APPENDIX-A
INCLUSION OF TIME DEPENDENT NETWORKS IN MSTM
PROJECT TASK 1 REPORT

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06/21/2013
The views expressed in this report do not represent those of the Maryland State Highway Administration or the U.S. Federal Highway Administration.
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EXECUTIVE SUMMARY

This report describes the results of Task 1 (Tool selection) of the Inclusion of Time Dependent Networks in the Maryland Statewide Transportation Model (MSTM) project. The report covers the following elements:

- Identification of functional specifications
- Review of existing software tools
- Tool selection

The following functional requirements were identified:

- Vehicle based capability
- Person based capability
- Transit routing and path finding capability
- Capability to run the entire MSTM network
- Subarea analysis capability
- Flexibility to modify software
- Simplified network procedures
- Visualization
- Technical and computational support

For the software review, three open source and two proprietary packages were examined. The open source packages included:

TRANSIMS – Which has both a routing and simulation capability. The routing capability can be used as a stand-alone, low level DTA or can be integrated with the microsimulator. TRANSIMS also has a transit capability more mature than the other open source packages.
DynusT – Which has a fully developed vehicle simulation capability and, when combined with the FAST-TrIPS model has a transit capability.

DTALite – A simplified DTA which can operate with a minimum amount of data and derives transit times from the travel times generated by the network simulation.

The Proprietary packages included:

Cube Avenue – Which has a vehicle simulation capability and can be integrated with other transit models, either static or dynamic.

TransModeler – Which has a full simulation capability and can represent the movement of transit vehicles, including fixed routes and stops, but is not person based.

Software Selection

The proprietary packages generally had better visualization capability and more user friendly interfaces. However they were not person based and their internal workings, such as methods of convergence, were not always available.

Of the open source packages, the transit capabilities in DTALite and DynusT were not fully developed at the time this report was prepared. TRANSIMS had the most mature transit capability and the capability had been tested in applications. TRANSIMS also had the advantage of being able to run the Router as a stand-alone, eliminating the need for network detail, a key issue given the 167,000 link size of the MSTM network. Finally, computational and technical support are available from the Transportation Research and Analysis Computing Center (TRACC) at the Argonne National Laboratory.

Based on the analysis we recommend TRANSIMS for this project. This recommendation is based on the specific project needs and is not a general recommendation for TRANSIMS. Other projects, with different needs, may use other software packages.
## 1 INTRODUCTION

The goal of this project, sponsored by the Maryland State Highway Administration (SHA) with support from the Federal Highway Administration (FHWA), is to advance statewide transportation modeling practice by demonstrating improvements offered by using time dependent, person based analyses in statewide transportation modeling.

The SHA has developed the Maryland Statewide Transportation Model (MSTM), a multi-layer travel demand model representing national, statewide and urban travel. The MSTM forecasts key measures of transportation system performance. The MSTM provides a very powerful tool for analyzing transportation movements within Maryland and the immediate surrounding areas. The MSTM accounts for nationwide truck movements, interregional external-internal movements and travel within the MSTM study area. The MSTM includes all of Maryland, Delaware and the District of Columbia, along with adjacent portions of Virginia, Pennsylvania, and West Virginia. The MSTM operates at a very large scale, with more than 167,000 links, 67,000 nodes and over 30,000,000 vehicle trips. The current MSTM model uses the traditional four step approach to modeling; trip generation, trip distribution, mode choice and static highway assignment. Travel is represented in four time periods with multi-class assignment capabilities of person and freight travel in and around the state. The MSTM was developed with technical support from the National Center for Smart Growth Research and Education (NCSGRE) at the University of Maryland with support from Parsons Brinckerhof.

Although, the current MSTM framework assists in planning and decision-making; as is the case with many statewide trip based travel demand models, these models are static in nature and lack the detail to analyze the spatial and temporal aspects of congestion. Effective planning, representing user response to emerging issues such as peak spreading, freight delivery and congestion requires a time dimension. The applications that a time dependent modeling approach can assist the SHA include: (i) tracking statewide time dependent flows, (ii) more accurate representation of congestion, (iii) analyzing impacts of temporal travel restrictions, (iv) impacts of peak hour tolling, and (v) tracking time dependent freight flows.
This research will follow a multi-resolution approach providing a linkage between macro- and meso-simulation platforms in that the output from the one model can be fed into the other to utilize strengths of both models.

This report describes the tool selection process (Task 1 of the project) for the time dependent networks. It includes the identification of the functional requirements (Task 1.a), a description of software packages with the potential to meet the requirements (Task 1.b) and the rational for the selection of the specific tool to be used (Task 1.c).
2 FUNCTIONAL SPECIFICATIONS (TASK 1.A)

The project team identified functional requirements for the software to be used considering SHA’s ongoing efforts, policies and programs along with project needs. These requirements have been determined through several meetings and interviews with senior staff members of the SHA, and supported by reviews of SHA policies and other documents recommended by SHA staff. The research team also conducted interviews with users and/or developers of various software tools to be aware of the latest developments. In light of all the information gathered, the following specifications are identified:

- **Vehicle-Based Analytic Capability**
  Current static assignment methods analyze the movement of large groups of vehicles through links on the network and do not have the capability of distinguishing individual vehicles. The selected system should have the capability of analyzing the movement of individual vehicles and tracking those vehicles as they move through the network. It should be able to identify different routes taken by an individual vehicle depending on changes in network conditions. It should also identify the time of day at which the vehicles pass through different points on the network.

