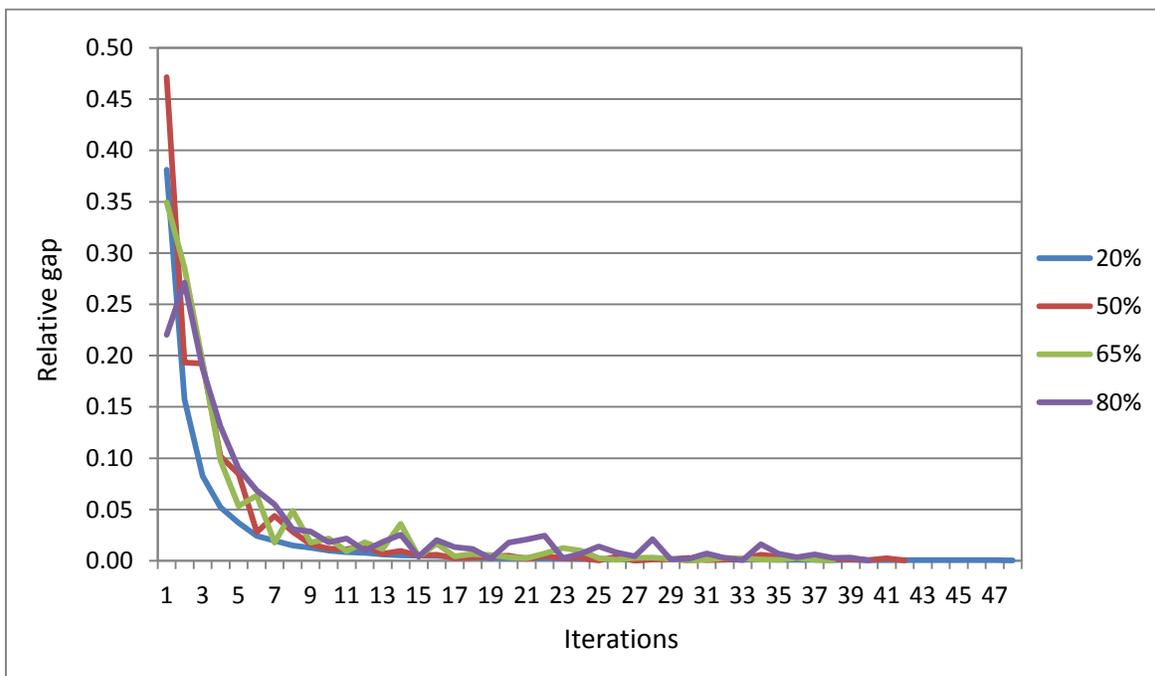
Figure 5-20 Cube Avenue PS method convergence for the I-95 network

Based on Figure 5-19 and Figure 5-20, increasing demand level causes more fluctuations in relative gap. To explore the effect of number of trips on convergence, demand level or number of trips is fixed on 80%, and then network capacity is increased to eliminate the congestion effect on convergence. Figure 5-21 shows that the oscillating behavior was reduced when the congestion was removed.

Figure 5-22 shows that the use of a one-hour cooling period for 80% demand also improves the convergence. However, it is not clear if this is due to allowing all queued vehicles to leave the network during the cooling period or due to diluting the convergence measure by introducing an additional less congested period. An additional observation from the test was that the different convergence measures reported the same values for convergence. Citilabs was made aware of this issue and they will be fixing the problem.
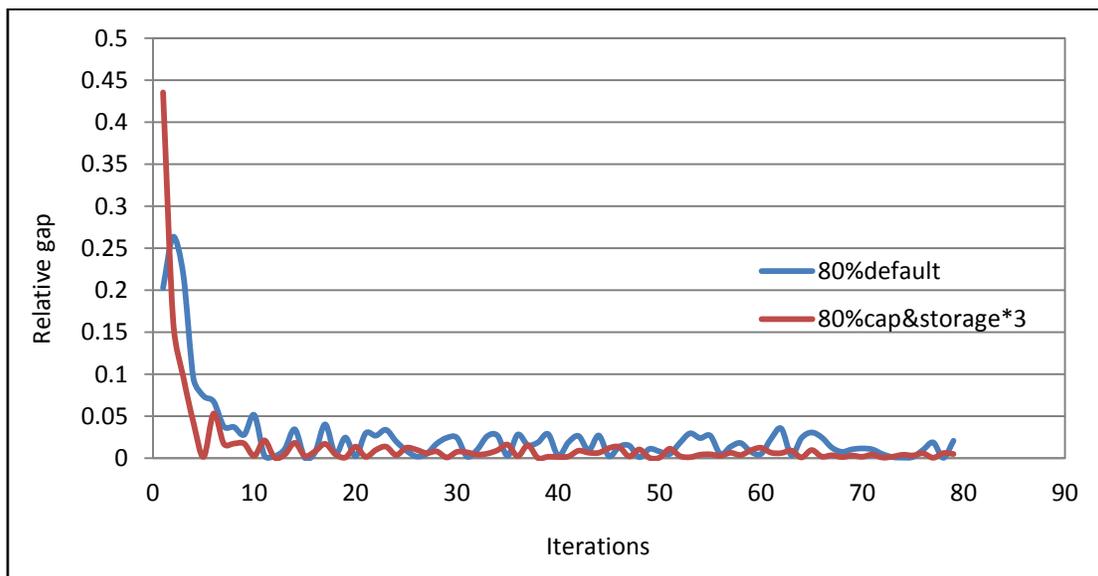
Note: computational time is exactly the same.

Figure 5-21 Cube Avenue PA method convergence for the I-95 network with 80% increase in capacity
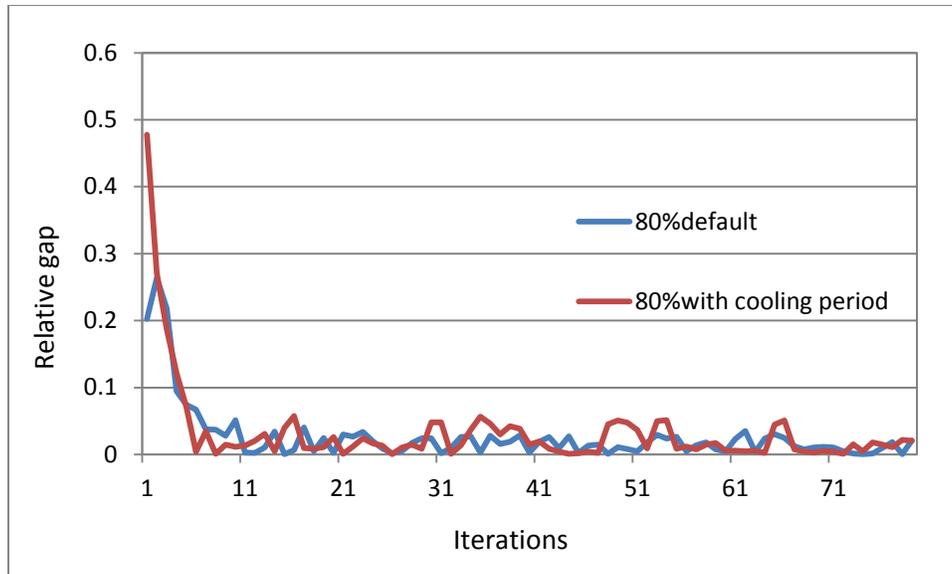
Figure 5-22 Cube Avenue PA method convergence for the I-95 network with one hour cooling period

Figure 5-23 and Figure 5-24 illustrate convergence for different iterations for Statewide Jacksonville in Cube Avenue with PA and PS modes. Again, the PS method produced better convergence.
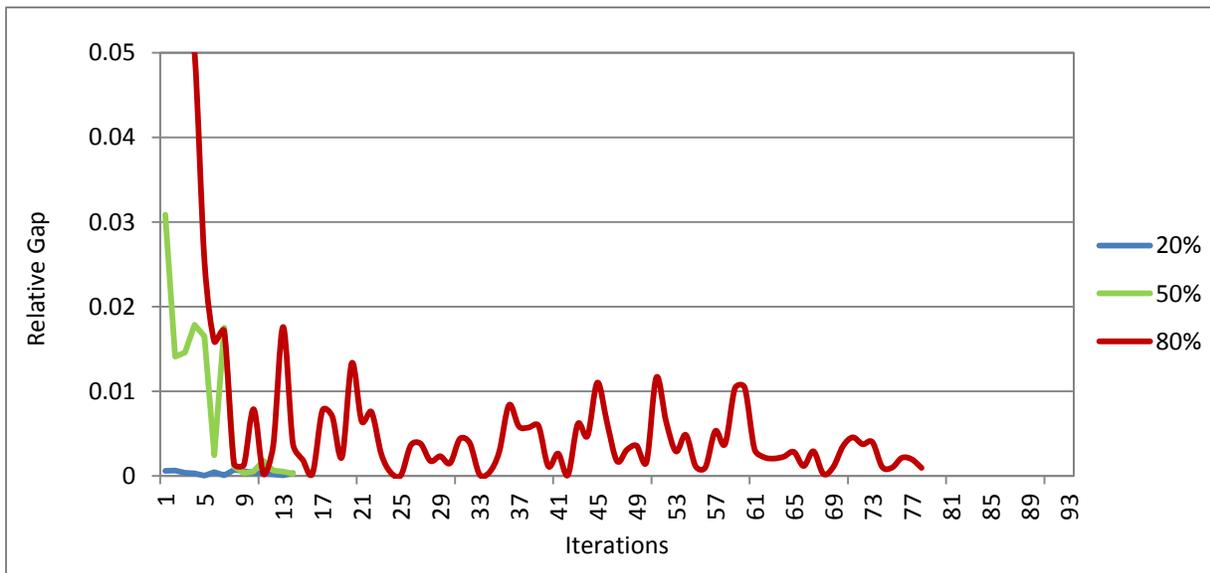
Figure 5-23 Cube Avenue PA method convergence for the Statewide Jacksonville network
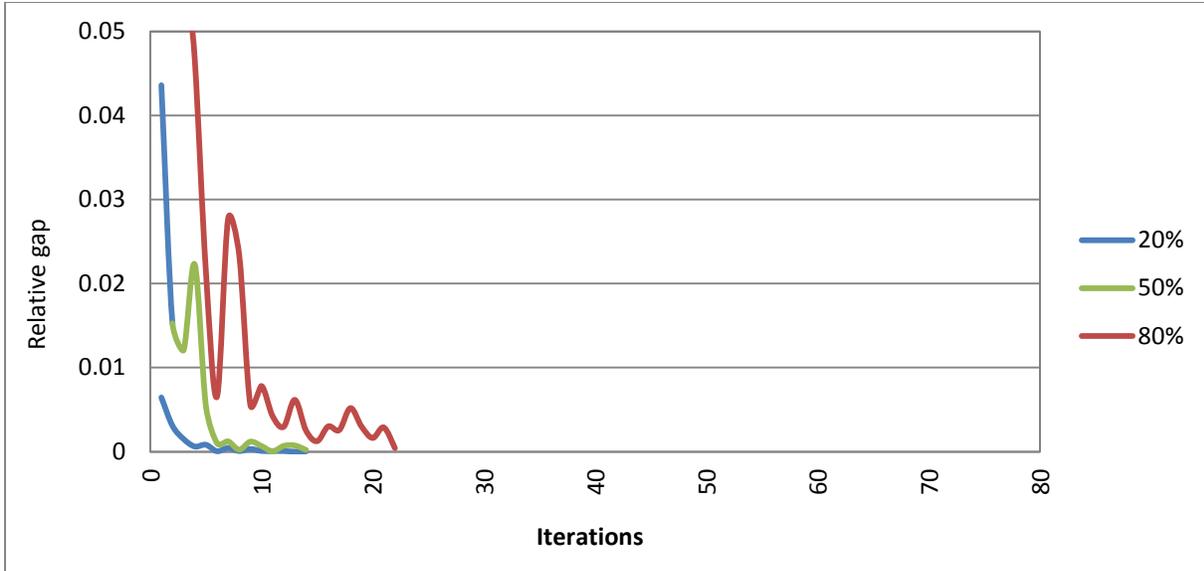
Figure 5-24 Cube Avenue PS method convergence for the Statewide Jacksonville network

Figure 5-25 shows convergence for different demand levels on NERPM Jacksonville network in Cube Avenue PA. A good level of convergence was achieved but it should be noted that the network was not congested even with 80% of demand. The software could not be run for the levels of demand that cause congestion. This may be a common problem for DTA applications when the congestion increases causing vehicles to queue for long periods of time within the network.
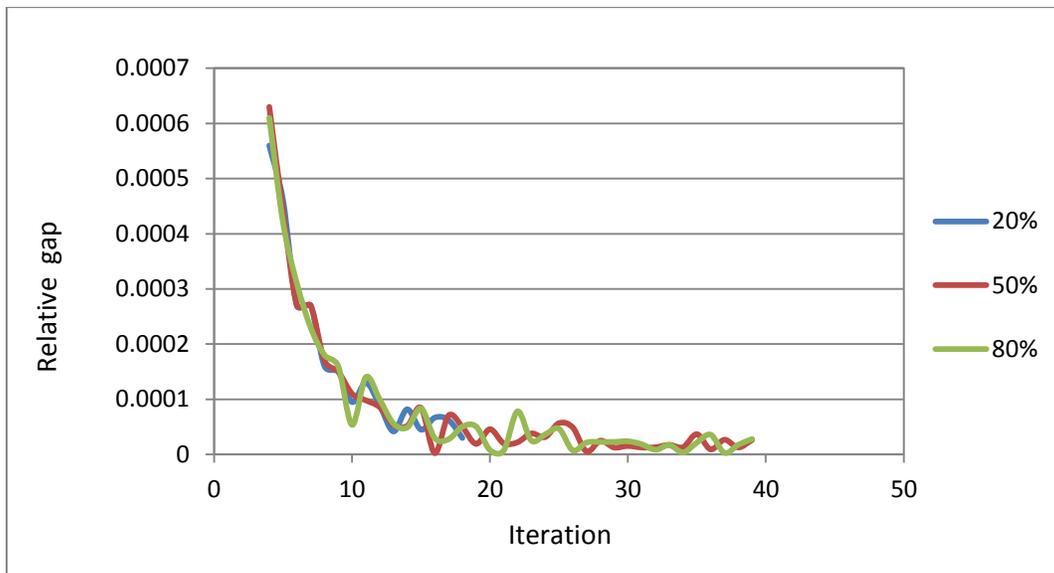
Figure 5-25 Cube Avenue PA for NERPM Jacksonville network for different demand levels

Figure 5-26 presents the convergence of DynusT for the I-95 networks for different levels of demands versus relative gap. Convergence for Statewide Jacksonville network is depicted for different demand levels with a one-hour cooling period for 80% demand. As can be seen in Figure 5-26 and Figure 5-27, the MSA method had difficulty converging while the gap-based method converged smoothly. Adding a cooling period eliminates the fluctuation.
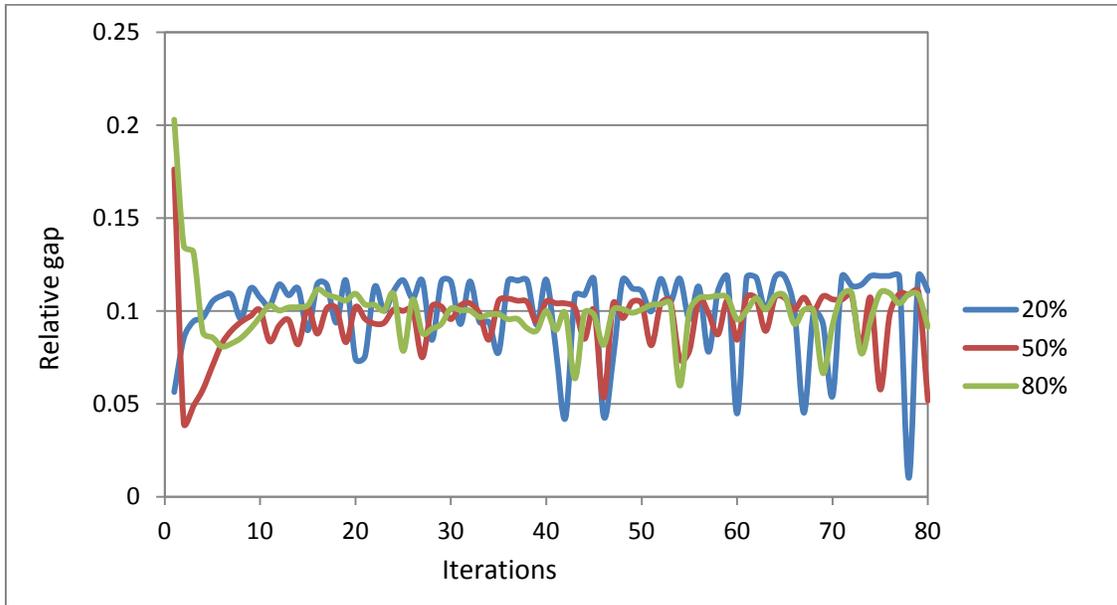
Figure 5-26 DynusT MSA method convergence for the I-95 network
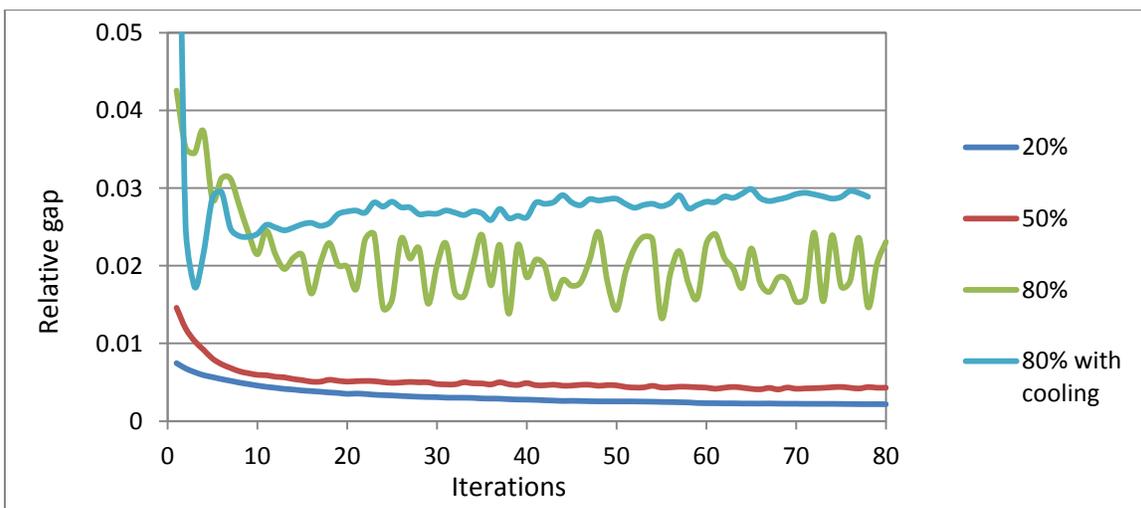
Figure 5-27 DynusT Gap-based method convergence for the I-95 network

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Figure 5-28 and Figure 5-29 show the relationship of relative gap versus number of iterations for DynusT MSA and GAP-based methods in Statewide Jacksonville network.
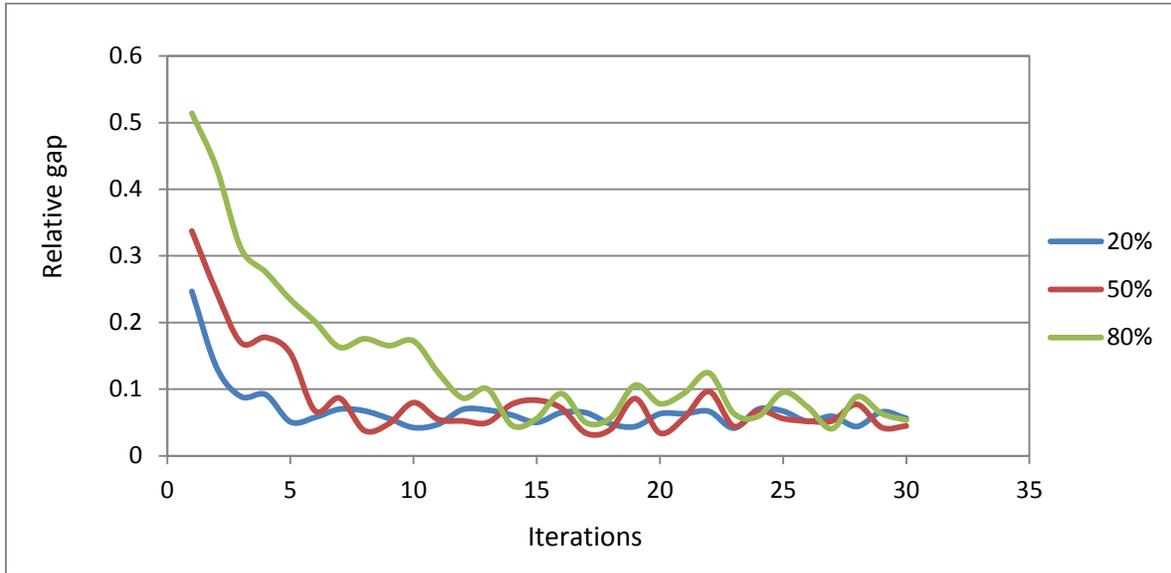
Figure 5-28 DynusT MSA method convergence for Statewide Jacksonville network
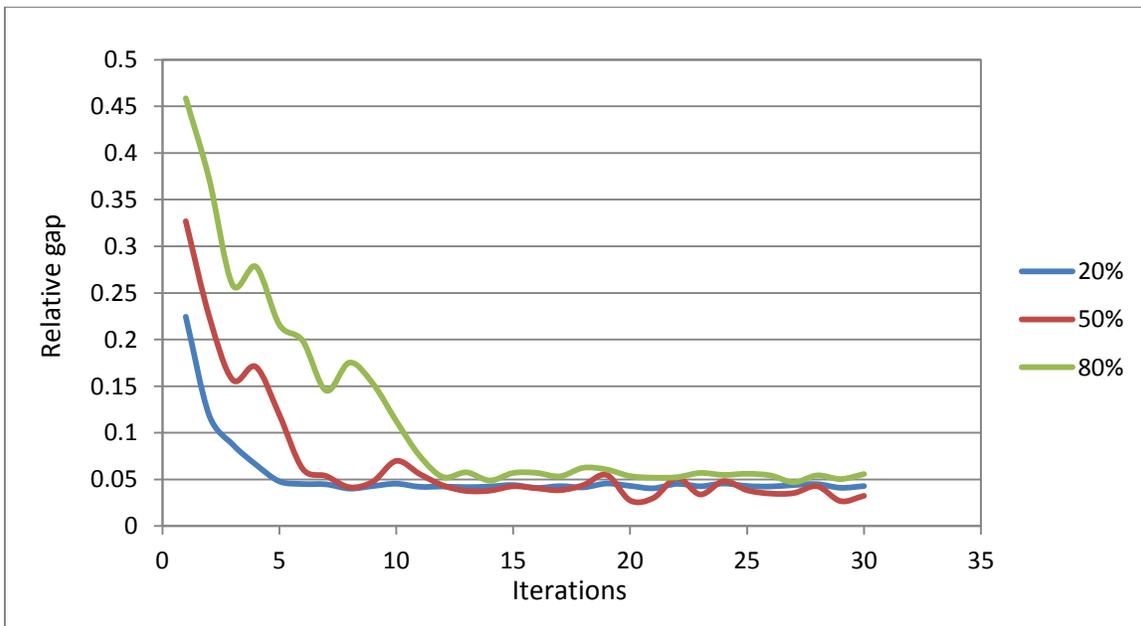
Figure 5-29 Convergence of DynusT Gap-based method for Statewide Jacksonville network

Figure 5-30 and Figure 5-31 presents TRANSIMS convergence for the I-95 and Jacksonville networks for different levels of demands versus relative gap. For the I-95 network with 80% demand level, the calculated gap continued oscillating between as low as 0.001 and as high as 0.06, until the end of the 80 iterations.
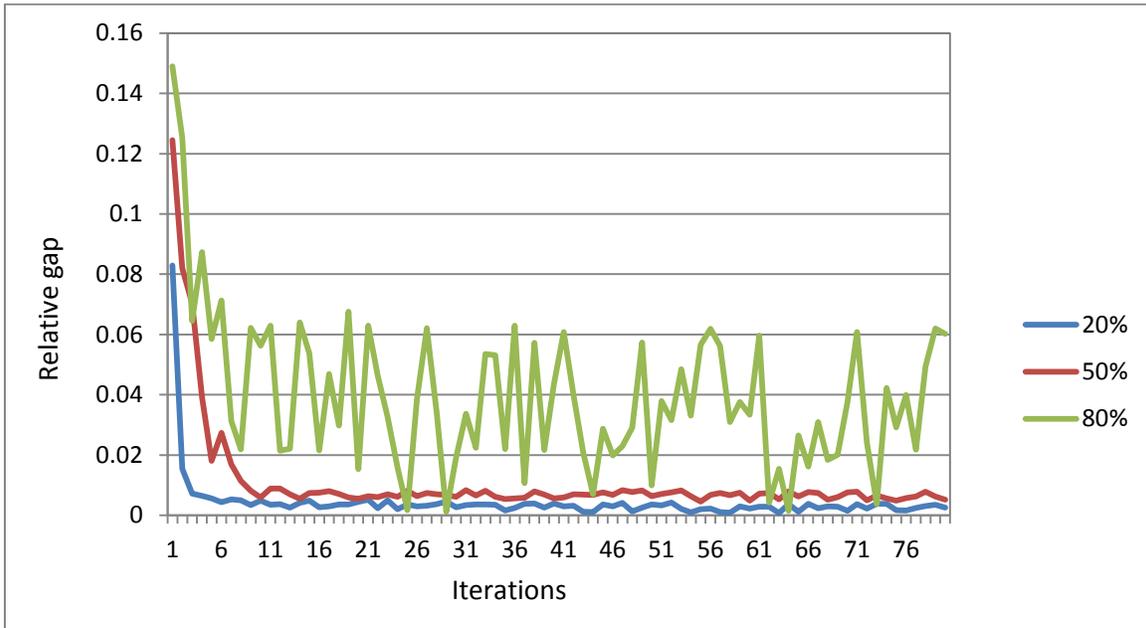
Figure 5-30 Convergence of TRANSIMS for the I-95 network
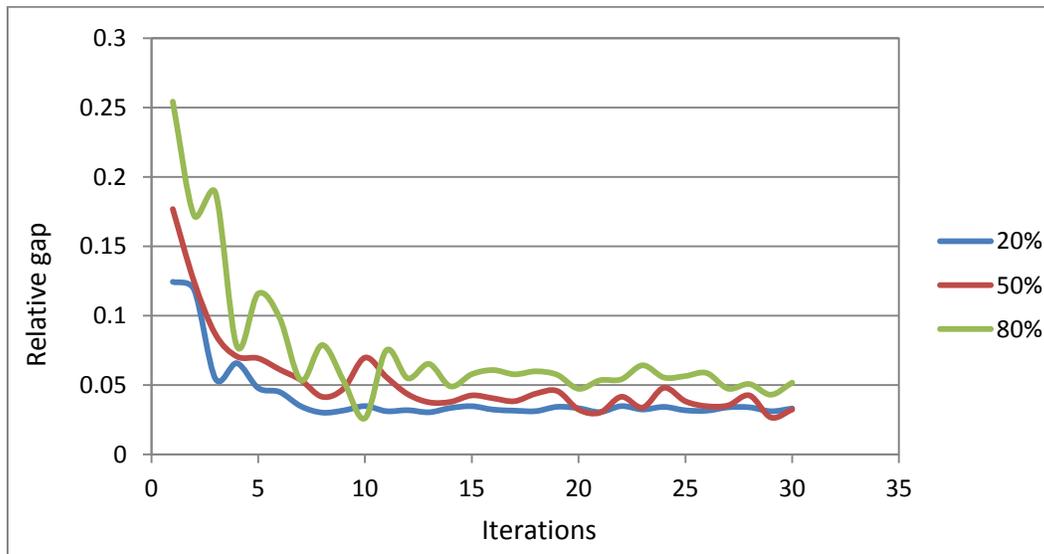
Figure 5-31 Convergence of TRANSIMS for Statewide Jacksonville network

5.3.6 Modeling Advanced Management and Information Strategies

One of the main objectives of DTA is to allow the assessment of advanced strategies. In fact, one of the motivations of the original FHWA funding of the original DTA efforts in the 1990s that resulted in the development of Dynasmart and DynaMIT was the modeling of ITS strategies.

Among the advanced strategies that are best evaluated using DTA is dynamic routing using in-vehicle or infrastructure-based devices. This requires the modeling tool to allow en-route assignment to emulate in-vehicle traffic information provision using different options, as specified in the criteria of Chapter 4. This will become even more important with the introduction of connected vehicle technologies in the next few years. Dynasmart/DynusT allows en-route no feedback en-route assignment, in which vehicles are assigned to paths based on instantaneous travel time while traveling on the network to simulate traffic diversion based on information while en-route. This en-route assignment considers the percentage of travelers with in-vehicle information and the proportions of travelers that change route under different conditions in response to the received information, while in route. The other three tools do not allow this modeling.

In addition to the vehicle-based guidance systems mentioned above, infrastructure based traveler information systems need to be modeled. This modeling would account for the impacts of dynamic message sign/highway advisory radio implementations on traffic diversion under incident conditions. Dynsmart/DynusT allows the modeling of these devices and also allows the user to change input parameters to impact the proportions of travelers that change routes under different conditions in response to the received information. It also gives the user the option to specify the paths used by travelers diverting in response to incident conditions. The other three tools do not have a built-up analysis of DMS. However, it may be possible to "trick" TRANSIMS and Cube Avenue to allow the modeling of DMS using multiple runs and multiple user group assignment.

There has been increasing interest in implementing managed lanes such as Truck Only Toll (TOT) Lanes, Express Toll Lanes (ETL) and High Occupancy Toll (HOT) lanes. There are many issues that need to be assessed when planning such facilities, including impacts on system performance measures, pricing strategy (e.g., time of day or dynamic pricing), lane use eligibility

criteria, optimum tolls, managed lane demands, associated revenues, and economic benefits vs. costs of these facilities. Recently, the use of dynamic traffic assignment combined with simulation modeling has been proposed as a strong alternative to provide more realistic and detailed analyses of the above issues. Determining the number of travelers paying for the managed lanes as part of demand forecasting models has been done as part of the assignment step or utilization a logit-based choice mode combined with the assignment step. Determining this number based on assignment limits the many options that can be considered in the choice between managed lanes (ML) and general-purpose lanes (GPL) since choice based allows a wide range of parameters to be included in the managed lane use choices and simplifies the assignment process. However, there are still questions about the ability to converge between a logit choice model of this type and assignment. This and several issues will be addressed in a research project that will start soon on modeling managed lanes in DTA.

5.4 Traffic Flow Model

As discussed in the review of literature section, traffic flow modeling may be accomplished using analytical procedures or by simulating vehicles' movements along their routes. The static Cube Voyager assignment of the FSUTMS utilizes an analytical function (the BPR curve) to assess travel time as a function of volume to capacity ratio with the parameters of these functions can be varied by facility type. The analyst is also allowed to code signalized intersections, permitting the calculations of delays using analytical intersection delay equations.

Cube Avenue and DynusT are both based on what can be regarded as mesoscope simulation models. In a typical application, Cube Avenue utilizes the BPR function to move the cars along the links. However, Cube Avenue constrains the volumes entering a link by the capacity of the link and the storage of downstream links. There is an option that let the user change the capacity constraint to be based on upstream link capacity, but the default is based on the downstream capacity, which is the preferred alternative. In case one of these is exceeded, a vertical queue is accumulated and used to compute the delay. If a signalized intersection is coded using the intersection option in Cube, then the delay is calculated using queuing delay due to capacity constraint at the intersection plus a delay component calculated using an analytical equation (e.g., based on HCM).

The mesoscopic traffic flow model in DynusT is originally based on that of Dynasmart, which determines the speed on a link based on speed/density functions (the modified Greenshields model), while utilizing capacity constraints at the downstream node to determine queue delay. As stated in Chapter 2, an enhancement was introduced to DynusT, referred to as the Anisotropic Mesoscopic Simulation (AMS) (Chiu et al. 2010), which assumes that vehicle's prevailing speed to be influenced only by the vehicles that are closely in front of it. The developers showed that this model produces a more realistic representation of traffic flow compared to the original DYNASMART model.

TRANSIMS traffic flow model is considered as a low-fidelity "microsimulation." It is a lane-by-lane simulation model and thus can be considered as more detailed than that of DynusT and Avenue. The travel time used by the TRANSIMS "Router" in the assignment can either be based on the outputs of the traffic microsimulator or calculated using volume-delay functions (e.g., BPR curves). This latter option has been utilized in some projects for big networks to reduce computation time. These projects justified this in that regional microsimulation is computationally intensive and results in extremely long runtime. However, they utilized the microsimulator as a post-processer to estimate system performance.

In this study, a number of tests were performed to test the traffic flow models of the four assessed software packages. The first test was conducted to determine the ability to estimate change in travel time with the increase in demand and the queuing at a bottleneck. A simple linear facility (with no parallel or intersecting links), which is Network 1 shown in Figure 5-32, was used in the test. In this network, the number of lanes was dropped from three lanes for Link 2 (5,400 vph capacity) to two lanes (3,600 vph capacity) for Link 3 to create the bottleneck. For different levels of demand from 1,800 vph to 5,400 vph, the travel time on Link 2 was obtained from program output at time intervals of 30 minutes. The modeling period was 120 minutes, but the demand was loaded on the network only for the first 60 minutes to show the build-up and dissipation of the queue. Figure 5-32 shows that the static assignment in Cube Voyager underestimates the increase in travel time with demand significantly since it uses the BPR functions with no consideration of queuing. It appears that the impact of queuing starts below the capacity level of 3,600 vph in TRANSIMS and DynusT, possibly due to the inclusion of a stochastic component in vehicle generation. Cube Avenue estimates higher delays than the other

two DTA tools for high V/C ratios, as shown in Figure 5-32 (e.g., 6.4 min. for Avenue versus 4.9 min. for 1.33 volume to capacity ratio). As seen in Figure 5-32, increase in travel time for DTA tools occurs on link 2-3 (Network 1) that is upstream of bottleneck, because these tools don't allow a V/C greater than 1 on Link 3-4, and therefore queue forms upstream of node 3. Whereas, in the case of static assignment, the increase in travel time occurs on link 3-4, simply because number of lanes drops and V/C increases even more than 1 which subsequently increases the travel time based on BPR formula.
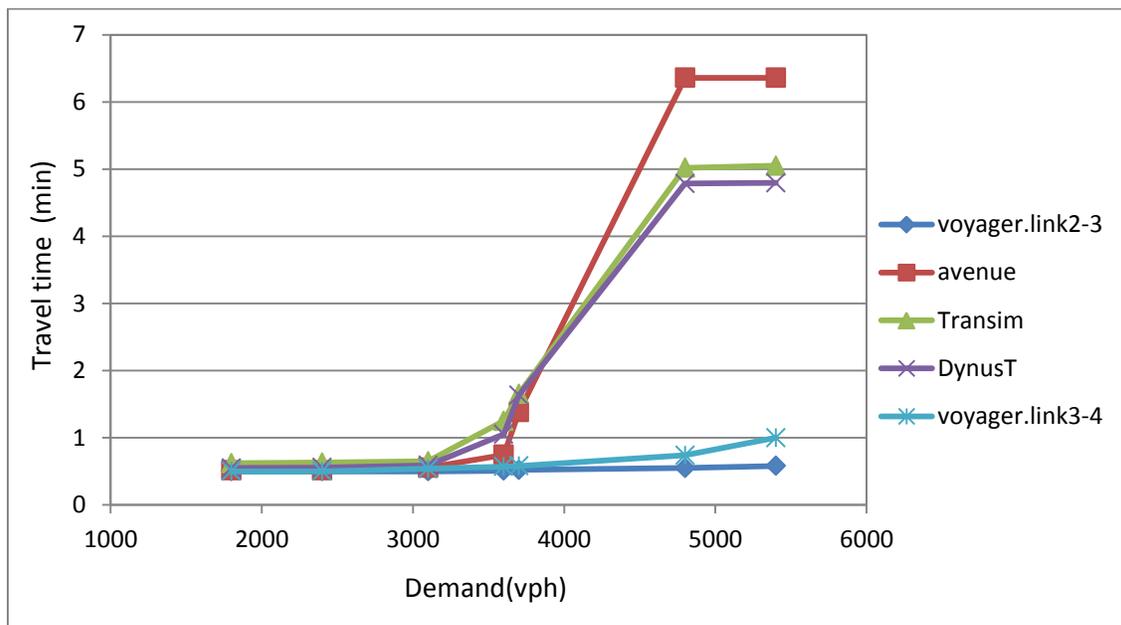
Figure 5-32 Demand-travel time relationships with capacity constraint from downstream link

Further analysis was done on the same network to test the ability of the three tools to simulate the building, propagation, and dissipation of queues. The same network mentioned above (Network 1 in Table 5-3) was used for this test with the same setup, except that the demand level used was 4800 vph for a modeling period of 120 minutes resulting in 1.33 v/c ratio due to capacity constraint from downstream link. Figure 5-33 and Figure 5-34 show that the jam density in Cube Avenue has an important effect on the queue estimation and spillback effects. This is because using lower jam density will result in the filling of the link queue capacity with less number of vehicles. However, even at a jam density of 295 vehicles/hr/lane, which is a high

value compared to what is observed in real-world conditions, the number of vehicles that could be queued on a link is lower in Cube Avenue. Again, the demand was loaded only in the first 60 minutes. It is interesting that the changes in queuing and travel time on link 1-2 in Cube Avenue and TRANSIMS show similar trend when the jam density in Avenue is specified as 295 vehicles/hr/lane, as indicated in Figure 5-33 and Figure 5-35.

Figure 5-33 and Figure 5-35 shows that in Avenue and TRANSIMS, after cutting demand, the queue starts dissipating but the travel time continues to increase for a while, possibly reflecting that the travel time is accumulated for the vehicles after they complete their trips and the vehicles that join the queue at its maximum length do not leave the network until sometime after cutting the demands. DynusT does not provide queue length as an output, so it was not included in this comparison. It is recommended that the DynusT developers produce this value.
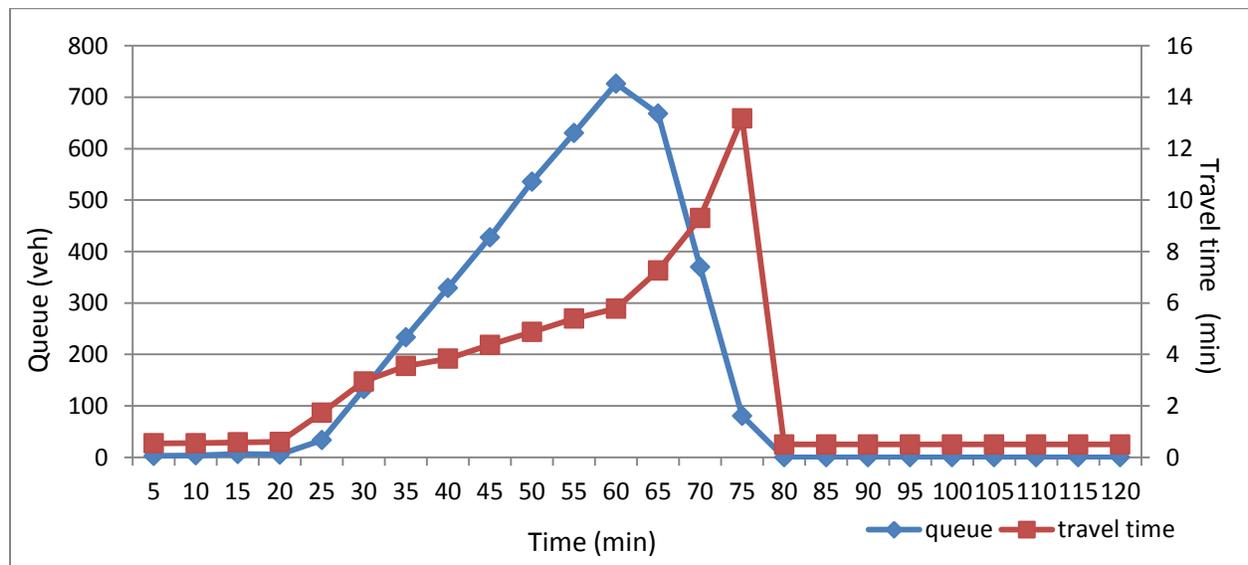
Figure 5-33 Cube Avenue queue and travel time trend over time (jam density=295 veh/mile/ln)
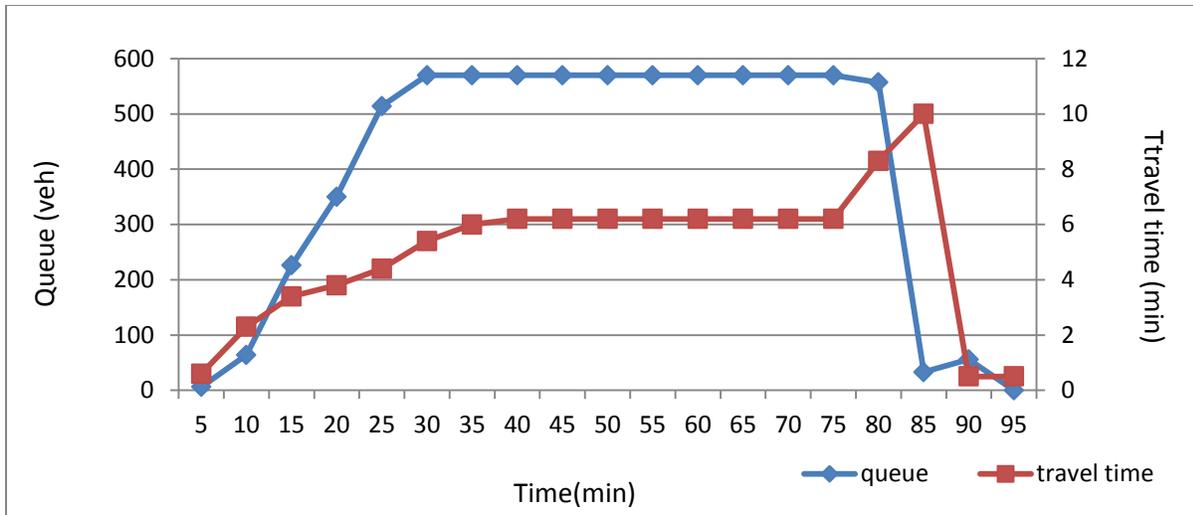
Figure 5-34 Avenue queue and travel time trend over time (jam density=120 veh/mile/ln)
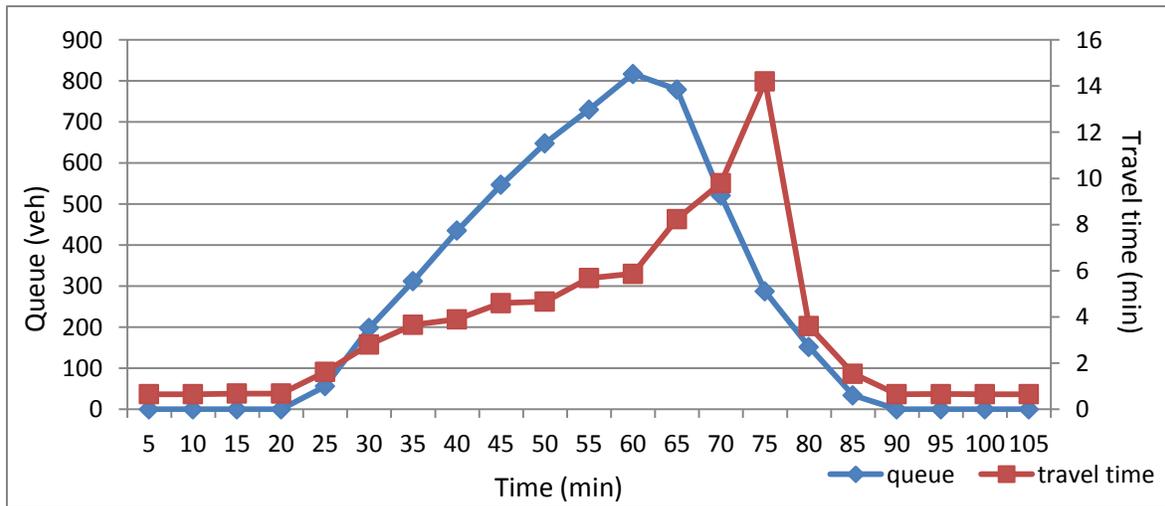
Figure 5-35 TRANSIMS queue and travel time trend over time

Another important criterion in Chapter 4 (Criterion 2.3) requires the modeling of queue spillbacks to upstream links. Again, Network 1 in Table 5-3 is used for this test. Since Cube Voyager does not deal with queuing, it was not tested for this criterion. Again the level of demand used was 4800 vph for a modeling period of 120 minutes with the demand loaded only in the first 60 minutes. The change in queues and travel times on link 1-2 and link 2-3 over time is depicted in Figure 5-36 to Figure 5-40 to show queue formation at the bottleneck and its spillback to the upstream node. Again, the queuing on TRANSIMS (Figure 5-39) and Cube Avenue (Figure 5-36) on link 2-3 (upstream of the links that have a capacity constraint due to the

reduction in queue) due to spillback is very similar with the queue forming at a rate of 1200 vph (which is the demand (4800 vph) minus capacity (3,600 vph)), and grows until the number of vehicles on the link equals the link jam density. When the link is full, the queue spills back to link 1-2, as is observable the figures. For DynusT, since the queue is not reported in current version, only the travel time reported in Figure 5-38. Please, note that there are differences in the travel time between the three tools with DynusT for example reporting travel times that are much lower than the other tools. This issue is being investigated further and the results will be discussed in the final report.
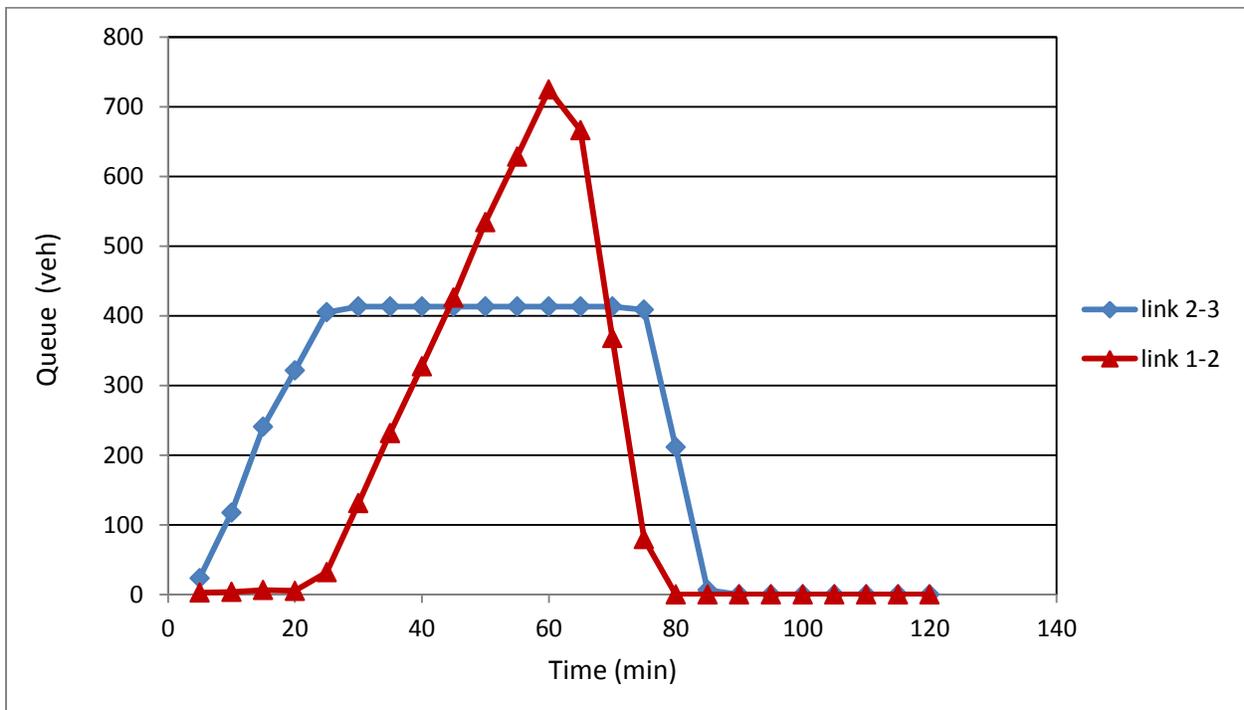
Figure 5-36 Demonstration of Avenue queue spillback (queue forming over time)
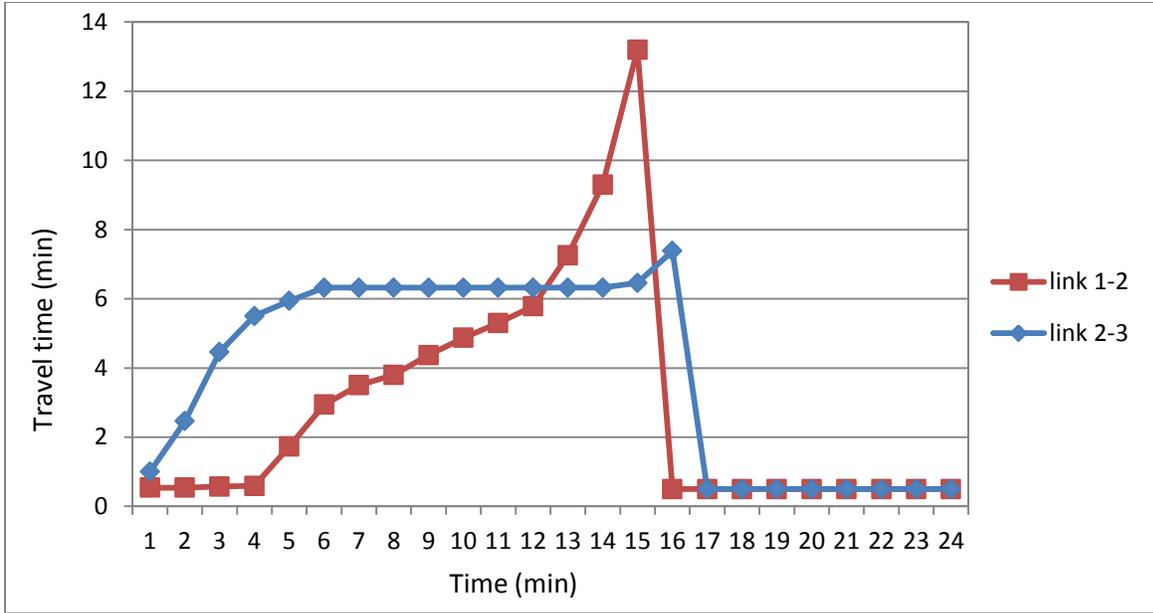
Figure 5-37 Demonstration of Avenue queue spillback (travel time over time)
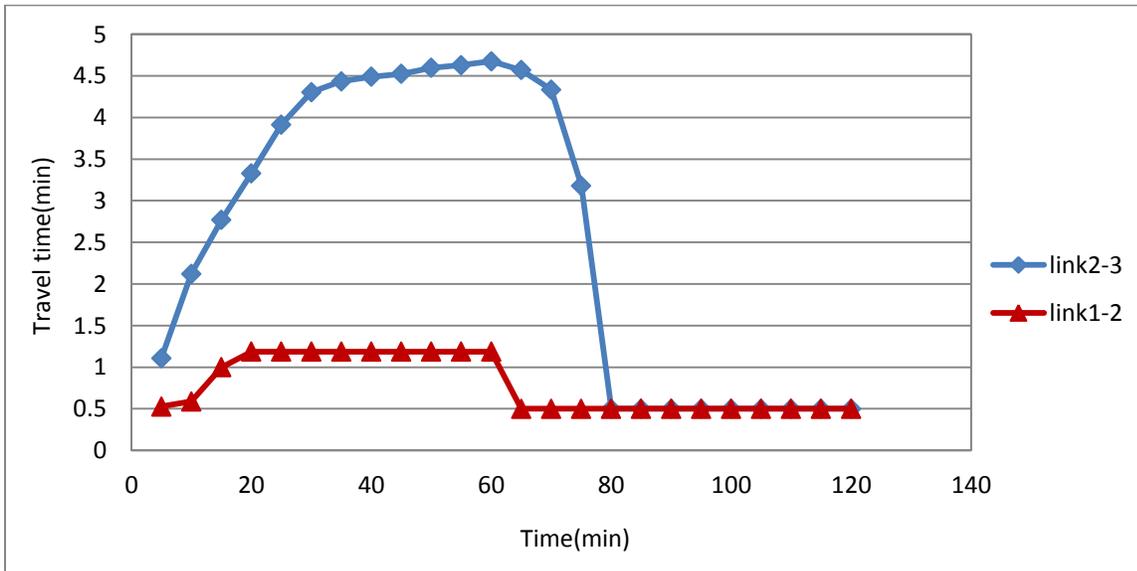
Figure 5-38 Demonstration of DynusT queue spillback (travel time over time)
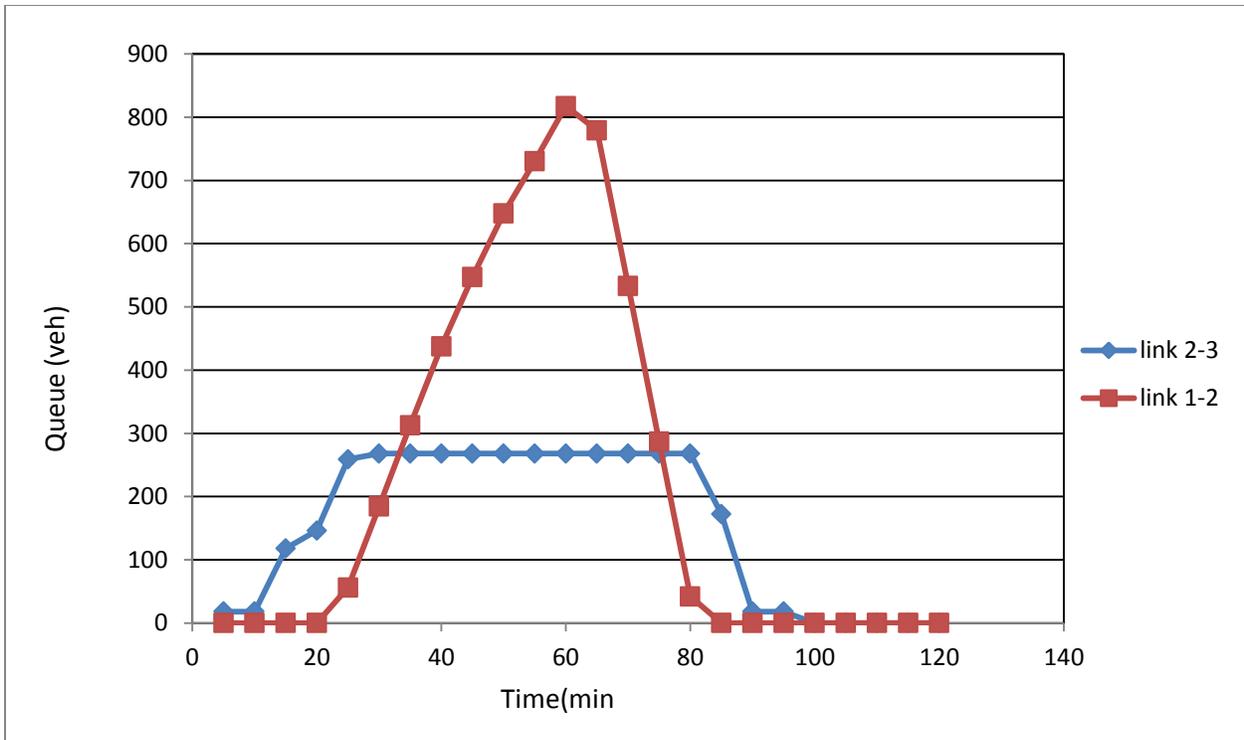
Figure 5-39 Demonstration of TRANSIMS queue spillback (queue over time)
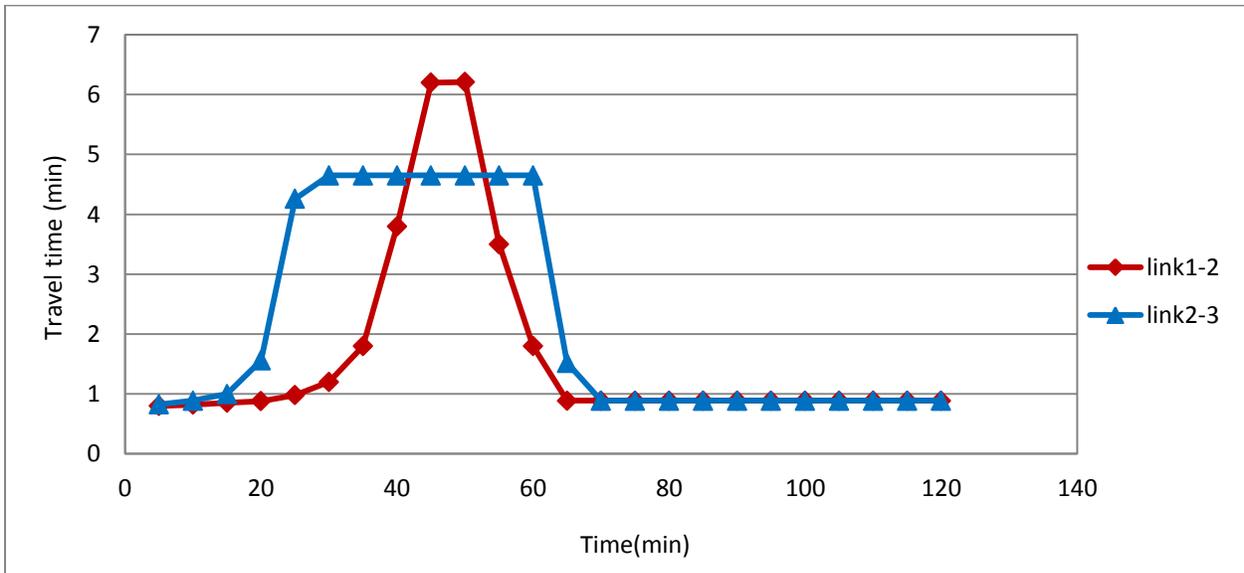
Figure 5-40 Demonstration of TRANSIMS queue spillback (travel time over time)

One of the concerns expressed by a modeler (see the user interview section) was that traffic flow models that are not lane-based may not be able to model the blocking of left and right turning

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movements without causing the through movements to be blocked. That was tested in this study according to the criteria of Chapter 4 by assessing the effect of high turning demands on through movements at an intersection without any control utilizing Network 2 in Table 5-3. The modeling period was set at 120 minutes with the network loaded only for the first 60 minutes. The demand from Origin 1 to Destination 1 was fixed at 900 vph and from Origin 1 to Destination 2 was increased from 900 vph to 2040 vph. The data from the trajectory files rather than output files were used to compute the average travel time from origin 1 to destinations 1 and 2. The left turn demand vs. travel time between origin 1 and destinations 1 and 2 are depicted in Figure 5-41 through Figure 5-43. The left turn and the through movement share a lane in this test.

It is interesting to see the difference of how different models show the effect of the left turn on through movements. Cube Avenue shows that the left-turn backups does not affect through movement travel time unless the link that approaches the intersection is full with the left turn volume. DynusT and TRANSIMS show lower impact of turning movement queuing on through movement.
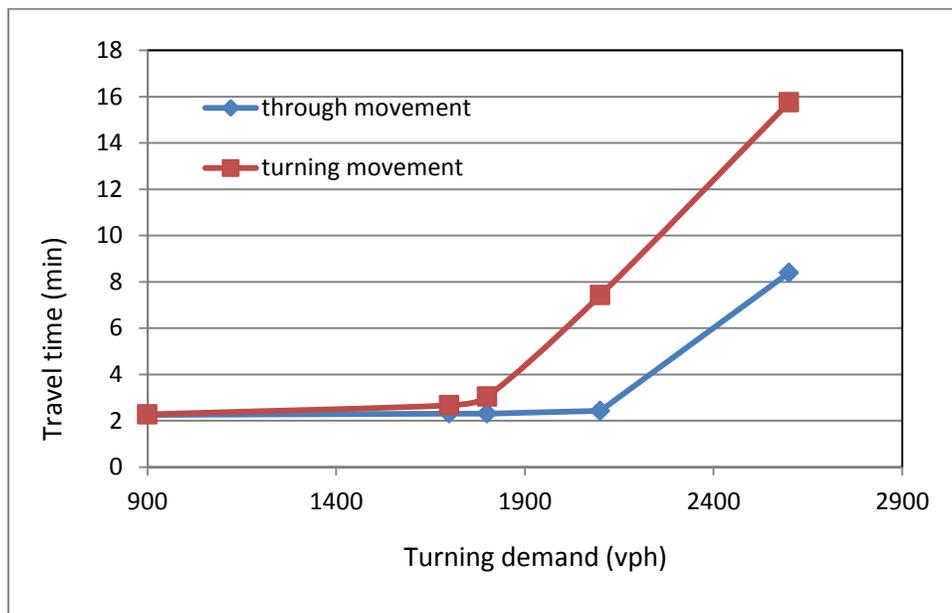
Figure 5-41 Effect of turning movement on through movement uncontrolled intersection in Cube Avenue
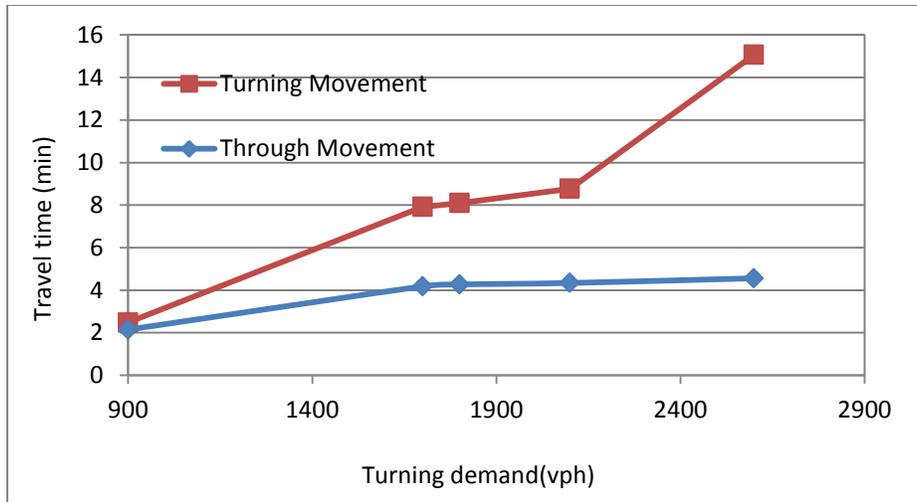
Figure 5-42 Effect of turning movement on through movement uncontrolled intersection in DynusT
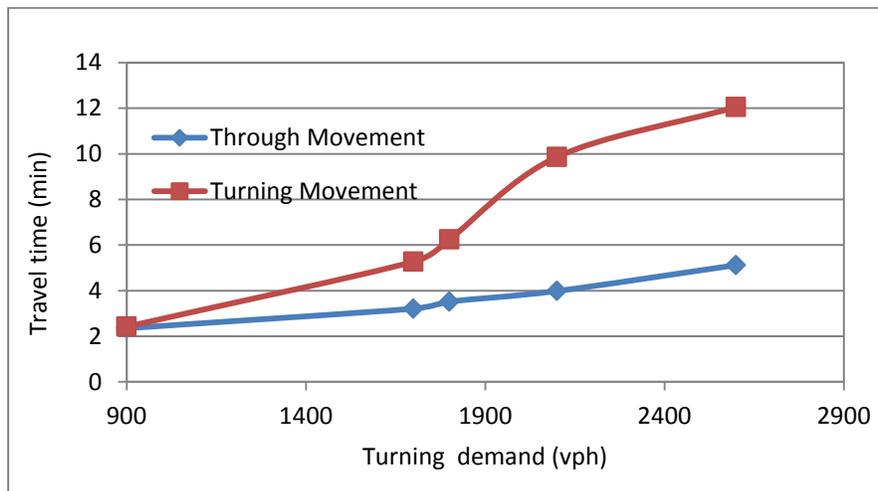
Figure 5-43 Effect of turning movement on through movement uncontrolled intersection in TRANSIMS

The issue discussed above was investigated further in the condition of the blocking of a lane due to back off from an exit ramp. Additional testing was conducted utilizing Network 3 in Table 5-3. The demand of through traffic is fixed at 1800 vph. Different levels of off-ramp demands were tested to create backups from the off-ramp. For each demand level, the volume downstream of the diversion point was obtained from simulation output. As shown in Figure 5-44 through Figure 5-46, as soon as off-ramp queue spill back occurs due to demand exceeding capacity of the ramp, both TRANSIMS and DynusT start showing drops in capacity due to off-ramp back

up. This drop in capacity increases with the increase in the back up (increase in off-ramp demand). The drop tendency in DynusT and TRANSIMS is similar. However, the drop in throughput volume in Cube Avenue is much more abrupt. The through volume continues to equal the demand until the link upstream of the off-ramp is full (all lanes) by the off-ramp traffic. At that point, the volume of through traffic drops to a level that is a function of downstream capacity. This is problematic because the point at which a queue fills a link is a function of the coded link length, which may not reflect real-world conditions.
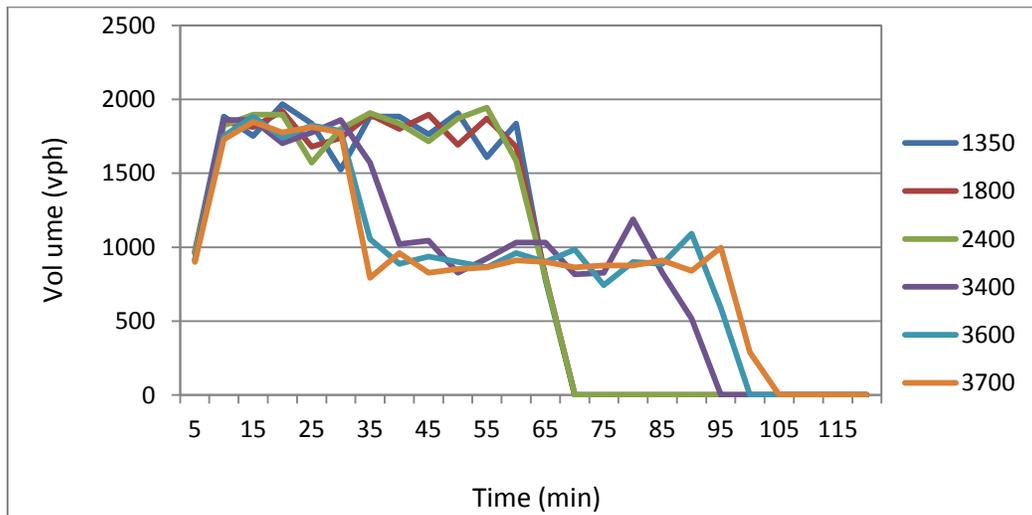
Figure 5-44 Variations in mainline volume with the increase in off-ramp volumes in Avenue
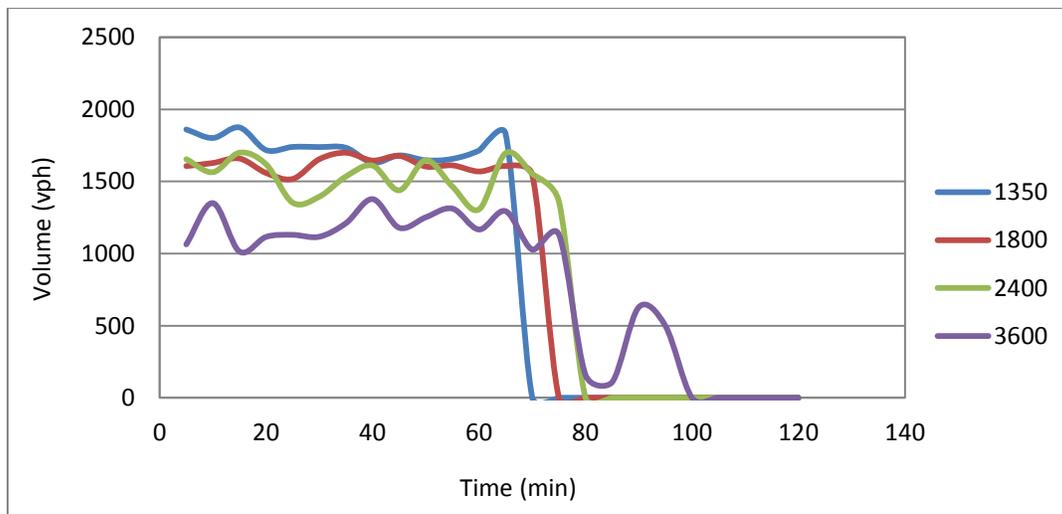
Figure 5-45 Variations in mainline volume with the increase in off-ramp volumes in DynusT
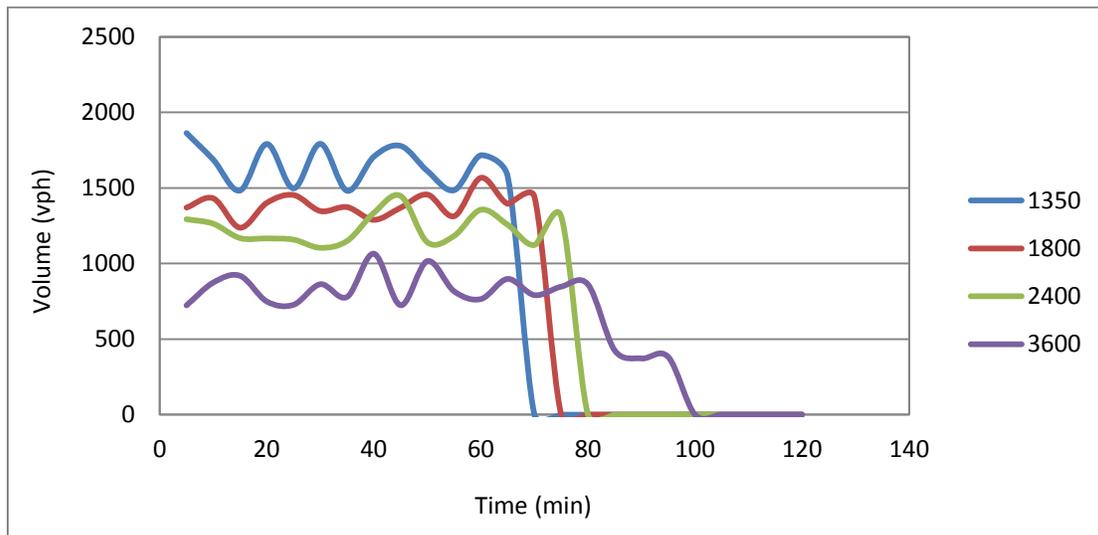
Figure 5-46 Variations in mainline volume with the increase in off-ramp volumes in TRANSIMS

Another criterion in Chapter 4 (Criterion 2.6) is that when there is a limited capacity at a merging point, the capacity should be distributed correctly and fairly between the two merging traffic streams. This criterion was tested using the Network 4 in Table 5-3, and the results showed that all three DTA tools satisfy the criterion.

Another criterion states that all the demands inputted to the model shall be processed by the software without eliminating a portion of the demand due to congestion. Cube static, Cube Avenue, and DynusT appear to satisfy this criterion. However, in TRANSIMS, it was stated that in some cases, all the downstream cells on the link are occupied, a warning message is generated, and the vehicle is deleted.

All tools allow the model parameters that affect capacity and performance measures to be changed by the users. The Cube static assignment allows link V/C ratios to be greater than 1.0. All DTA tools do not allow this and queue vehicles if this happens.

DTA tools shall be able to simulate non-recurring congestion. This should allow the modeler to model and assess the impacts of incidents and work zones with specified capacity drops, beginning time, and ending time. This is possible in all DTA tools. In Cube Avenue and DynusT,

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a drop in capacity can be specified between two points in the simulation. In TRANSIMS, lane blockage rather than a percentage drop in capacity is specified. The linear network described above (Network 1 in Table 5-3) was used for the test of capacity drop due to incidents. A 35% drop in capacity was introduced on link 2-3, from time = 30 min to time = 45 min and the queue on links 1-2 and link 2-3 was obtained. The results are seen in Figure 5-47 - Figure 5-49. Because DynusT does not report queue lengths, throughput volumes were used instead of queues to assess the ability to drop capacity in this tool.
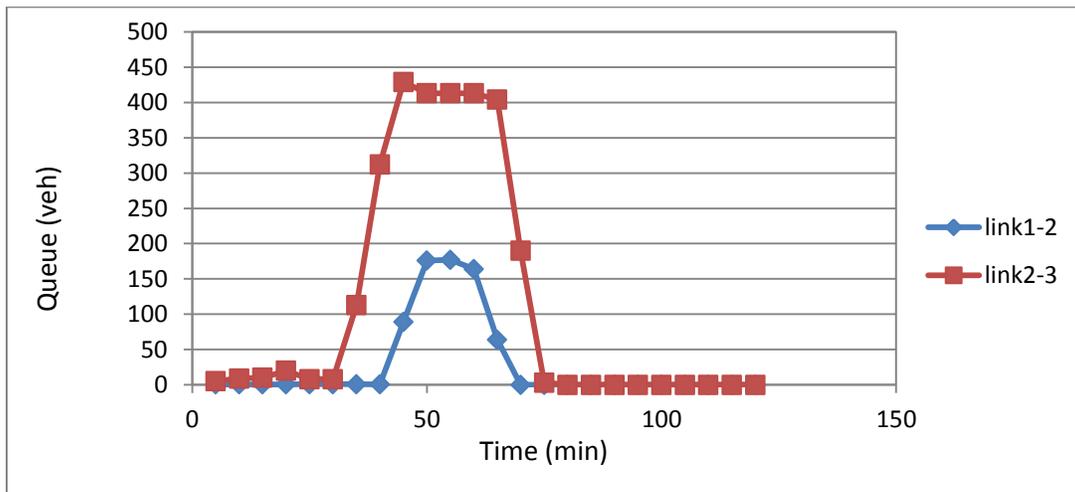
Figure 5-47 Avenue modeling of incident effects (jam density=295 veh/mile/ln)
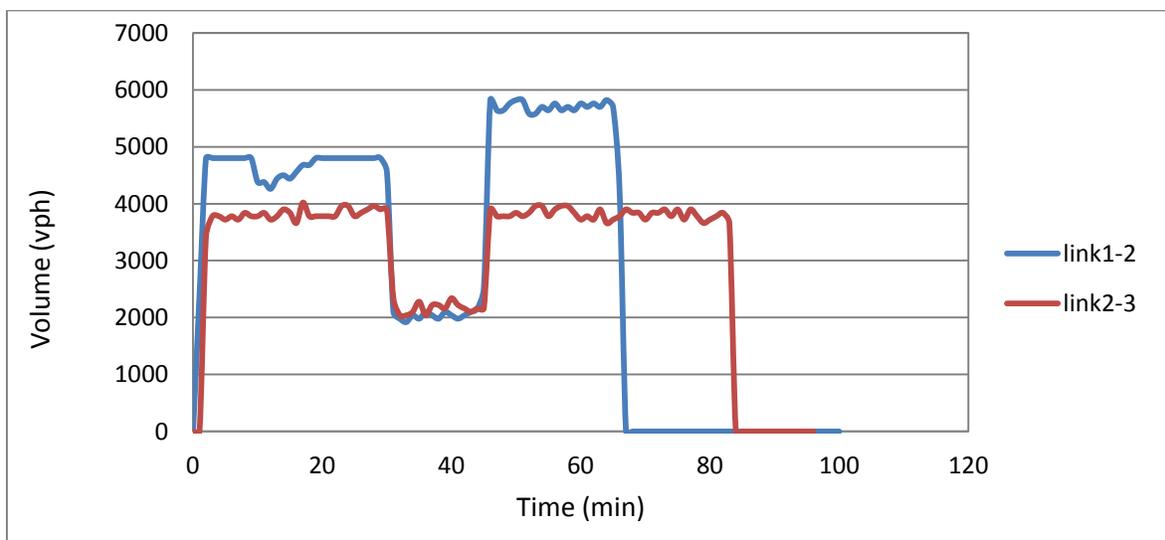
Figure 5-48 DynusT modeling of incident (volume over time)
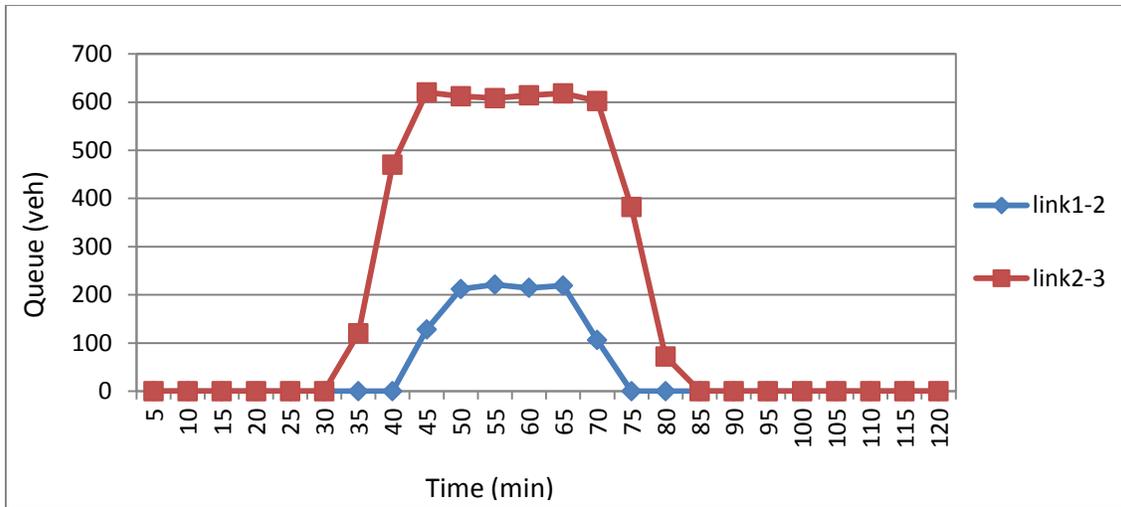
Figure 5-49 TRANSIMS modeling of incident effects
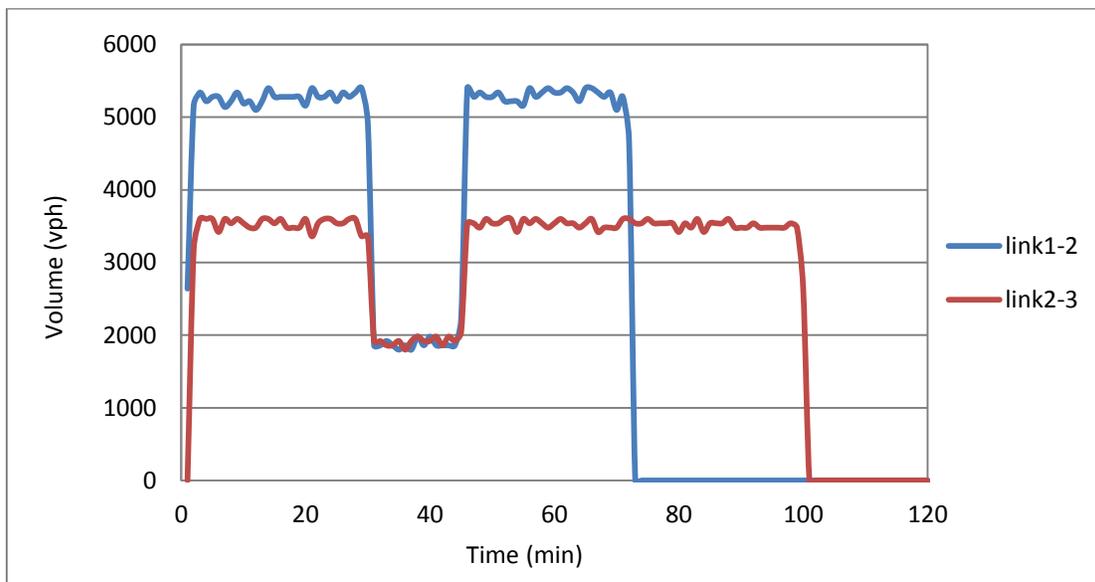
Figure 5-50 TRANSIMS - accident effect (volume over time)

Another issue that needs to be assessed is signal control impacts on approach travel time/delays. In large networks, it will be difficult to specify the timing for each signal. Also, the timing for future years is not available. Thus, the analyst should be able to specify a simplified method of assessing the impacts of signals on traffic flow travel time/delay for large scale networks without requiring detailed modeling of signal control attributes and intersection geometry. It should be

mentioned that some of the interviews discussed in Chapter 3 indicate that the timing resulting from these automated procedures may not be satisfactory.

Alternatively, the TFM shall optionally automatically calculate the signal timing using an acceptable methodology. All tools allow the automatic calculation of signal timing based on supplied signal parameters. In Cube Avenue and TRANSIMS, the user can also try the use of volume-delay functions that already incorporates the effect of signals. This may not be possible in DynusT since the Modified Greenshields model is build-in the tool. It is also not possible in TRANSIMS microsimulation but may be possible to incorporate with the analytical-based assignment of the router.

All tools allow the user to input the signal timings by time period of the analysis. Cube and Cube Avenue does not account for the coordination between signals and thus does not allow the coding of offsets. The model of signal delays in Cube Avenue is based on analytical equations, rather than on simulation of the stop on red and release on green of the vehicles. Both TRANSIMS and DynusT allow the coding of offsets and account for the effect of coordination between traffic signals.

In this study, a comparison was made of the effect of cycle length and green split on intersection delay. Network 2 in Table 5-3 was used. The results were compared to the results produced by a commonly used traffic signal analysis tools (Synchro and SimTraffic). The effect of cycle length and green split was examined in this test. The intersection delay was calculated by comparing the travel time (veh-hr) at intersection with, and without signal. The model period is 2 hours, including 1 hour of network loading and 1 hour of cooling. To assess the effect of green split, the demand was set as follows: Origin 1 – Destination 1 is 900 vph, Origin 1- Destination 2 is 450 vph, and Origin 2 - Destination 2 is 900 vph. The average intersection delay for different percentages of green split in the eastbound direction is depicted for a cycle length of 120s. The average delay versus green split is shown in Figure 5-51 for the different software tools. As shown in the figure, all tools produce delay estimates close to the optimal green split but Cube static produced unrealistic delay for splits that are far from the optimal. When comparing the three DTA tools, DynusT and TRANSIMS produced somewhat closer results to Synchro for non-optimal splits, particularly for low green split for the eastbound movement.
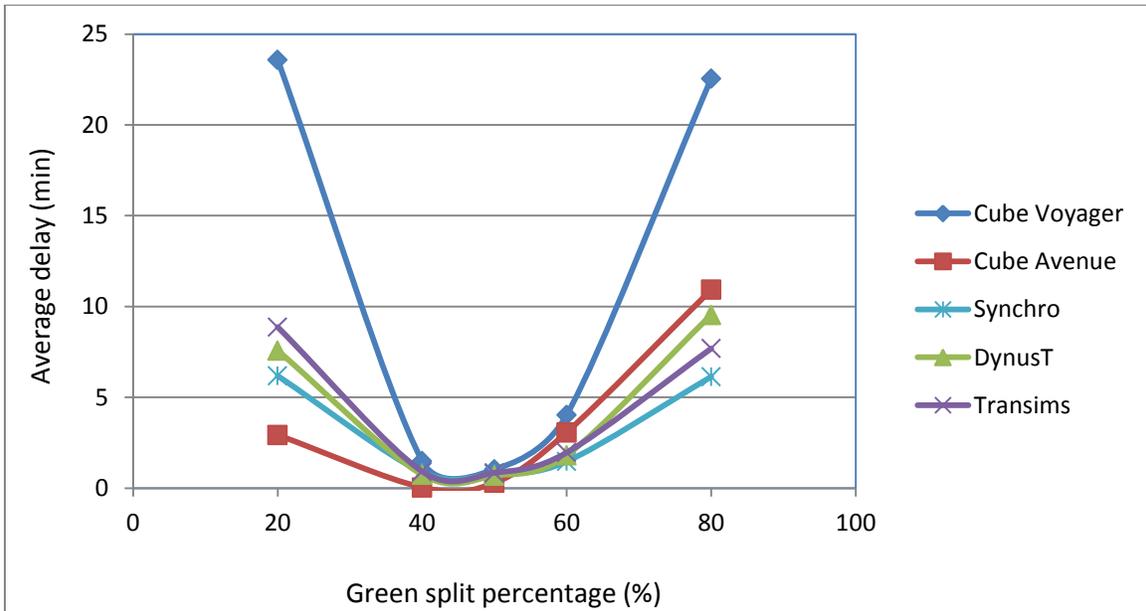
Figure 5-51 Impacts of green split percentage

The effect of cycle length was also examined for four different demand levels as is shown in Figure 5-52 to Figure 5-55. As is shown in these figures, DTA tool produced similar delays to Synchro around the optimal cycle length (optimum cycle length around 70s among six different cycle lengths), but they underestimate delays for cycle lengths longer than the optimum one. Cube Avenue produced closer variations of delay with cycle length to that in Synchro than the other tools, particularly for low to moderate traffic, possibly reflecting its use of an analytical model similar to Synchro in assessing delays. All DTA tools produced higher delays than Synchro as the intersection volume became high.
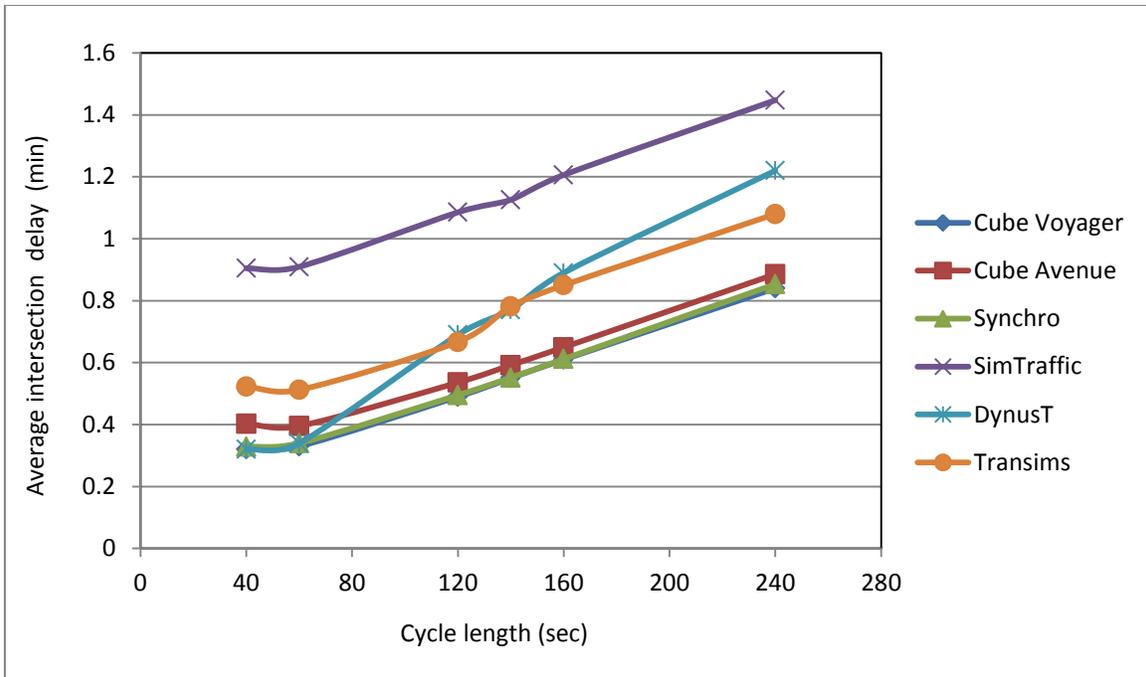
Figure 5-52 Effect of cycle length (demand = 600 vph)
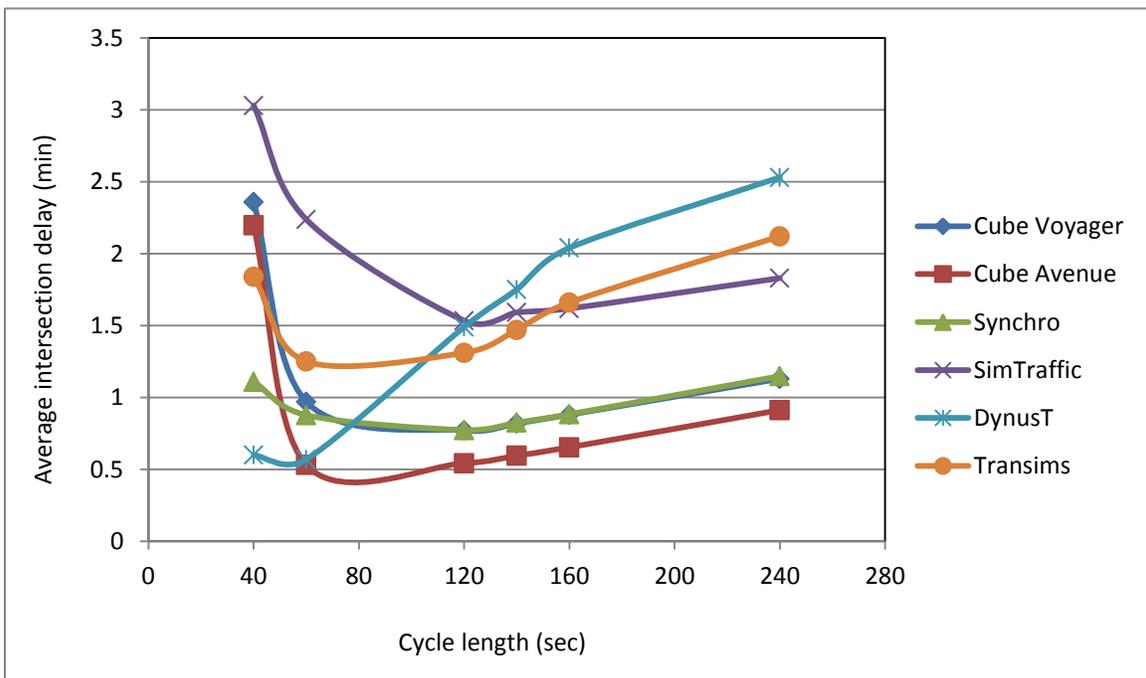
Figure 5-53 Effect of cycle length (demand = 800 vph)

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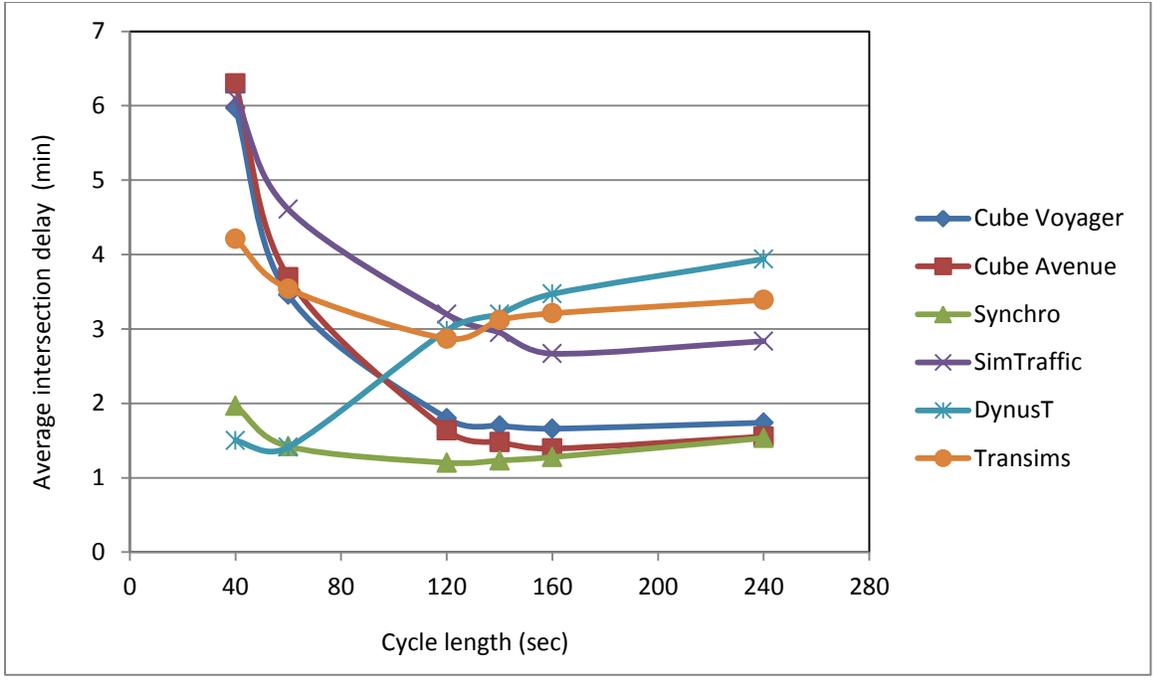
Figure 5-54 Effect of cycle length (demand = 900 vph)
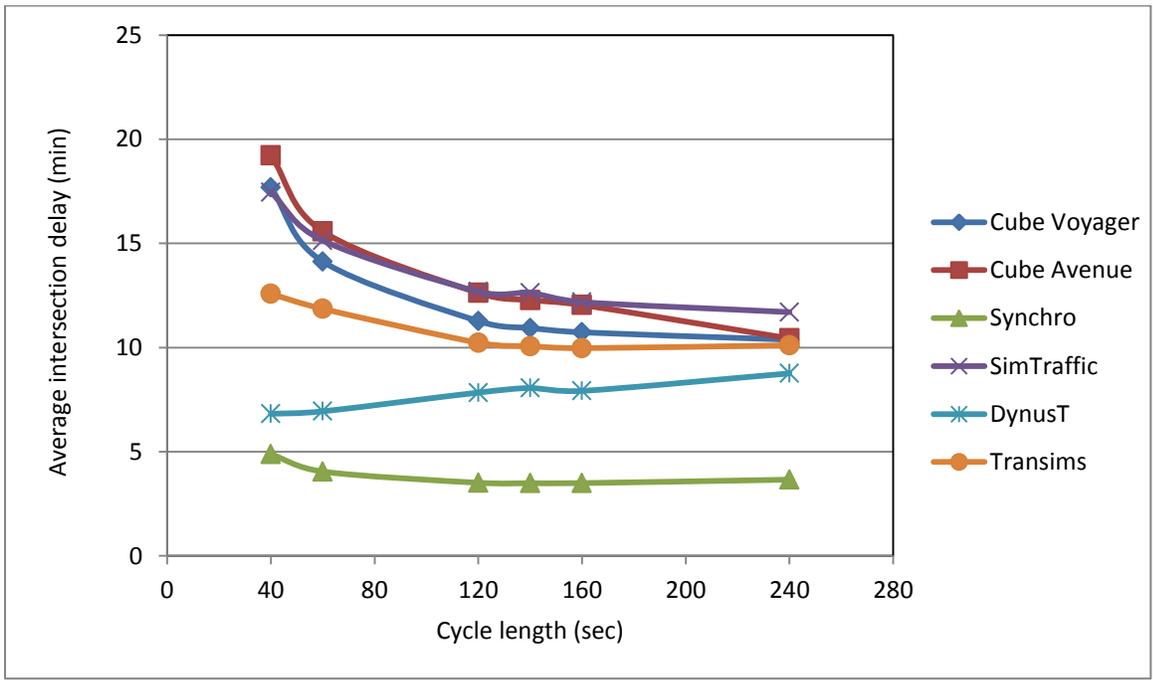
Figure 5-55 Effect of cycle length (demand = 1200 vph)

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The impacts of ramp metering on freeway mainline and on-ramp traffic using time-of-day rates and/or traffic responsive rates can be modeled using DynusT. TRANSIMS can also model time-of-day ramp metering. Cube and Cube Avenue do not have this feature. However, it can be modeled at a macroscopic level by coding a delay function for on-ramp metering similar to that of signals and modifying the throughputs at bottlenecks.

DynusT allows simulating time-variant speed limits on links, at least at the time-of-day level to simulate applications such as dynamic speed limit and school zoning. TRANSIMS does not allow this feature. This feature can be changed in Cube Avenue by changing T0 for different time segments.

The impacts of bus priority on signal operations cannot be modeled explicitly in the four tools but can be estimated at a sketch planning level by introducing factors to calculate the impacts based on previous studies. All four tools can model the operations of bus-only lanes but not bus congestion by-pass lanes.

All four tools are able to model managed lanes with different number of lanes and different capacity per lane compared to general use lane. The modeling of reversed/contra-flow lanes is also possible by changing the capacities by time period. Only DynusT allows the modeling of dynamic congestion pricing.

All tools allow the inclusion of warm-up and cooling periods that are not considered when reporting the statistics of the system in the outputs.

5.5   Transit Modeling

The assignment environment criteria that are related to transit modeling, are supported by the Cube Voyager environment. With transit modeling, Cube Avenue or the Cube Voyager static HIGHWAY assignment program can be used as the assignment tool. Since the data and scripting environment is common to both, it is easy to exchange data between the dynamic traffic assignment and public transport processes. In fact, it is possible that the user can integrate any other static or dynamic tool with Cube public transit processes. For example, if DynusT or TRANSIMS are integrated within the Cube environment, the transit modeling in Cube Voyager

can be interfaced with these assignment tools. This will develop a hybrid dynamic model for the highway network and static model for the transit network. Ideally both models would be dynamic but this is an excellent interim step when moving to a full dynamic process.

Cube Voyager can be used to model any mode of public transportation. Cube Voyager allows the modeler to represent access to transit via walking or driving by generating "support links" based upon minimum generalized cost paths from zone centroids to transit stops across a multi-modal transportation network. Additionally, Cube integrates ArcGIS geoprocessing methods that can be used to estimate the percentage of the zonal area that is within walking distance of a transit stop. Version 6.0.1 of Cube Voyager also incorporates the AUTOCON methodology for developing drive access links for transit networks, as widely used in FSUTMS models. The Cube Voyager Public Transport module supports assignment of trips to optimal transit routes. Public transport routes are defined as sequences of alternating transit and non-transit "legs", where each leg traverses a connected series of nodes and links, from the origin of a trip to the destination. The non-transit legs include walk or drive access links as well as transfer and egress links, and the transit legs include the portions of the trip taken on actual transit services. The Cube Voyager Public Transport module includes such a route enumeration process. The parameters controlling what set of routes may be considered reasonable are input by the user using script commands and keywords.

The network output by an equilibrium highway traffic assignment process can be used as input to the Cube Voyager Public Transport module. The travel time for each run of a transit line may be determined using the congested link times along the route, as well as schedule-derived assumptions or actual timetables. The Public Transport module includes a route evaluation process that uses behavioral decision models to determine the probability of a traveler using one of the enumerated routes. The network output by an equilibrium highway traffic assignment process can be used as input to the Cube Voyager Public Transport module. The travel time for each run of a transit line may be determined using the congested link times along the route, as well as schedule-derived assumptions or actual timetables. The analyst is able to specify that transit line choice based on service frequency and/or generalized cost of travel to account for users with different information levels of the travel time to destination.

Either the service frequency or service frequency-and-cost models may be selected as sub-options for transit line choice.

Although the transit speed can be based on the congested speed/time resulting from the assignment, it is possible to differentiate transit from highway travel times utilizing a function that relates the two. These differences may be further differentiated by line- and node-level DWELL and DELAY variables representing the time required to pick up and drop off passengers at each stop. Cube Voyager also permits adjustment of travel time to account for bus priority by using the LinkWork variables mentioned previously, or by using turn penalty input files.

Cube also allows the estimation of the wait time, transfer time, and number of transfer for use in the assignment process by using a wait curves to compute initial and transfer wait times based on the frequency of services. In Cube, the user can assign at each stop node, two wait curves: one for the first boarding point and the other for transfer points.

Cube Voyager allows for accounting for the impact on highway performance of the extra auto traffic generated due to driving to park-and-ride facility, as specified by the analyst. To do this, park-and-ride volumes can be outputted from the Public Transport model in a link file that can then be merged into the input network for a highway traffic assignment process. Alternatively, the user can assign a vehicle trip table corresponding to the drive portion of the park-and-ride trip to the network.

The Cube Voyager route evaluation is based upon generalized cost, including fare, in-vehicle time, walk time, wait time, boarding penalties, and transfer penalties. The route enumeration is based upon a simplified version of the generalized cost. In version 6.0.2 it is possible to take fares into account in route enumeration. Separate factors are available for route enumeration and route evaluation. It is possible to specify the relative weights of different components of the generalized cost function that are different for different user groups to reflect the importance of each of the generated cost components. The relative weights of different components of the generalized cost function are specified in a separate factors file for each class of user loaded onto the network.

Multiple fare systems may be analyzed by the Cube Voyager Public Transport module, including complex fare systems such as fare-zones, peak/off-peak fares, transfer fares, monthly pass discounts, etc. The fare system may be varied by user class via the FARESYSTEM keyword in the FACTORS file.

In Cube, it is possible to specify the fares as a function of a number of measures, including trip distance, number of fare zones crossed, and boarding/alighting fare zones. To specify fares as a function of distance, the user may set STRUCTURE=DISTANCE. To specify as a function of number of fare zones crossed, the user may set STRUCTURE=COUNT. To specify as a function of boarding/alighting fare zones, the user may set STRUCTURE=FROMTO. It is also possible to specify different fares for initial boarding compared to subsequent transfers.

The Cube modeling environment allows the modeler to put limits on the parameters of the selected transit options. These limits may be implemented within the Cube Voyager Public Transport module using script commands and keywords in the FACTORS file for each user class. The user can also specify a "must-use-mode," which must be used during at least one leg of a public transport route. This function is provided by the FACTORS keyword MUSTUSEMODE.

Cube Voyager accounts for transit capacity constraints/crowding effects. The estimated average wait time shall include the estimated additional wait time due to passengers not able to board (and must wait for a later service). The link travel time adjustment shall account for riders' perception that travel time has higher disutility when standing compared to sitting, for example. This crowd modeling capability can be implemented using the parameter CROWDMODEL=T.

If the analyst wants to account for the impact of the presence of transit vehicles on the capacity of highway links, it is possible to export a LINKO file containing the links associated with all transit lines and information regarding service headways, which may then be translated into "pre-loaded" volumes within the highway network traffic assignment.

Modeling of bus lanes, bus-toll lanes, and bus-on-shoulder is possible by considering that the unique characteristic of these types of facilities is that the buses are not exposed to congestion that arises from mixed traffic flow.

Cube also produces detailed reports from the assignment/passenger loading including link based outputs, network based outputs, and line based outputs; as specified in the assessment criteria. Transit system skim matrices can also be obtained as needed.

In addition to the potential of utilizing DynusT and TRANSIMS on conjunction with the transit modeling of Cube Voyager in the manner described above, both TRANSIMS and the upcoming release of DynusT are person based simulation software packages. Transit assignment can be explicitly modeled in TRANSIMS. The upcoming version of DynusT will be integrated with FAST-TrIPS, which is a simulation-based dynamic transit assignment model, as discussed in Chapter 2. Thus, with these tools, each person riding transit is assigned to a specific transit path including walk links, wait times and routes taken. Due to the disaggregate nature of the model, probability does not play a role in the assignment. All types of transit are represented except paratransit. Paratransit is essentially demand responsive. So representing it would involve modifying the demand model as well as the transit network procedures. For each traveler, the system develops a skim including the route, walk time, wait time, and ride time etc. by link. A skim or path is assigned to each rider. Zone-to-zone skim files by time of day can be created by aggregating individual trips or specifying locations, start times and modes for building paths between zones.

5.6   Summary

This chapter presented an assessment of assignment tools as an example of using the assessment criteria presented in Chapter 4 to assess such tools. Table 5-9 presents a summary of the assessment conducted in this chapter. The information presented in this chapter and in Table 5-9 is not meant to be used to select between different tools. The software selection process is inextricably tied up with the problem to be solved and future plans for further application. The information presented in this chapter is just an example of how to assess assignment tools. In considering DTA packages, the users should evaluate these packages at the time of selection rather than relying solely on the assessment of this document. DTA software is rapidly evolving in terms of capability, run time, and application methods. With these rapid changes it must be kept in mind that the evaluations represent conditions as of on May 31, 2012, when the draft report was submitted to FDOT. In addition, as stated earlier, due to the limited resources available to the project not all, or most, of the packages available were considered for evaluation.

The three packages evaluated in more detail include TRANSIMS and DynusT, the packages selected for the SHRPII applications, and Cube Avenue, currently available to users in Florida through FDOT.

Prior to analyzing specific packages using the dimensions of Chapter 4, a few Strategic issues must be considered, if a decision to use DTA has been made:

- Current and Future Analyses – Learning new software takes time. In order to avoid learning new software for each new application, users should consider not only the immediate needs but also the longer term applications required. If the immediate need is for a subarea analysis but future applications will involve longer corridors or regional analyses, software should be selected with this capability. Likewise if the initial application is for traffic operation analysis but future applications require linking to demand models, the users should consider software which has the capability of linking to demand models. This issue has particular relevance to future enhancements additions of transit modeling.

- Person based and vehicle based – vehicle-based DTAs simulate the movement of vehicles on the network. Issues such as carpooling and transit ridership must be addressed outside the model. Person-based DTAs track people through the system, assigning persons to vehicles, then moving both the vehicle and the person through the network. Person- based methods are a major consideration when linking with demand models.

- Open Source and Proprietary Packages – Open source packages generally have more flexibility and their internal algorithms are transparent to the user. They also allow the user to modify internal processes such as convergence methods when desired, although this is in general difficult to do unless the user is very knowledgeable with the software code under consideration. There is no cost for open source packages, although recently the developer of one of these packages (DynusT) started charging costs for software maintenance and user technical support. Proprietary packages can provide better user interfaces, user support, and stability but the specifics of the internal procedures may not be available and users cannot modify the packages for new applications. Users pay a fee for the proprietary packages.

- Analytic DTA – Simulation-based DTA provides a very powerful tool for analysis, but as network size increases the amount of data required and the validation process becomes daunting. In addition, if a user wants to do a future year forecast, e.g. 20 years ahead on a regional basis, estimating future signal timing and detailed network configuration can be problematic at best. An analytic DTA can provide a simplified method to begin to address these issues. Analytic DTA lacks the fidelity of the more detailed simulation-based DTAs but compensates through ease of use, ability to handle large networks and simplification of forecast procedures.

- Computer power – Computer power doubles in processor speed every two years according to Gordon Moore, founder of Intel.[1] This rule of thumb has held true since the 1970s. Any concerns about slow run time or run speed are likely to be overtaken by changes in hardware capability within the next few years.

Table 5-9 Summary of the Results of Utilizing the Assessment Methodology of this Study

Criterion	Cube Avenue	DynusT	TRANSIMS
Hardware/Software			
Open Source	No	Yes	Yes
Utilization of Additional Hardware Computational Capabilities[2]	None	Run faster on 64 bit computer. Also, 2012 version make use of parallel processing.	Parallel processing. Multi-threading and multi-processing options.
Flexibility in Modifying Procedures	Cube scripting language provides flexibility. Access to Internal built-in variables should be provided to increase flexibility	Open source. Code can be modified but requires extensive knowledge to modify	Open source. Code can be modified but requires extensive knowledge to modify. Also, scripting language is provided to increase flexibility
User Interface/Display	Make use of Cube environment powerful interface	Original User interface is not high quality. High quality interface is commercially available	User interface is difficult to use. Tools have been recently developed by Argonne National Lab that provide powerful visualization
Shortest Path and Path Choice			
Generalized Cost in Assignment	Can be specified to include various variables using scripting language	Allow travel time and toll. SHRP 2 version also allows reliability to be included	Based on travel time, cost, and distance
Assignment Type	UE. Non-iterative assignment can also be used for all or part of the demands	UE. Non-iterative assignment can also be used for all or part of the demands	UE. Non-iterative assignment can also be used for all or part of the demands

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[1] http://computer.howstuffworks.com/moores-law.htm

[2] All are likely to change within the next few years.

Table 5-9 Summary of the Results of Utilizing the Assessment Methodology of this Study (Continued)

En-route Dynamic Routing (e.g., Dynamic Navigation System)	No	Yes	No
Link Access Restrictions/Prohibitions by Vehicle Type	Yes	Yes	Yes
Specification of Fine-Grained Assignment Interval (e.g., 15-30 minutes)	Yes	Yes	Yes
UE Assignment Method	MSA (both PA and PS)	MSA and recently introduced GFV-based method that performs significantly better	Use different heuristic assignments. However, different methods than those provided can be coded including MSA or other advanced assignment
Allows Fixing Paths for Parts of the Demands	Yes	Yes	Yes
Convergence Criteria	Link based	Trip based	The default link-based. However, the user has flexibility in defining in defining other link or trip gaps
Outputting and Using Interval-based Convergence Gap	Utilized gap is for the whole iteration rather than each interval. Individual interval gaps are not reported	Utilized gap is for the whole iteration rather than each interval. Individual interval gaps are not reported	Utilized gap is for the whole iteration rather than each interval. However, individual interval gaps are reported in the output
Modeling DMS/HAR	May be able to trick model to approximate using multiple runs	Yes. Model DMS/HAR	May be able to trick model to approximate using multiple runs
Modeling Ramp Metering	No. May be approximated by modifying capacity and utilizing analytic models	Yes, time-of-day and traffic responsive	Yes, time of day.

Table 5-9 Summary of the Results of Utilizing the Assessment Methodology of this Study (Continued)

Modeling Managed Lanes and Reversed Lanes	Possible	Possible	Possible
Dynamic Congestion Pricing	No. Can be modeled combined with a logit model and toll curve	Yes	No. Can be modeled combined with a logit model and toll curve
Modeling Variable Speed Limits	No. It may be possible to approximate it using BPR model parameters	Yes	No
Traffic Flow Model			
Model Type	Mesoscopic	Mesoscopic	Macroscopic (if analytic function such as BPR is used) or low-fidelity microscopic simulation (if the simulator is combined with the router)
Queuing	Model queuing and spillback. Link-based (rather than lane-based) queuing	Model queuing and spillback. Link-based (rather than lane-based) queuing. Queue lengths are not reported in the current version	Model queuing and spillback. Lane-based queuing
All demands are modeled	Yes	Yes	In some cases, when all the downstream cells on the link are occupied, a warning message is generated, and vehicles are deleted.
Modeling incidents and work zones	Yes	Yes	Yes
Automatic Calculation of Signal Timing	Yes	Yes	Yes

Table 5-9 Summary of the Results of Utilizing the Assessment Methodology of this Study (Continued)

Explicitly Modeling of Signal Coordination	No. However, the effect of coordination may be approximated by using a progression factor in the HCM signalized delay formula used by the model	Yes. Offsets can be specified.	Yes. Offsets can be specified
Lane-by-Lane Simulation	No	No	Yes
Merging/Weaving Simulation	No	No	No
Modeling Turn Lane Length	No	No	Yes
Network Demand			
Person-Based	No	Yes	Yes
Feedback to Activity models	No	Yes	Yes
Demand as Activity List	No	Yes	Yes
Traveler Groups	Allows the specification of up to 20 different types of demand matrices	Allows the coding of only three types of demand matrices. To code more user types, the user can use trip rosters (individual travel records)	TRANSIMS allows coding ten different types of vehicles. Unlimited number of traveler types can be coded.
Transit Modeling			
Integrating static transit methods in Cube Voyager with DTA	Yes	Yes, if integrated with Cube	Yes, if integrated with Cube
Dynamic Transit Assignment[3]	No	Being integrated with FAST-TrIPS (see Chapter 2 discussion of DynusT	Yes

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[3] When transit is modeled, needed for feedback to activity models

6. Development of an Environment to Support Advanced Assignment

6.1 Introduction

When examining user needs and the criteria developed in this study based on these needs, it became clear that there is a need to develop tools that support the development and calibration of DTA applications. There is a need to support dynamic (time-variant) trip matrix estimation at a fine-grained resolution (15-30 minutes) based on available trip matrices from demand forecasting models and count data. In addition, there is a need to support the model calibration process, in which adjustments are made to global and local parameters related to capacity, demands, assignment, and traffic flow model parameters to produce link capacities/throughputs, travel times/speeds, volumes, density, queue lengths, and other measures comparable to those observed in the real-world. The supporting tool mentioned above should be able to import and use data from multiple sources as needed, as long as the data is coded in standard formats to support model development and calibration.

6.2 Integrated System Support for Trip Assignment (ISSTA)

A support environment referred to as Integrated System Support for Trip Assignment (ISSTA) satisfies the identified need of calibration and development support mentioned above. The environment allows the use of data from multiple sources, different developed and existing tools, and existing techniques to support static or dynamic trip assignment. An overall view of the tool is shown in Figure 6-1. It should be mentioned that this environment was developed as a basis for further developments and was not meant to satisfy all the needs for support tools but some important ones. In future efforts, additional processes, methods, tools, and data sources can be incorporated into the environment.

Figure 6-2 presents an overview of the ISSTA modules. A discussion of these ISSTA modules is presented in the remaining sections of this document.
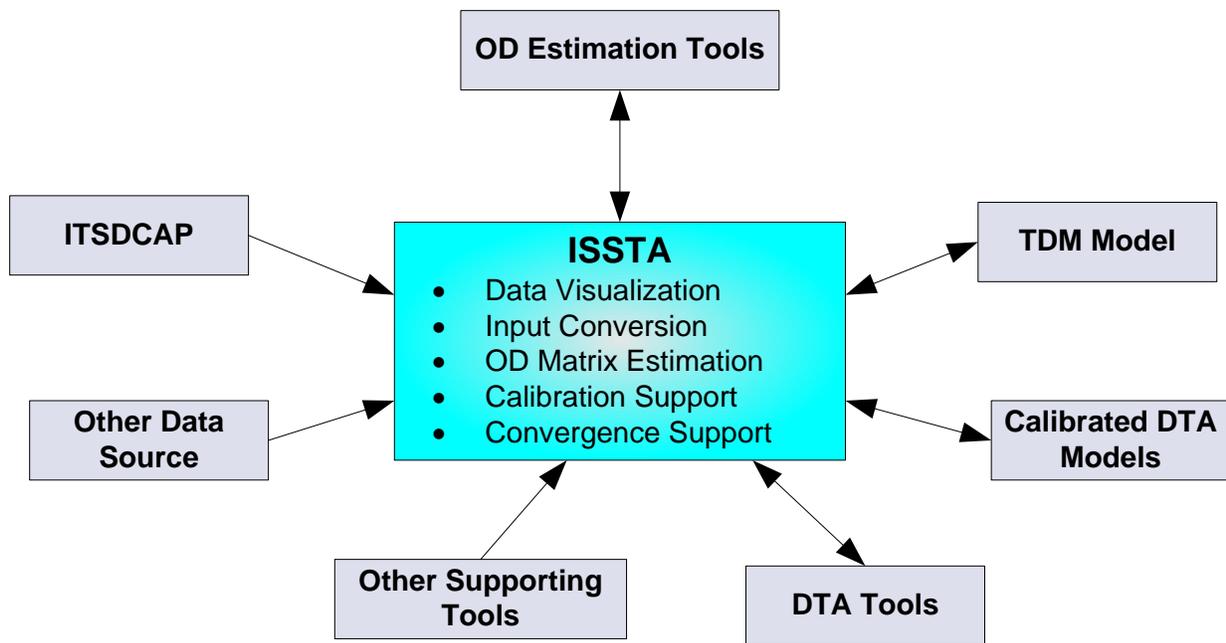
Figure 6-1 ISSTA environment interfaces
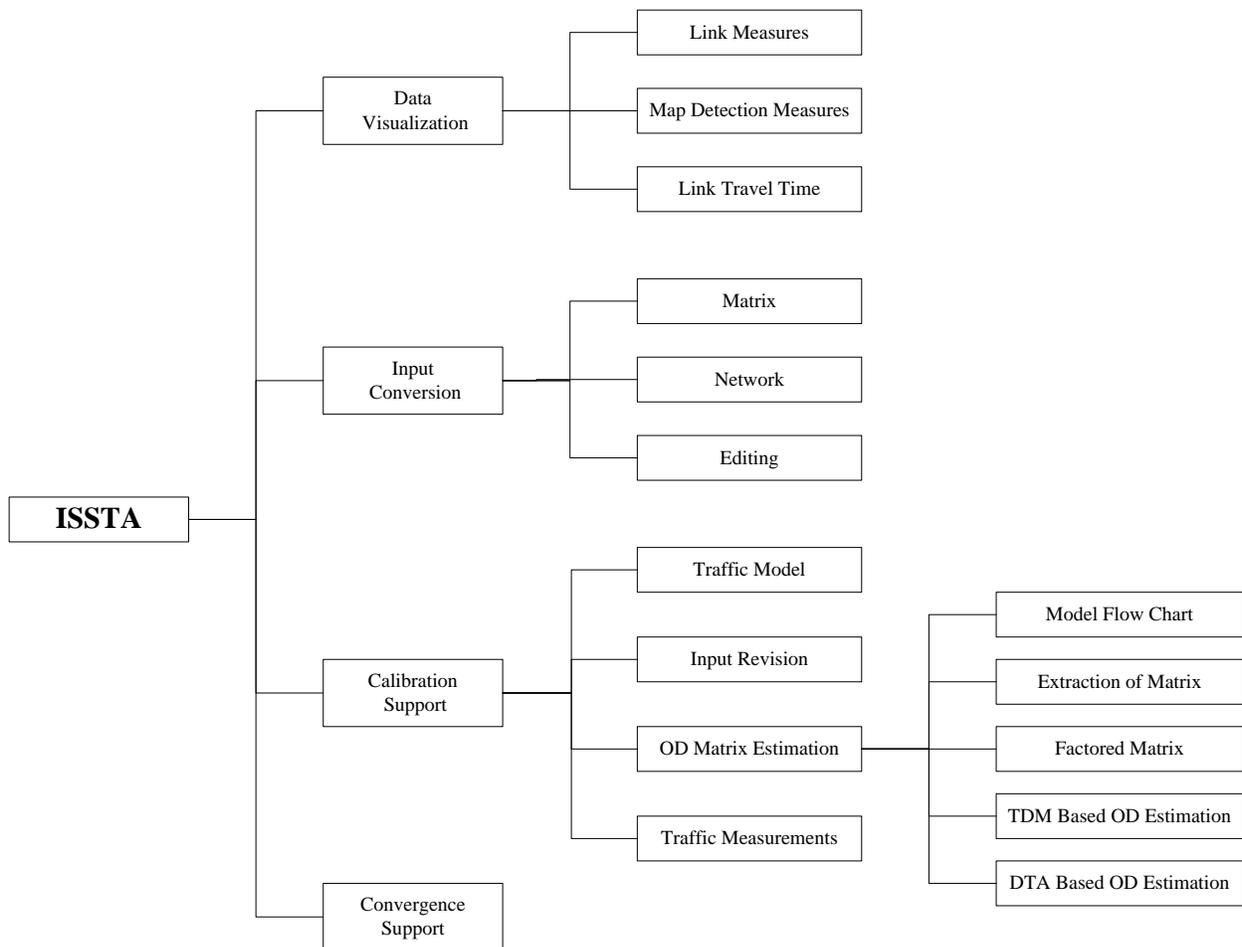
Figure 6-2 ISSTA environment modules

6.3 Visualization

The purpose of using the visualization module is to integrate required data from different sources with the ISSTA environment, associate the data with the subject network, and visualize the data to have an overall feeling of different performance measures of the network operations. The imported data includes data collected by or calculated based on traffic detector data such as traffic flow, speed, density, travel time, classification, and queue measures. These measurements are collected and archived by traffic management centers utilizing their ITS system point detectors and the FDOT statistics office detectors. The data that are currently imported to the environment also include data offered by a private sector provider (Inrix). Other sources of data could also be used, such as turning movement counts and tube counts, if they are coded in a

standard format. In the future, other data such as freight and transit automatic vehicle location (AVL) data could be imported to this environment.

As shown in Figure 8-1, ISSTA interfaces with the Intelligent Transportation Systems Data Capture and Performance Management (ITSDCAP) developed for FDOT by FIU. ITSDCAP captures data from multiple sources including ITS detector data, statistics office data, and Inrix data, and outputs them to text files to be read by other tools including ISSTA. Data from sources other than ISSTA can also be imported, if they are in the required format, as specified in Appendix A.

ISSTA associates the traffic data mentioned above with the assignment network links. This allows the visualization of the network performance measures based on real-world data, along with the visualization of the assignment tool outputs, which is important to the calibration of assignment applications. Traffic point detector data can be used to visualize link volumes, speed and density for different time intervals together with simulated network output. The user interface to import and visualize link measures is shown in Figure 6-3 and the output of the network in Figure 6-4.
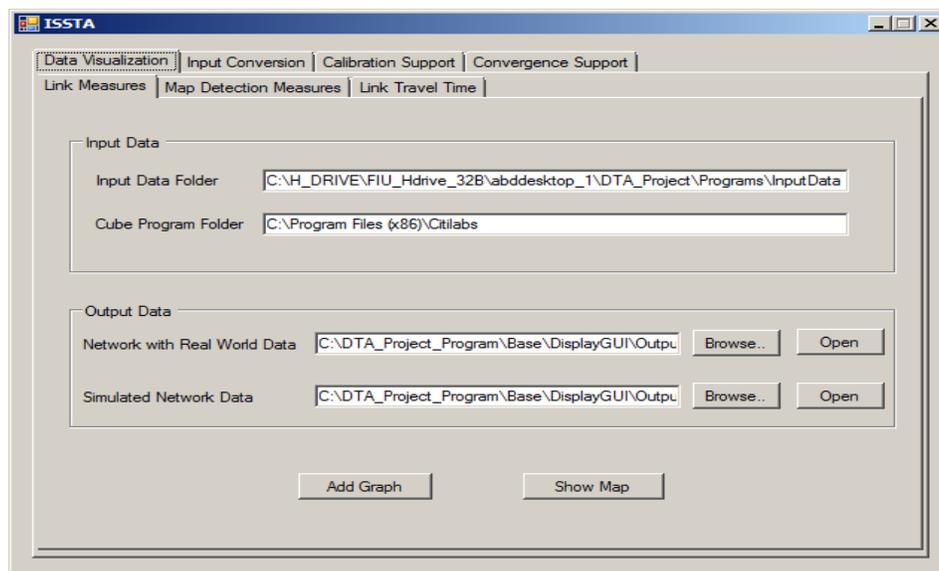
Figure 6-3 Interface to request the visualization of data
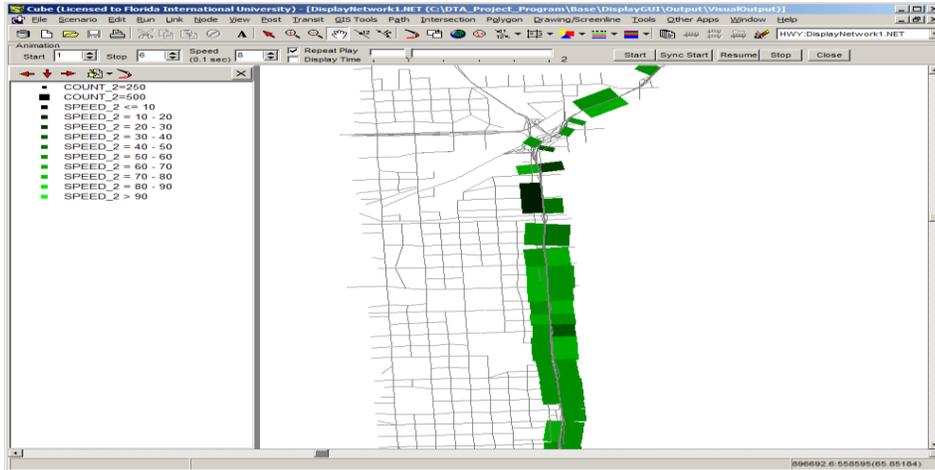
Figure 6-4 Visualization of link measures

The user can visualize the variations of volume, speed and density by time of day at each individual detector point using the "Map Detector Measures" tab of the program (Figure 6-5). This helps to evaluate the traffic patterns in the network.
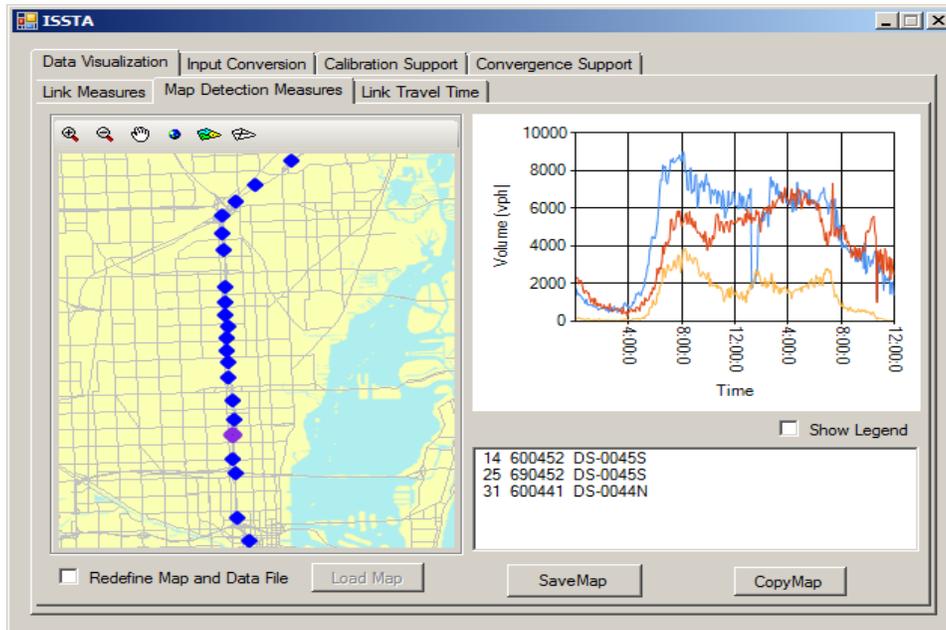
Figure 6-5 Variations of measures by time of day at each individual detector point

The travel times, estimated based on either point detector or Inrix data, can also be visualized for the links either by themselves or in comparison to the assignment tool outputs, as shown in

Figure 6-6 and Figure 6-7. As seen in Figure 6-7, the modeler has the opportunity to visualize and compare link travel times, which are obtained from different real-world data sources and/or simulation tools.
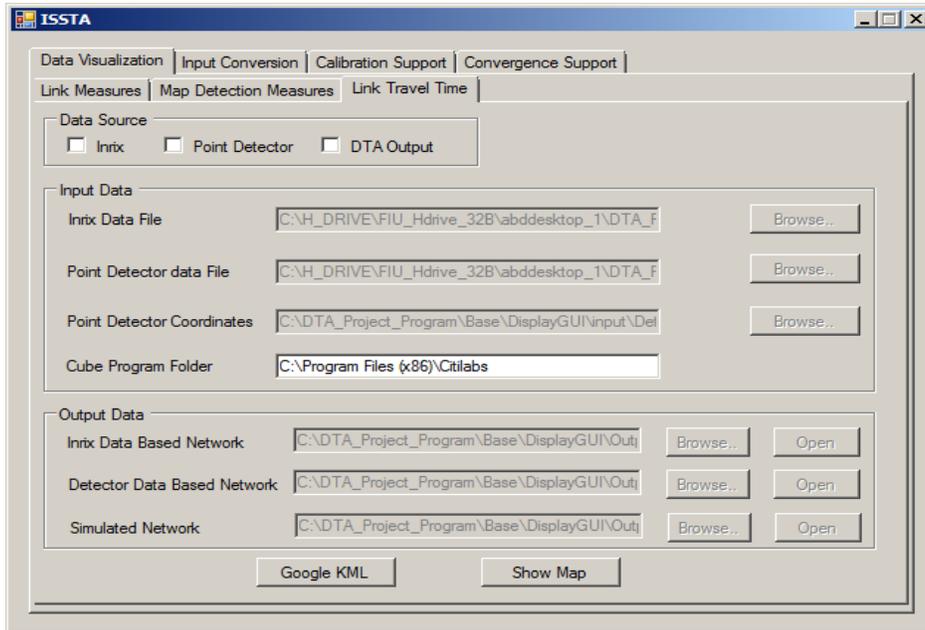
Figure 6-6 Interface to request link travel time
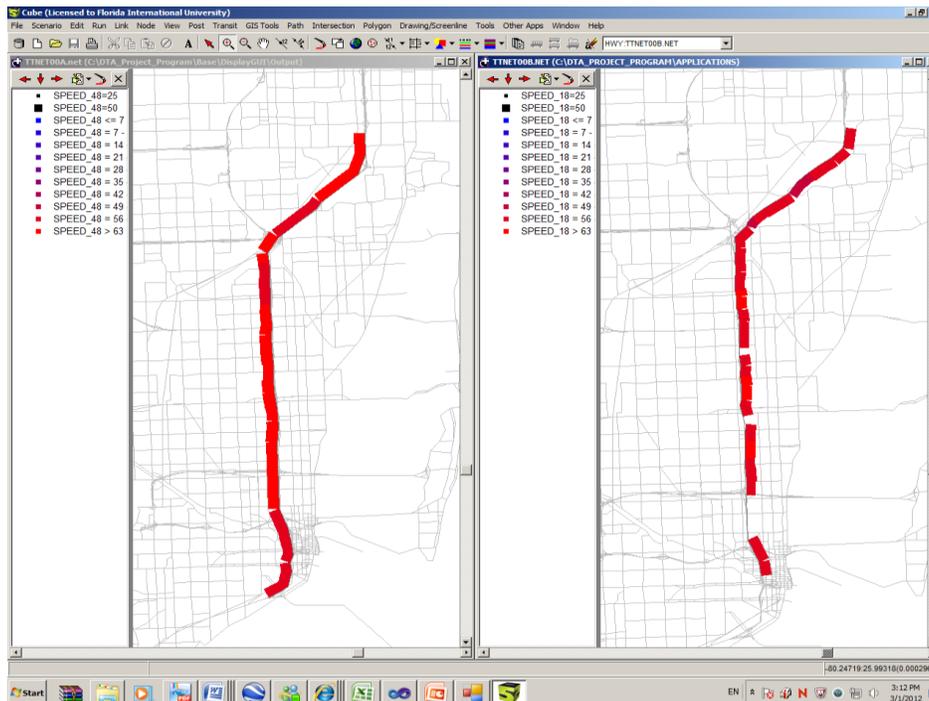
Figure 6-7 Output of link travel time visualization

6.4 Conversion to other DTA Tool's Inputs

The input conversion module of ISSTA is meant to convert the Cube Voyager inputs to other DTA tool formats, if required by the user. At this stage, the only conversion available is that of the DynusT network. However, in future versions, conversion to other tool inputs can be supported. The input network and demand matrices will be converted to create a preliminary input to the DTA tool. The modelers should perform editing of the resulting network and input other parameters to allow the running of the DTA tool. The conversion from Cube to DynusT is based on a procedure developed in a previous FDOT research center project and the details can be found in the final report (Hadi et al. 2010).

6.5 Calibration Support

The "Calibration Support" module is designed to support the user in examining the results of the DTA tool, compare the results with real-world data, and fine-tune model parameters to improve the results produced by the tool for the modeled system. Calibration of DTA tools is a complex process that will be examined in further detail as part of the FDOT project "Application of Dynamic Traffic Assignment to Advanced Managed Lane Modeling." In the current project, basic tools that support the calibration processes are developed.

Calibration requires the estimation of both supply and demand parameters and addressing these parameters jointly is a challenging task and is still an area in need of research. Supply calibration involves estimating the segment's capacity, free-flow speeds, and traffic flow model (TFM) parameters assuming that the time-variant demand is acceptable. In this project, the addressed demand type is trip-based (O-D) demand. In the future, activity-based demands could be addressed. Thus, in this study, demand calibration refers to O-D estimation. In the case of DTA, dynamic (time-variant) O-D matrix estimation will be needed based on a seed initial matrix and traffic data (such as traffic counts). To account for interactions between supply and demand calibrations, there may be a need for joint supply-demand calibration until it converges to an acceptable solution. This issue has not been sufficiently addressed in the literature and most DTA applications treat these two calibration components separately.

The current version of ISSTA includes five components including traffic flow model, input revision (network parameter setting), O-D matrix estimation and traffic measurement. The remaining subsections discuss these modules.

6.5.1 Traffic Flow Model Calibration

The traffic flow module estimates traffic model function parameters. It allows the user to input the format of the traffic flow model used in the DTA tool, changing the parameters of the model, determining how they fit real-world data, and utilizing real-world data to fit the model parameters. Currently, three types of models are supported: the Modified Greenshields model (used in DynusT), the BPR Curve (used in most FSUTMS models) and the Akcelik Formula (used in some demand models). The user interface of this module is shown in Figure 6-8.
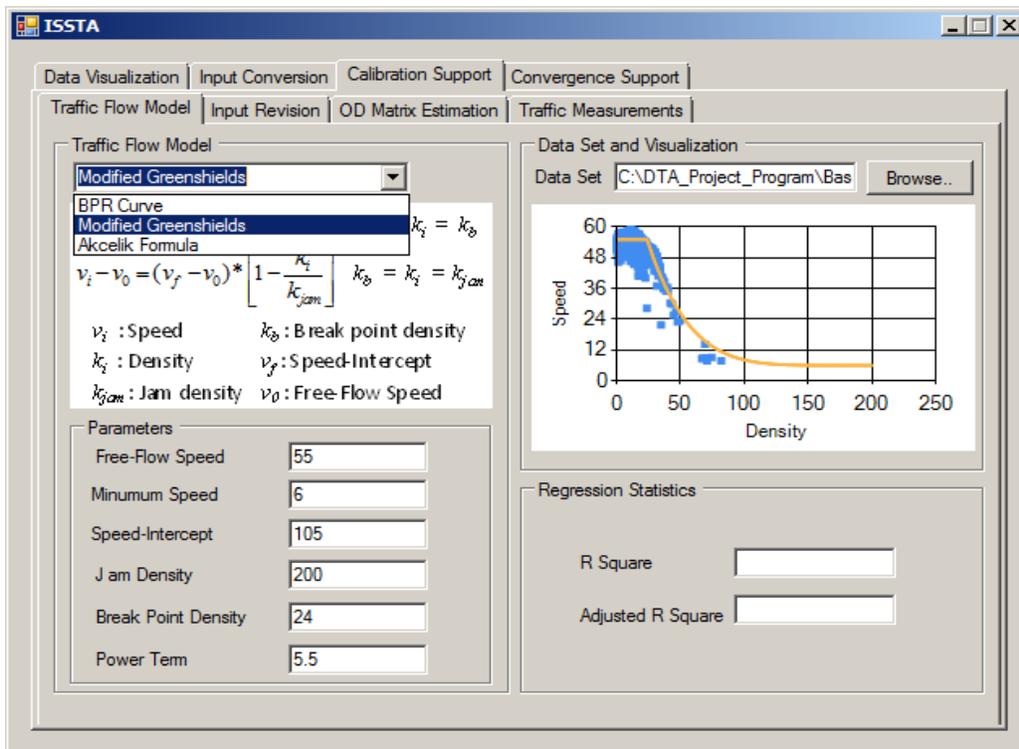
Figure 6-8 Module for calibration support of traffic flow model

The model parameters should be calibrated for selected data sets based on real-world data representing bottleneck locations in the network; however, the default parameters could be used, if sufficient data is not available.

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The calibration can be done based on the data collected from ITS detectors. To perform the analysis, there is a need to first identify the appropriate location(s) for which the model will be calibrated. This is an important step that needs careful and detailed analysis to ensure that the variation of the flow at a selected location covers all levels of flow, from light to very congested conditions, that the congestion is not caused by a downstream link, and that the congestion is not a result of unusual conditions which impact capacity and speed (such as bad weather, incidents, and construction). Another criterion is that the section should have a maximum throughput close to the HCM capacity, which corresponds to the free-flow speed of the segment. The free-flow speed for the segment can also be determined based on ITS or INRIX data.

6.5.2 Network Parameter Setting

Network parameter setting refers to the revision of network input parameters including capacities and free-flow speeds. The current version of ISSTA requires the user to calculate these parameters utilizing external tools and inputting them in the input revision section. Figure 6-9 presents the user interface allowing the input revision of network parameters. Capacity and free-flow speeds can be calculated utilizing the Highway Capacity Manual (HCM, 2010) procedures. However, real-world data such as those obtained from ITS devices can be used to estimate these parameters. The ITSDCAP mentioned earlier can be used for this purpose.
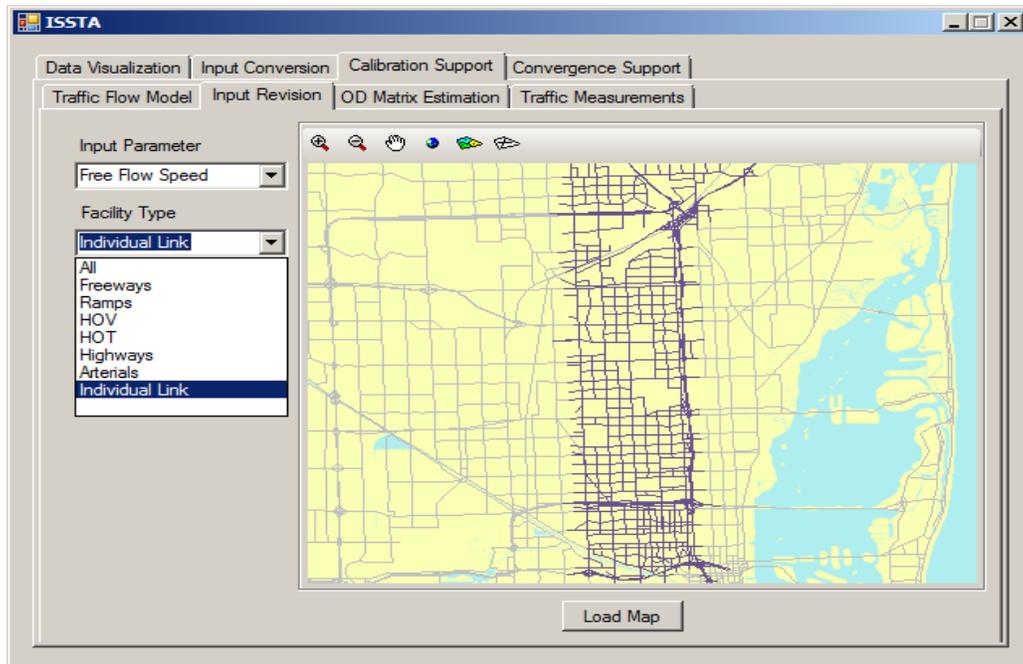
Figure 6-9 User interface of network parameter setting (input revision)

6.5.3   O-D Matrix Estimation

The time-variant O-D matrix estimation is an important step in the assignment process. The flow chart of the O-D estimation process in ISSTA is shown in Figure 6-10. The flow chart is included in the user interface of ISSTA.
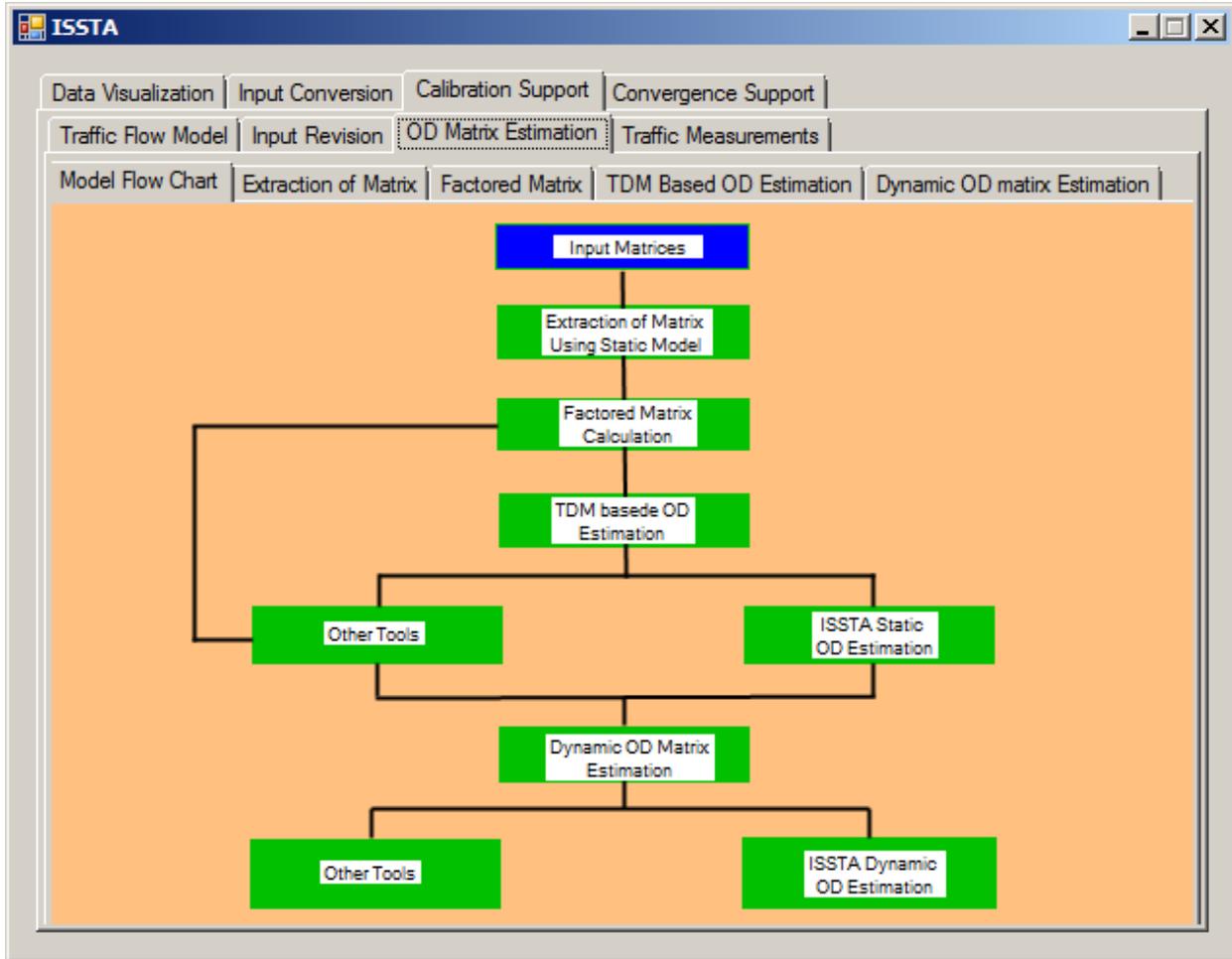
Figure 6-10 O-D matrix estimation flow chart

As shown in Figure 6-10, the O-D matrix estimation process includes initial matrix extraction, factored matrix calculation, static (traffic demand model or TDM-based) estimation, and dynamic O-D matrix estimation. Tools were developed by this study to estimate the O-D matrices based on static assignment (referred to as TDM-based in ISSTA) and dynamic assignment. However, tools from other sources (if available) may also be incorporated.

ISSTA allows a multi-step procedure for matrix extraction and estimation. The analyst may choose to conduct one or all of these steps, with the resulting time-variant matrices expected to improve as additional steps are conducted. The first step is to extract a subarea network from the regional model. Next, the daily matrices or peak-period matrices are converted to 15 min., 30 min., or hourly matrices using time-of-day distribution factors which reflect the proportion of the

trip tables for each time interval. Next, these matrices are adjusted using an O-D matrix estimation procedure that is based on static traffic assignment. Finally, an optimization procedure is used to derive the time-variant trip matrices based on minimizing the differences between the measured volumes and the volumes produced by the DTA, with consideration to initial trip tables resulting from any of the previous steps mentioned above. More details about this procedure are presented in the remaining parts of this section.

O-D Matrix Extraction

Factored calculation matrix calculation is that initial input matrix divided into period based matrix based on each period factor that calculated based on traffic counts.

 The O-D matrix estimation process starts with the extraction of an initial matrix from the static model utilizing the Cube Voyager subarea matrix extraction program. Figure 6-11 shows the user interface of the O-D matrix estimation process. The boundary of the subarea network of interest must be specified first. The subarea boundary can be specified using the Cube Voyager polygon feature or using a GIS tool. Cube can then be used to extract the subarea network from the statewide model network using this predefined subarea boundary. The result of this extraction is a subarea network with new node and zone numbers, which are different from the original numbers. Cube stores the association between the old numbers (in the whole network) and the numbers in the new network (in the subtracted network) in two new node features in the subtracted network. These two features are OLD_NODE and SUB_TYPE. The OLD_NODE attribute gives the old node number used in the whole network representation. The SUB_TYPE can have one of four values as explained below:
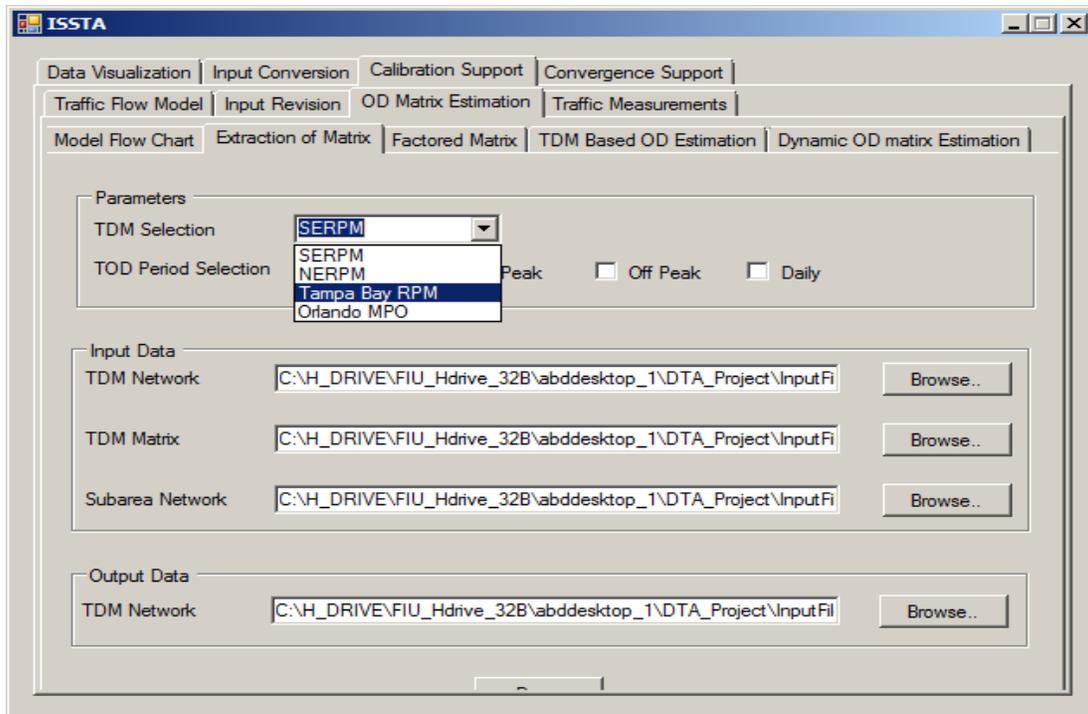
Figure 6-11 User Interface of the O D matrix extraction module

Matrix Factorization

A step that could be conducted in the fine-grained matrix estimation process is to factorize the daily trip matrices or peak-period matrices produced by the demand forecasting models to 15-60 minute trip tables based on time-of-day distribution factors. The factors in this study can be calculated based on traffic counts obtained from the Statistical Bureau TTMS (permanent) count stations and/or ITS detectors or from the factors obtained from FDOT studies to support time-of-day modeling based on travel surveys. In any case, these factors need to be supplied by the user as inputs to ISSTA. The resulting matrices can be used as inputs to assignment models or additional processing of the matrices. However, the analysts may want to conduct additional processing to optimize the O-D matrices based on how close the resulting assigned volumes are to the observed volumes considering the initial seed matrices. This can be based on static or dynamic assignment, as discussed next. Please note that if the analyst is conducting O-D estimation based on static or dynamic assignment, matrix factorizing is not necessary. Further research is needed to determine if the factorization is useful in these cases.

Static O-D Matrix Estimation

As stated earlier, the static or TDM-based O-D matrix estimation processes can be performed using a tool produced in this project or other tools (such as the Cube Analyst tool provided by Citilabs). This section discusses the tool produced in this project referred to as the Matrix Estimation (ME) and made to work with Cube network in this study, as described in this section. Cube Analyst2 that can implement the static O-D matrix estimation for the large-scaled highway network without converting trip matrices and path files to the TRANPLAN format. Software from other vendors could also be used.

The Matrix Estimation was an element of the software suite used for the development of the Turnpike State Model project for the Turnpike Enterprise, Florida Department of Transportation. Jim Fennessy of Fennessy Associates, sub-consultant to URS Corporation, developed the Matrix Estimation (ME) program specifically for that project. The specifications for ME were defined by the Project Team members: Mike Doherty, URS Corporation; Youssef Dehghani, Parsons Brinkerhoff; and Tom Adler, Resource Systems Group.

ME reads an initial, or seeded, trip matrix from which to modify based upon an iterative process of evaluating the ratios of assigned trips to counts on links with counts, the modification of the O-D trips, and the reassignment of the modified trip matrix until the user-specified number of passes is reached. ME contains a feature which permits the restart of the program, should the user wish to do so. ME also reads in an initial or iteratively generated highway loaded network to get the link loadings and counts. Also required as input are the minimum path files, one per iteration, which are generated during the equilibrium highway loading.

The user specifies the number of iterative passes for the ME program and can also specify weights by facility type or by specific links. Also, the user can specify the minimum link count for links to be utilized in the analysis.

ME writes a file containing the details of each link for each pass and summary statistics, including RMSE and other program statistics. ME also writes the summary statistics on a

separate file – for ease of reference. The detail and summary information is also written to comma-delimited file for input to other analysis software.

The creation of a new trip table is an iterative process a highway assignment is run and the output loaded highway network is input to the ME program along with a seed matrix to generate a new trip table; this trip table is input to a subsequent highway assignment and a new output loaded highway network input to the ME program with the new trip table; and this process is continued until a statistically acceptable trip table and assignment is generated.

For the current project, Jim Fennessy developed a standalone program, VOY_CONV, to convert CUBE Voyager trip matrices to the TRANPLAN format and to convert the Voyager highway network assignment path files to the path count format utilized by the ME program. The Voyager path files from the assignment contain information not required by the ME program and are extremely large compared to the path count file format. The flow chart of the static O-D estimation module is shown in Figure 6-12. The technical details of static O-D matrix estimation are presented in Appendix A.
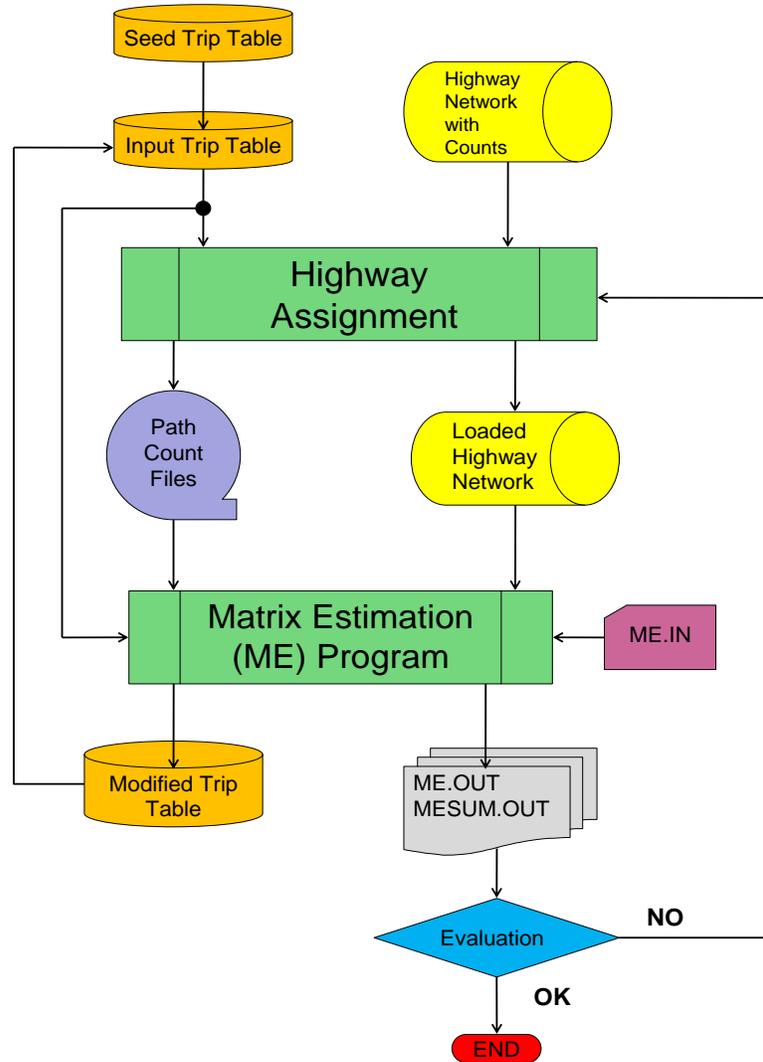
Figure 6-12 Static O-D estimation procedure

Dynamic O-D Matrix Estimation

As with the static O-D matrix estimation processes described above, dynamic traffic assignment can be performed using a tool produced in this project or other tools that may be available from other sources. This section discusses the tool produced based on work originally conducted at FIU and later modified and programmed by Citilabs.

The dynamic Origin-Destination Matrix Estimation (ODME) process can be implemented with the Cube Avenue program that allows dynamic traffic assignment to enable the prediction of

time-varying costs and flows. It utilizes general input data files such as route choice probability matrix, O-D matrix, and screenline counts. As major input data, the simulated routes can be identified from the packet log file that is generated from the Avenue as an output log file containing simulated packet movements. The dynamic ODME model is solved by a mathematic optimization method as described in the following sections.

As part of the DTA project, the dynamic ODME procedure has been developed using a data assimilation type O-D estimation model that solves a quadratic optimization problem to carry out the matrix estimation procedure.

The optimization problem is given by:

$$\min \quad (AX - b)^T(AX - b) + \omega(X - X_0)^T(X - X_0)$$

subject to $X \geq 0$

where A is the route choice probability matrix, the design variable X is the O-D matrix, X0 is the initial X matrix, and b is a vector of observed counts.

The matrix product AX gives the simulated volume. The boundary constraints are treated with a hybrid penalty / reduced gradient method. In this manner, penalty terms are added to create an augmented cost function:

$$L(X) = (AX - b)^T(AX - b) + \omega(X - X_0)^T(X - X_0) + \beta B^T B$$

where β is a scaling factor and B gives a discrete boundary penalty function of the form:

$$B(i) = \begin{cases} (X(i)_{lower} - X(i)) & \text{if } X(i) < X(i)_{lower} \\ (X(i) - X(i)_{upper}) & \text{if } X(i) > X(i)_{upper} \\ 0 \text{ otherwise} \end{cases}$$

A direct gradient is computed from the augmented cost function L by using a discrete positional derivative for the individual elements of B. The upper level code completes the minimization of L by employing a gradient descent algorithm.

$$X^{k+1} = X^k - \alpha^k G$$

where α is the computed step length and G is the computed gradient. The algorithm uses sparse matrix routines and a quadratic minimization sub-problem to determine the optimal step length α, producing a reasonably fast and efficient optimization program.

As shown in Figure 6-12, the dynamic ODME procedure is described as follows: Cube Avenue assigns the O-D trips into highway network based on a dynamic traffic assignment, and generates packet log file. The route choice probability matrix A is extracted from the packet log.

The technical details of the program are included in Figure 6-13. The dynamic O-D matrix estimation is implemented with the appropriate input data. As shown in Figure 6-12, if the objective function value is reduced, the program iterates to Step 1 (Avenue Simulation). If the objective function value is increased, the program iterates to Step 3 (O-D estimation) after increasing the weight factors. If converged, the estimation process stops.
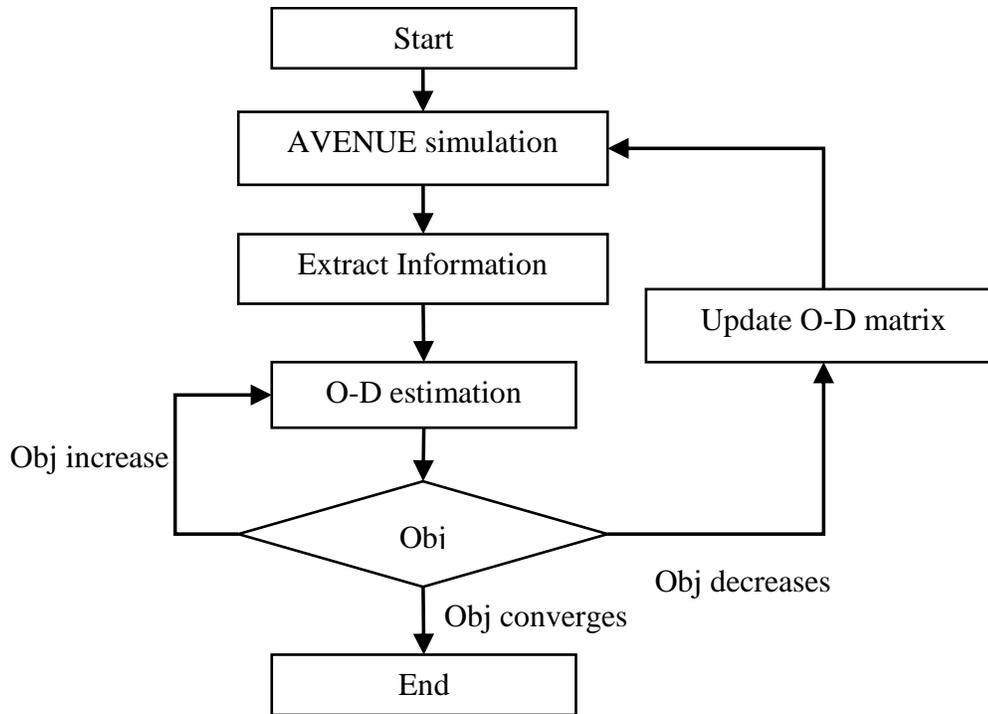
Figure 6-13 Dynamic O-D estimation procedure

6.6   Performance Measure Comparisons

The "Traffic Measures" module accessed from the "Calibration Support" tab provides a tool for comparing traffic performance measures, based on real-world data and simulation results. The visualization and statistical measures output from the module allow the identification of overestimation/underestimation, underutilized versus over-utilized paths, and inaccurate estimation of demand profiles (time-of departure), based on visual examination of time-series plots of link and path measures such as volume and travel time.

To accomplish this, the module produces time-series plots of link and path measures, such as volume, travel time, and density from both the real world and simulation. The module also produces time-series plots of the number of vehicles in the network by user group, at each simulation interval. In addition, the tools provide time-series plots of the number of vehicles waiting to enter the network by user group at each simulation interval and origin zone. The module also provides time-series plots of time-varying, spatially averaged network speed. In

addition, the module produces speed and density spatial-temporal contour maps for both real-world and simulated network.

Figure 6-14presents comparison of observed and estimated volumes on 45 degree graph and also some statistical measures like mean absolute error and root mean squared error given at the bottom. Selected route observed and simulated speed counter plot is depicted in Figure 6-15.
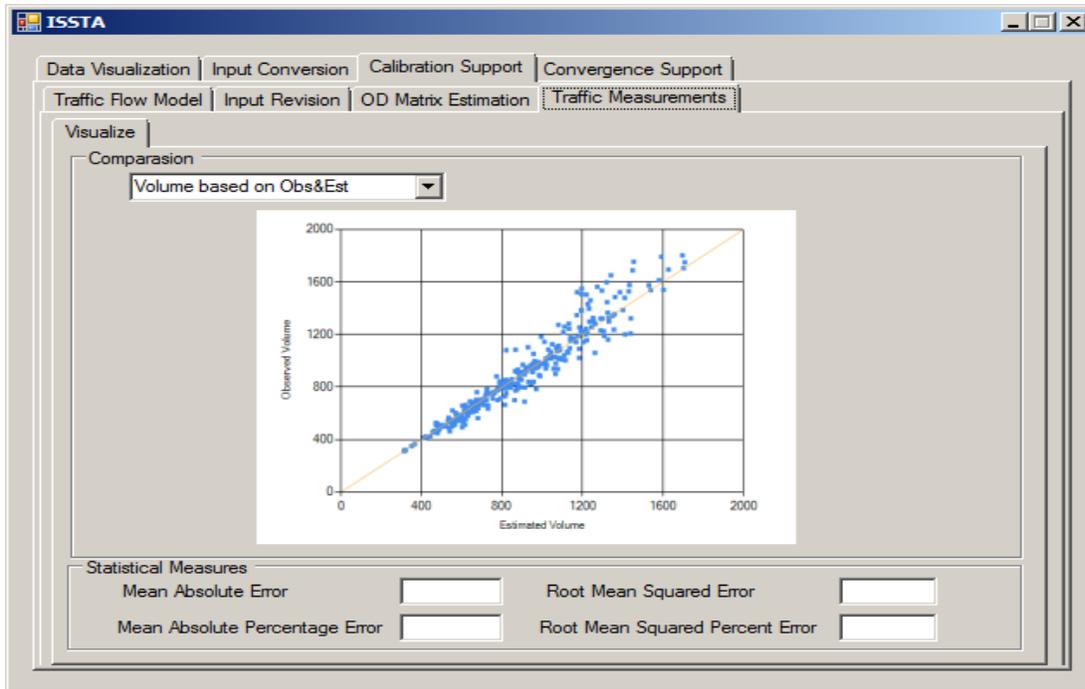
Figure 6-14 The traffic measurements user interface for comparison of observed and simulated volume comparison
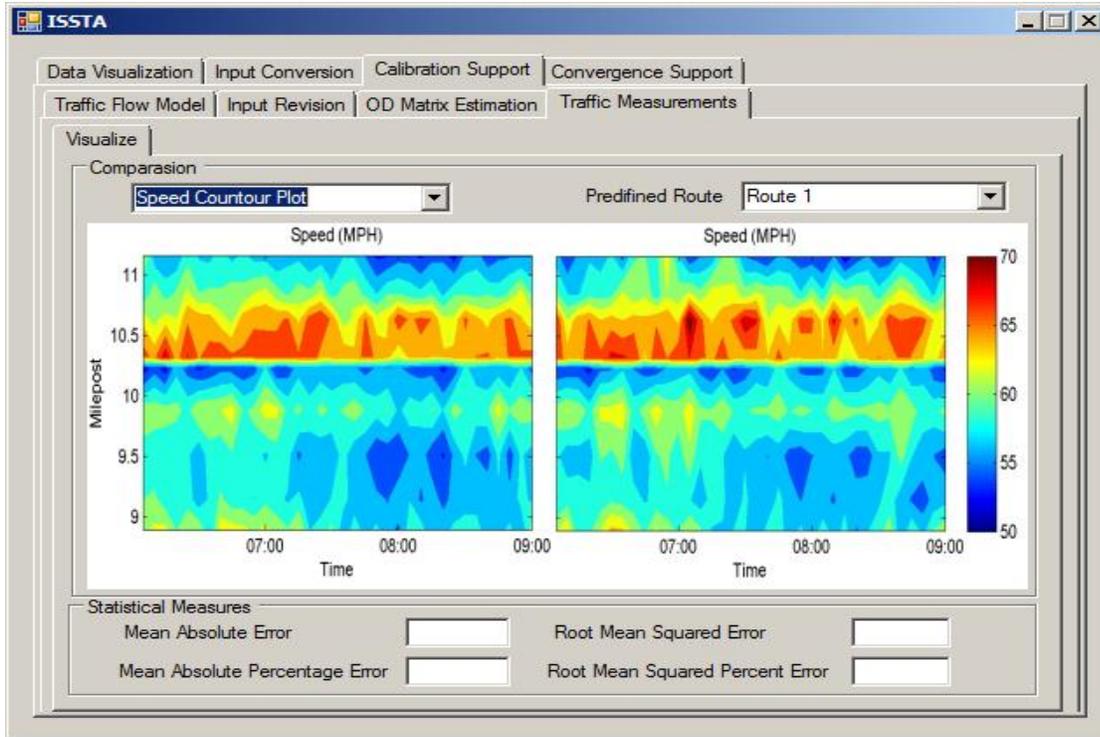
Figure 6-15 Example of speed counter plot comparison between real-world and observed speed counters output by ISSTA

In addition to visualization, the module calculates statistical measures to assess the degrees of deviation between the model estimates and real-world measurements for each time interval for a link or path. Examples of the calculated measures include the mean error (ME), mean absolute error (MAE), mean percentage error (MPE), and mean absolute percentage error (MAPE). These performance measures are defined as follows:

$$ME = \frac{1}{N}\sum_t \left(TT_t - TT_{t,a}\right) \tag{6-1}$$

$$MAE = \frac{1}{N}\sum_t \left|TT_t - TT_{t,a}\right| \tag{6-2}$$

$$MPE = 100\frac{1}{N}\sum_t \frac{\left(TT_t - TT_{t,a}\right)}{t_{t,a}} \tag{6-3}$$

$$MAPE = 100\frac{1}{N}\sum_t \frac{\left|TT_t - TT_{t,a}\right|}{t_{t,a}} \tag{6-4}$$

where, TT_t is the estimated travel time at time interval t, and $TT_{t,a}$ is the corresponding real world travel time estimated based on ground truth data. N is the total number of the time intervals.

Each of the error types in Equations 6-1 to 6-4 provides a different aspect of the error and thus accuracy of the travel time. The sign and magnitude of the ME and MPE can be used to assess the measurement bias (i.e., measured values are consistently less than or greater than the ground truth value). However, the magnitude of these errors cannot be used to assess the magnitude of the error since positive and negative error values cancel each other when averaged. This averaging may indicate low error even when the error is high. The absolute values of the error reflected by the MAE and MAPE measures can be used to assess the magnitude of error. Another measure that will also be used is the proportion of the overestimates and underestimates of the total estimates.

6.7   Convergence support

This module is expected to be developed as part of future efforts. It is currently included in ISSTA as a place holder. Its purpose will be to ensure the convergence of the network to ensure stability, consistency, and proportionality.

7.   Conclusions and Recommendations

This section presents the main findings of this study based on the results presented in Chapters 2 to 6.   In addition, recommendations are presented regarding DTA implementations in Florida.

7.1   Conclusions

It is clear from the results of the activities of this project that DTA is maturing and can play a major rule in demand and performance forecasting. DTA can also be applied as part of a multi-resolution analysis of transportation systems.

For successful implementations of DTA, a number of issues have to be addressed, as confirmed by the user survey and workshop conducted in this study. The main technical and institutional constraints to DTA applications identified by the modeling community in Florida include the lack of data (36% of responses to the users surveyed), lack of experience (24%), calibration and validation requirements (22%), computational time (21%), estimation of parameters for future years (21%), complexity of process (18%), need for training (15%), and cost of software (11%). The most needed supports by the modeling community were specified as the provision of training (25%), standards/guidelines (15%), case studies (13%), assistance in DTA tool selection (13%), long-term support (13%), knowledge center (11%), and peer review (8%).

Interviews with the users of three DTA tools (TRANSIMS, DynusT, and Cube Avenue) revealed that the experience with real-world applications is still limited, although agencies are increasingly considering and willing to invest in the use of DTA tools for the assessment of recurrent, incident, and evacuation conditions.   These agencies recognize the abilities of DTA to provide time-variant measures not available from static demand models (such as queues, delays, and bottleneck locations) and the ability to model advanced management strategies such as pricing, managed lanes, and ITS. Only few applications were identified where DTA has been applied or are being attempted to be applied on a regional scale, and some modelers found difficulty when applying specific tools to large size networks. Thus, the analyst should be mindful of the amount of effort required for such an exercise and in the selection of the DTA

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platform for regional applications. It is anticipated that in the next two to three years, results from few large scale and regional applications of DTA will become available, providing additional insights on the applications of DTA to large scale applications.

Interviews with DTA users confirmed the benefits and issues with DTA. It appears that most of the issues related to converting to DTA involve the greater level of network and demand details required for DTA in general and are not associated with particular software packages. Another finding is that the ability of tools to simulate the interaction between queues of different movements on the same link and the spillback to above links are critical to DTA analysis and need to be considered when selecting the DTA tools. Coding the additional details of the network for DTA tools is time consuming. An important finding from the interviews of DTA users conducted in this study is that coding good signal timing plans that ensure realistic coordination between adjacent signals is important (though time consuming) and that in many cases the simple plans calculated internally by the tools are not adequate to provide good results. It should be recognized that the interviews present a snapshot at a particular point in time. All of the packages are evolving including the commercial packages. It appears that all three tools addressed in the interviews have been improving as new releases come to the market.

When comparing open source tools like DynusT and TRANSIMS versus commercially available tools. General statements may be possible regarding three different dimensions:

a. Stability and Usability – the commercial packages are easiest to use and are the most stable since, in general, they perform sufficient testing of their new features. The new features are better documented in these tools and the technical user support is more adequate. Commercial packages also provide reliable technical support.

b. Flexibility and Openness– The open source packages have the most flexibility. The user can make modifications or even modify the code (although this is generally extremely difficult for a normal user). Similarly to commercial packages, , it is sometime difficult to find out how the algorithms work.

c. Capability – The open source packages have greater capabilities, particularly when it comes to transit and to person based simulation. This is a result of considerable investment in these packages by the USDOT and the TRB SHRP2 program in the past 20 years.

The review of DTA research and documentation available about DTA methods and tools revealed that these tools and methods vary considerably in their implementation of DTA components including the determination of time-dependent shortest path (TDSP), assigning traffic to these paths, loading the traffic to the network and assessing performance, and assuring convergence of the solution.

The TDSP component is important particularly due to its impacts on computational time and memory efficiency of the DTA tool. Some newer implementations of TDSP utilize more efficient algorithms and data handling capabilities. Other implementations have utilized parallel processing to improve efficiency. For tools to be used for large size networks, it is important to increase the computational efficiency of the TSDP component.

All existing DTA tools allow assignment based on travel time. However, some tools offer needed flexibility in allowing the use of generalized cost functions that include other parameters such as cost, distance, and reliability and allow changing the weights of these parameters by user groups. The consideration of reliability will become an increasingly important consideration in modeling.

The assignments of the trip demands to the identified paths in the TDSP step of DTA has been traditionally conducted using the method of successive average (MSA). In the past few years, a number of studies have questioned its convergence properties and computational efficiency, particularly for larger scale real-life networks and high congestion levels. Some of the existing tools have introduced new assignment methods that improve the performance of the DTA considerably.

The assurance of convergence of the assignment, particularly DTA, still needs further investigation. There is no agreement on how low the values of the convergence criteria should

be, given that the lack of convergence can affect the consistency, stability, and proportionality of the resulting solutions. Some existing DTA tools such as DynusT have used trip-based criteria to test convergence. Others such as Cube Avenue have used link-based criteria. Recent DTA literature has indicated that trip-based criteria may be preferred. It is recommended that both types of convergence measures be calculated by the software and examined by the analyst to determine if the assignment solution has actually converged. In addition, tools should allow better testing of the convergence and the quality of the solution by providing sufficient information to the users to calculate their own convergence criteria. Reaching path flow convergence is particularly important for applications such as multi-class assignment, "Select Link" Analysis, estimation of origin-destination (O-D) flows from link flows, derivation of O-D flows for a subarea of a region, average travel time and average distance per O-D in a generalized cost assignment, and so on. DTA tools should calculate, report, and use in assessing convergence the gaps. It appears that the stopping criteria in existing tools are based on the gap at the end of the iterations with no consideration of the convergence of individual periods.

In general, simulation models have been categorized into macroscopic, mesoscopic and microscopic models. In this study, the microscopic category is further subdivided into low fidelity and high fidelity. Most prevalent DTA models for larger scale modeling applications apply either mesoscopic or low-fidelity microscopic simulation approaches. These approaches provide much better computational efficiency, allowing much faster simulation compared with high-fidelity microscopic simulation. Further examination of the existing simulation-based DTA tools indicates there is significant variation in the level of detail of the implemented traffic flow models, even within each of the above categories, and careful examination of the individual model rather than the categories of models are needed. Queuing and spillback simulation is a critical component of simulation modeling. Some agencies have started utilizing DTA as part of multi-resolution (macro-meso-micro) analysis, which is an attractive option for certain types of applications.

The existing tools vary in their abilities to model advanced strategies such as reroute diversion due to the information provided via in-vehicle or infrastructure-based devices, dynamic congestion pricing, and traffic responsive ramp metering. Thus, the user needs to examine how different tools deal with these strategies, if they are important to the analysis. The details by which the different tools are able to model signalized intersections also vary and need to be closely examined.

This review of DTA has focused on the network side. Implicitly the review has assumed that demand remains fixed with fixed auto trip tables and fixed time of day of travel. The situation changes radically when the DTA is linked to demand models. While there is debate over stopping criteria within the DTA, there is a much broader issue of convergence criteria when a DTA is combined with choice models and activity-based models (ABM). With iterations between demand and the DTA, the number of trips on the network can change with diversion to or from transit, the trip destinations can change and the departure time of the trip can also change.   It should also be mentioned in this regard that only a subset of the existing DTA tools allow combining DTA and ABM.

7.2   Recommendations for DTA Implementations in Florida

Travel modeling is in the midst of an evolution away from static assignment and trip-based paradigms to dynamic assignment and activity based models. Both the dynamic assignment and tour based approaches provide much greater detail in modeling network conditions and individual behavior, both of which are needed to address today's transportation issues. However, to get to this end point, further work needs to be done in the short term and long term. The recommendations below are to allow Florida to move forward toward the goal of wide spread implementation of DTA, and at the same time to proceed at a measured pace allowing staffs to become familiar with dynamic network analysis.

General and Agency Recommendations

In the immediate future, the focus of simulation-based DTA in Florida should be on small regional networks, subarea networks, and corridor studies. However, the utilization of analytical-based DTA may also be considered for larger regional networks. It is recommended that agencies begin the implementation of DTA at the corridor and subarea levels to familiarize themselves with the benefits associated with DTA and issues involved in implementing DTA. The modeling community in Florida should continue monitoring the on-going tool enhancements, experiences with these tools, and applications to large network to determine the feasibility, benefits, and lessons learned of using DTA for different applications.

It is recommended that the modeling community in Florida support the application of DTA in case studies that demonstrate the benefits of DTA. Examples of cadidate applications include, but are not limited to:

- Accurate modeling of congestion
- Modeling non-recurrent events such as evacuation, incidents, special events, and construction impacts
- Providing time-variant performance measures not available from static demand models (such as queues, delays, and bottleneck locations)
- Modeling of advanced management strategies such as pricing, reversible lanes, freight management, traffic management, managed lanes and other advanced applications.

Agencies should ensure that the case studies follow correct model development, validation, and calibration procedures and should also document lessons learned, benefits, and best practices from the case studies. It should be mentioned in this regard that work will start soon on a FDOT research center project to investigate methods for the use of DTA in modeling managed lanes. This should be an important step in line with the recommendation given above.

Shifting to DTA will be an evolutionary process and static models will remain for some time. Static assignment procedures will be here for the next several years. It is recommended that agencies at least initially maintain their existing network analysis methods and use them in

conjunction with DTAs. As DTA tools and applications evolve and staffs become more familiar with DTA methods, agencies can replace static methods with simulation-based DTA in increasing numbers of applications and for larger size networks, eventually moving away from static methods entirely. The use of static assignment for long range planning is expected to remain in use for a longer period of time, although analytical-based DTA procedures may also be considered as a strong alternative for long-range planning. Analytical-based DTA approaches do not accurately model queuing but do provide a more fine grained estimation of the time variant qualities of the network.

Recommendations to FDOT

It is recommended that the FDOT takes a leading role in supporting DTA deployment through the following activities:

- DTA Library: In order to build a DTA user community and develop a skilled group of DTA users, it is recommended that the FDOT should review and document applications of DTA within Florida; identifying the types of application, the results obtained, and user experience. This will enable agencies to review applications by others and learn from the experience of others. This library of DTA experience will support agencies in further applications of DTA and provide background for agencies considering either first time applications or new types of applications. In particular, the review will document cases where DTA produced improved answers over static methods and document examples where a DTA could change project decisions. The utilized procedures, lessons learned, benefits, and best practices from the case studies should be carefully recorded for future use by the modeling community. The reviews should cover model development, validation, and calibration procedures. The library may also include exemplary DTA applications from outside Florida, provided they have been sufficiently documented. Given the day to day demands placed on agencies, this documentation, and the assembling of results in a library, should be performed directly by FDOT, either through staff or a contracting procedure.

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- Capacity Building/Training - The user community must develop the capacity to understand DTA concepts and applications. To accomplish this, FDOT should provide training on DTA and the benefits of using DTA in place of static assignment. The training should focus on DTA applications and be as independent as possible of specific software packages. As part of this effort national DTA experts may be invited to present to the modeling community in persons or through the web.

- Further applications - The SHRPII C10A Project in Jacksonville Florida represents the state of the art in advanced travel modeling. A long range goal of the DTA effort should be to move to this type of modeling, combining DTA with activity based demand. To support moving to this long range goal, the FDOT should sponsor further research with the Jacksonville model, identifying where the approach is more effective than static trip based models. In particular the FDOT should examine improvements offered by an analytical DTA for regional modeling and issues in which the DTA combined with activity models would provide results which differ significantly from traditional models. This research will ensure that as Florida moves toward more advanced models that there is a series of demonstrations on how to apply and best use such models.

Recommendations to Users

The following recommendations apply to users considering the application of a DTA or applying a DTA:

- Selection - When deciding on DTA, the analysts should consider the nature of the questions that need to be answered. The analysts should select the tools that best meet the needs for the specific project under consideration. Analysts may also consider potential future applications and should select a tool which not only meets current needs but also anticipates future needs. The DTA tool assessment criteria presented in this document should be used by agencies as a starting point to select the best type(s) of tool for different applications. All of the DTA tools, both proprietary and open source, are rapidly evolving and will improve in terms of ease of use, run time and capability. Analysts should consider the current and evolving state

of particular software packages when making selections. One major consideration in using a DTA should be whether the analyst feels that the use of a DTA would lead to not only better conclusions than static assignment, but also lead to different decisions than would be reached by static assignment.

- Reliability - It is recommended that agencies incorporate reliability in their modeling activities. The SHRPII program has produced products which address how reliability may be considered.

- Data Sources - It is recommended that Transportation agencies utilize the wealth of data produced from emerging data sources such as ITS data and private sector data in DTA calibration and validation. The ISSTA and ITSDCAP tools developed by the research team can help in this regard and should be continuously enhanced and extended, as needed in the future.

- System Defaults - Most DTA packages have default methods for estimating green times at intersections. While these may be appropriate for many intersections in a network, it is recommended that analysts carefully review results and obtain actual green times where appropriate.

- Convergence - The users of DTA should ensure convergence of DTA applications. Convergence can be a challenging task, particularly for congested networks and when DTA is combined with demand models (such as mode and time shifts). Careful consideration should be given to the used convergence criteria and the methods of calculation.

Additional Needed Research

- The trip matrix estimation procedures developed in this study and those available from vendors should be further investigated to determine the quality of the resulting trip matrices and the impacts of various factors on this quality such as the impacts of the utilized traffic measurements, initial seed matrix quality, utilized weights in the optimization, and so on.

- Best approaches and guidelines should be identified for multi-resolution modeling of transportation networks utilizing combinations of macroscopic, mesoscopic, and microscopic models. This should be done as part of the FDOT community support.

- Convergence of DTA, when used alone and when combined with other traveler choice models, will continue to be an important area of needed research.

Other Recommendations

- Vendors and developers should always be encouraged to improve the efficiency, accuracy, stability, usability, capabilities, flexibility, openness, visualization quality, and documentation of their software. Florida, through the FSUTMS program plays a very strong role in the modeling community. By announcing the results of the DTA research and providing a library of DTA applications, Florida will position itself as a national leader in DTA and have a strong influence on the activities of vendors and developers. In particular Florida should ask vendors to describe plans for future improvements to DTA packages and when packages will be available that can perform the types of analyses conducted in the SHRPII C-10 projects.

Summary of the Recommendations

These recommendation support Florida's movement forward in the continual improvement of travel modeling capability. They provide a method proceed at a slow, measured pace; gradually improving staff capability and at the same time enhancing analytic methods. The proposed DTA library will form a basis for understanding peer activities and support the activities of individual agencies. By encouraging agencies to begin with smaller applications, expertise can be built up without needing to 'jump' to a totally new modeling paradigm. At the same time, by continuing to experiment with the work of the Jacksonville SHRPII application, a long term vision of where the models are to go will be maintained.

These recommendations will not only advance the modeling capability in Florida, but will also provide Florida and opportunity to demonstrate national leadership in the improvement of modeling practice.

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APPENDIX A: Membership of the Advanced Traffic Assignment Committee

Advanced Traffic Assignment Subcommittee

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Vice-Chair: Jack Klodzinski
Model Advancement Committee Chair: Wilson Fernandez

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List updated on January 30, 2012

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List updated on July 28, 2011

APPENDIX B: Survey Questionnaire of the Needs for DTA in Florida

Survey of the Needs for Dynamic Traffic Assignment in Florida

Modeling Task Force Meeting, Orlando, FL
November 30 - December 2, 2010

The purpose of this survey is to gather inputs from Florida Modeling Community related to Dynamic Traffic Assignment DTA application in Florida.

1. Please indicate which of the following best describes your background.

   ☐ MPO/TPO   ☐ Private   ☐ Other: ....
   ☐ State   ☐ Academia

2. How do you envision that DTA will be used as part of the demand modeling process? Check what applicable.

   ☐ Replace static assignment in regional model
   ☐ For subarea or corridor planning studies
   ☐ With activity based models
   ☐ For traffic operational analysis
   ☐ Others: ....

3. What do you think are the main technical and institutional constraints that need to be overcome for DTA to be widely applied in Florida, as part of the modeling process? Check all applicable.

   ☐ Lack of data   ☐ Computational time   ☐ Parameter assumption for future year
   ☐ Lack of experience   ☐ Cost of software   ☐ Complexity of the process
   ☐ Training   ☐ Calibration and validation ☐ Others: ....

4. What do you think are the types of assistance that the modeling community will need to apply DTA? Check all applicable.

   ☐ Long term support   ☐ Standards/guidelines   ☐ Peer review, data and experiencing
   ☐ Training   ☐ Selection of tool   ☐ Others: ....
   ☐ Knowledge center   ☐ Case studies

5. What is the largest size of the network (nodes, links, and zones) that you think the DTA tool should be able to handle? (Select one)

   ☐ Small network   ☐ Medium network   ☐ Large network   ☐ Other
   (e.g. Gainesville)   (e.g. Jacksonville)   (e.g. SERPM)   Zone : ....
                                                                        Node : ....
                                                                        Link : ....

6. What types of demands should be included in the DTA assignment? Select all that applicable.

   ☐ SOV   ☐ HOV   ☐ Truck   ☐ Truck by commodity
   ☐ Pedestrian   ☐ HOV by occupancy ☐ Truck by size ☐ Others: ....

7. What is the reasonable increase in computation time that you are willing to tolerate with the use of an integrated DTA compared to static models?

If the current running time of the demand model is:

2 hours	5 hours	10 hours	More than 10 hours
☐ up to 10%	☐ up to 10%	☐ up to 10%	☐ up to 10%
☐ 11%-25%	☐ 11%-25%	☐ 11%-25%	☐ 11%-25%
☐ 26% - 50%	☐ 26% - 50%	☐ 26% - 50%	☐ 26% - 50%
☐ more than 50%	☐ more than 50%	☐ more than 50%	☐ more than 50%

8. Should we require modelers to input signalized intersection control and detailed geometry to the modeling process?

   ☐ Yes   ☐ No   ☐ Some time

   Explain : ....

9. Please select applications or scenarios that you need the DTA tool to be able to handle

   ☐ Incident management   ☐ Tolling   ☐ Freight
   ☐ TOD pricing   ☐ Diversion   ☐ DMS/HAR
   ☐ Dynamic pricing   ☐ Transit   ☐ Ramp metering
   ☐ Bottleneck impacts   ☐ Work zone   ☐ Others: ....
   ☐ En-route info   ☐ Pre-trip info

10. What type of demand should the software accommodate?

   ☐ Vehicle based   ☐ Person based   ☐ Either   ☐ Both

11. Please, discuss any other important issues that you feel need to be addressed for DTA modeling application in Florida.

12. What temporal modeling resolution would satisfy your needs?

   ☐ 15 minutes
   ☐ 30 minutes
   ☐ 1 hour
   ☐ Other: ....

APPENDIX C: Technical Details of the Static O-D Estimation

ME Analysis Application

The basic application of the ME program is as follows:

```
    DO 400 JZ=1,MAXZ4
    VOLOUT(JZ) = 0.0
 400  CONTINUE
C
C LOOP ON ITERATIONS -- READ IN THE PATH FILE(S)
C
    DO 1500 IT=1,NUMITR
    FAC = BPRPER(IT)
     DO 600 JZ=1,MAXZ4
      VOLOUT(JZ) = VOLOUT(JZ) + P(JZ)*FAC*VOLIN(JZ)
 600   CONTINUE
 1500  CONTINUE
```

The ME program is run in a DOS environment under any Windows operating system.

INPUT FILES

The following files are input to the ME program:

ME.IN   This file (required) must be in the DOS working directory, and it contains all the information to control the execution of the program. It is a text file, and its format is described later in this document.

Input Trip Table   This file (required) is an input trip table, a base or seed matrix, which will be modified by the program.

Loaded Network   This file (required) is a loaded highway network from a highway equilibrium assignment – it contains for each link: A-node, B-node, trips loaded, link counts, and facility type for weighting.

Fixed Zones   This file (optional) contains a list of traffic analysis zones for which no modification to/from is permitted in the ME program. These zones can be external stations or special generators.

Path Counts   These files (required) are generated, one per iteration of assignment, in the VOY_CONV program. They contain path information related to links with counts and, because they contain much data, they are written in a compressed format to save disk space.

ME_RESTART.IN   This file (optional) permits the restart of the ME program to continue more ME passes. The file is automatically generated during an ME run as the file **ME_RESTART.OUT**. For example, if ME were run with five passes specified and, after review of the ME output it was decided to an additional five passes, ME could be run with this file and the number of passes set to 10. The program would restore the program with the information internally when it ended with five passes and continue for another five passes.

Link Counts   This file (optional) contains link counts in A-node and B-node sort and the counts are read with the following: ANODE, BNODE, (COUNTS(I),I=1,10) – up to 10 modes may be specified on each count records. These counts override any count data on the loaded highway network file.

OUTPUT FILES

ME.OUT   This file, always generated, contains the detailed statistics of the ME run. It also contains an echo of the ME.IN file; a detailed analysis of each link, with specified counts; a summary of the differences; and an RMSE summary – for each ME pass.

MESUM.OUT   This file, always generated, contains an echo of the ME.IN file; a summary of the differences and an RMSE summary – for each ME pass.

Output Trip Table 1   This file (required) is the output trip table.

Output Trip Table 2   This file (required) is a dummy file – legacy file for TRANPLAN processing.

LINK.CNT   This file (optional) contains link information: each link with selected count values and the number of iterations which that link is used during the assignment process.

ME_RESTART.OUT   This file, always generated, contains the memory contents of the ME program at the end of its execution. It may be input as the **ME_RESTART.IN** file to restart the program to perform more passes.

ME.CSV   This file, always generated, contains the detailed analysis of each link with the specified counts. This file is a comma-delimited format for input into spread sheet software.

MESUM.CSV   This file, always generated, contains the summary of the differences and an RMSE summary – for each ME pass. This file is a comma-delimited format for input into spread sheet software.

ZONECNT.DAT   This file, always generated, is in TRANPLAN trip table integer format and contains the number of links with counts which are traversed over the paths for the first iteration of assignment.

ME.ERR   This file is generated if any critical errors are detected during the ME run. If the ME run is in a DOS batch (.BAT) file, the script can be written to terminate a process if any ME error(s).

SOFTWARE LIMITATIONS

The ME program will handle any 200,000 highway network links and will permit up to 10 highway modes and 20 iterations of assignment.

VOY_CONV PROGRAM

The VOY_CONV program is a DOS program which prompts user for the following file names:

Input Voyager trip table: This file is an input trip table, a base or seed matrix, which will be modified by the program.

Output TRANPLAN trip table: This file is the input file converted to TRANPLAN format for processing by the ME program.

Input Highway Path File: This file contains the paths for each iteration of assignment.

Highway Assignment File: This file contains the link counts required to generate the output path count files.

Output Path Files: These files with the names, PATHCNT.xxx (where xxx is the assignment iteration number), contain all the path information required by the ME program.

APPENDIX D: Technical Details of the Dynamic O-D Matrix Estimations

INPUT DATA and FILES

The dynamic O-D matrix estimation (DODME) process uses several model keys as listed in Table 1. The user can update these settings based on the user's preference.

Table 1. Description of input keys

File name	Description
{MesoIterations}	Maximum iteration in running Avenue program
{Packet Size}	Packet size in Avenue run
{TimeSegment}	Number of time interval in Avenue run
{TrafficMode}	Number of traffic modes
{MAX CountLinks_AM}	Maximum traffic count locations for AM
{MAX CountLinks_PM}	Maximum traffic count locations for PM
{AM_weight}	Initial weighting factor to estimate O-D matrix for AM period
{PM_weight}	Initial weighting factor to estimate O-D matrix for PM period
{AM_WeightStep}	Incremental weighting factor to estimate O-D matrix for AM period.
{PM_WeightStep}	Incremental weighting factor to estimate O-D matrix for PM period.

Both {AM_weight} and {PM_weight} are used to define the initial weights on the O-D demand. The {AM_WeightStep} and {PM_WeightStep} are used to increase weight factors when objective function value is increased reversely after performing dynamic O-D estimation. The users can use the default weight factors to implement the dynamic ODME process in the first iteration. The number of traffic count locations is set by two different keys as {Max_CountLinks_AM} for AM period and {Max_CountLinks_PM} for PM period.

Cube Avenue can be run up to the maximum iterations, but the user can also increase the maximum iteration number using the {MesoIterations} key to get better convergence results. The packet size for Avenue program is also defined by {PacketSize}.

The DODME process requires several input files, such as O-D trips, empty road network, and turn penalty data. As shown in Table 2, each O-D trip matrix file by traffic mode contains several O-D trip matrices additionally by time segments.

Table 2. Description of input files

File name	Description
SUBAREA_V1_AM.MAT	AM trip matrix for vehicles with one person (DA)
SUBAREA_V2_AM.MAT	AM trip matrix for vehicles with two person (SR2)
SUBAREA_V3_AM.MAT	AM trip matrix for vehicles with three or more persons (SR3P)
SUBAREA_V4_AM.MAT	AM trip matrix for trucks
SUB_STORAGE.NET	Input empty road network
SUB_PENALTIES.PEN	Turn penalty files
PARALLEL_DODE.exe	Program to perform dynamic O-D estimation
Inputs.ctl	Control file used by 'Parallel_DODE.exe'

The dynamic O-D estimation program called 'PARALLEL_DODE.exe' can be executed using the input control file (e.g., 'Inputs.ctl') that contains all the information including parameters and input file names. In the control file, names and contents are hard-coded with a specific format, and the user comments can be input using the '#' symbol in the first column.

Each record in the input control file is described as follows:

Record 1:   specifies the number of origin zone, destination zones, departure time interval, screenline, observed time interval, initial weight factor, maximum iteration and flag index indicating whether a separated lower bound of trip matrix file is provided (1 stands for the low bound file is provided, otherwise zero).

Record 2:   specifies the name of the demand file for warm-up period. The file is automatically generated in AM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION AM 01>> MATRIX (execute order 15) and PM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION PM 01>> MATRIX (execute order 15).

Record 3:   specifies the name of the demand file for estimation period. The file is automatically generated in AM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION AM 01>> MATRIX (execute order 15) and PM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION PM 01>> MATRIX (execute order 15).

Record 4:   specifies the name of the lower bound demand file for estimation period. The file is automatically generated in AM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION AM 01>> MATRIX (execute order 15) and PM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION PM 01>> MATRIX (execute order 15).

Record 5:   specifies the name of the upper bound demand file for estimation period. The file is automatically generated in AM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION AM 01>> MATRIX (execute order 15) and PM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION PM 01>> MATRIX (execute order 15).

Record 6:   specifies the name of the link proportion file for the warm-up period. The file is automatically generated in AM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION AM 01>> MATRIX (execute order 15) and PM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION PM 01>> MATRIX (execute order 15).

Record 7:   specifies the name of the link proportion file for the estimation period. The file is automatically generated in AM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION AM 01>> MATRIX (execute order 15) and PM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION PM 01>> MATRIX (execute order 15).

Record 8:   specifies the name of the observed link count file for the estimation period. The file is automatically generated in AM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION AM 01>> MATRIX (execute order 11) and PM AVENUE SUBAREA>>DYNAMIC O-D ESTIMATION PM 01>> MATRIX (execute order 11).

Record 9:   specifies the name of the estimation output. The file is automatically generated in by the parallel_DODE.exe.

An example for the input control file is also referred as follows:

```
#Include File Read By Main DTA Program
#DO NOT alter line positions or add extra comment lines
#
#I=origin, J=destination, D=departure time, K=link number, T=arrival time
#
#All input data on a line should be seperated by a single space
#Room for additional comments at end of file
#
#
#Max I, J, D, K, T followed by w and max_iterations go below this line
143,143,6,19,6,0.000002,4000,1
#
#
#Begin listing input files with the number of nonzero entries after
#the file name, this should be the total number of data lines
#same setup as the example files
#
#This is line 18, the file for X_w goes below this line
targetdemand17_1.inc
#
#This is line 21, the file for X goes below this line
targetdemand17_0.inc
#
#This is line 24, the file for X_lower_bound goes below this line
targetdemand17_2.inc
#
#This is line 27, the file for X_upper_bound goes below this line
targetdemand17_3.inc
#
#This is line 30, the file for A_w goes below this line
LP_ODFlow_1.inc
#
#This is line 33, the file for A goes below this line
LP_ODFlow_0.inc
#
#This is line 36, the file for b goes below this line
observecount.inc
#
#This is line 39, the output file name goes below this line
ODDEMAND_EST.DAT
```

OUTPUT FILES in DYNAMIC O-D ESTIMATION

Table 3 lists all the final output files from the dynamic ODME process that are stored to the scenario directory (e.g., \Base\). There are 2 different types of output files for each time period such as the estimated O-D matrices and the statistic reports between traffic counts and assigned volumes.

Table 3. Description of output files

File name	Description
SUBAREA_Vm_AM_ADJ.mat	Estimated O-D matrix for vehicle type m in AM period
SUBAREA_Vm_PM_ADJ.mat	Estimated O-D matrix for vehicle type m in PM period
Compare_Links_AM_OPT_Itn.PRN	Statistic output for optimization in n^{th} iteration in AM period
Compare_Links_PM_OPT_Itn.PRN	Statistic output for optimization in n^{th} iteration in PM period