- **Person-based Analytic Capability**
  The MSTM is a multi-modal statewide transportation forecasting model. The model is a trip-based aggregate model, i.e. OD level demand loading, and it cannot track trips made by individuals in the network. The SHA\(^1\) would like to have trip information at the individual person level. With a person based model, it is possible to track each person and assign the person to vehicles in the network. For example a person who uses transit can be tracked from his/her origin to destination with walk times, wait times at stops and transfers along the way. Moreover, transit vehicle schedules can reflect congestion effects and vehicle capacity can be considered as people using transit are tracked. While tracking people and the vehicles they use through the network may not be implemented in this project, the capability should be there for potential future use.

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\(^1\)Meeting with Subrat Mahapatra of SHA on October 16, 2012 at SHA Headquarters and Project Kick-off Meeting discussions on November 8, 2012.
• **Transit routing and path finding capability**
  One of the critical needs stated by the SHA is to have a transit routing and path finding capability. The existing MSTM model uses a schedule based transit assignment and this does not allow bus transit to be affected by the congested road conditions. The selected tool needs to be able to reflect congested traffic conditions on bus travel times and delays at stops. Two capabilities must be included in the transit capability:
  - Adhering to a schedule and route – Transit vehicles must be able to adhere to a fixed route and not reroute due to congestion. In addition vehicles must adhere to a fixed schedule. If they arrive at a transit stop early they must wait at that stop until the scheduled departure time.
  - Also, the tool needs to have the capability of routing persons through the transit network and identifying the time it takes to move through the network via transit. i.e. a person can walk to transit, take a bus, then transfer to another transit line and then walk to the final destination after leaving the transit system.

• **Capability to run entire MSTM Network**
  The selected procedure must be able to cover the entire MSTM network. By doing this the model will be able to demonstrate the potential benefits of using time dependent network models on a statewide basis. In addition, with full coverage any policy or scenario analyzed with the current MSTM can also be analyzed with the time dependent network methods.

• **Subarea analysis capability**
  Based on the SHA’s need for conducting detailed analysis for selected subareas or for corridors, the project team also identified subarea analysis capability as a functional requirement, (either built into tool or can interface with other tools). This project follows a multi-resolution approach aimed at providing linkages between macro-, meso- and micro-simulation platforms in that, the output from the one model can be fed into the other. While the selected tool does not specifically need detailed capability to analyze a subarea, it needs to provide results which can be integrated with tools which can provide detailed subarea analyses.

• **Flexibility to modify software**
The planning needs of state agencies have been changing with evolving federal or state mandates such as Greenhouse Gas emission reduction requirements and statewide planning requirements. Developments in software and hardware related to transportation planning also have been changing rapidly providing newer analytic capabilities. Therefore, it is desirable for the software to be able to accommodate new demands both as in analysis capability and software modifications.

- **Simplified network modeling**
  Despite recent developments, the very large size of the MSTM network makes modeling with very detailed networks very challenging for current DTA models, e.g. detailed intersection geometry, signal control timing plans and transit route information. Therefore, the project will examine methods which do not require details such as signal control, queuing at intersections and intersection geometry. The desired capability is to use network “as is” in the macro modeling platform.

- **Visualization**
  This project will be first of its kind to demonstrate benefits of introducing time dependent person based modeling to statewide transportation models. Therefore, displaying the model results in a form that is clear and presentable for decision makers as well as for scientific community is critical. The tool to be used should either have built in visualization tools or should be flexible enough to allow the project team to add new visualization methods.

- **Technical and computational support**
  The project team is well aware of the challenges this state-of- the practice project presents due to its large scale, new software and additional computational requirements. Therefore, being able to receive technical and computational support is critical throughout the project. The type, amount and cost of support will all be considered for the tool selection.
3 SURVEY OF EXISTING TOOLS (TASK 1.B)

3.1 MULTI-RESOLUTION MODELING

Models in general, and network models in particular, can be broadly divided into three classes, Macroscopic, mesoscopic and microscopic. Macroscopic typically divide the day into three or four time periods, then use static assignment techniques to analyze traffic conditions in each of these periods. Microscopic techniques have a fine grained level of detail and represent detailed lane change behavior, intersection movements and car following behavior. Mesoscopic models operate between the macroscopic and microscopic, applying macroscopic traffic flow models to individual vehicles, producing more realistic traffic flow measures such as speed and flow, while tracking individual vehicles. Mesoscopic models allow for temporal changes in traffic and for a discrete (with small intervals, e.g. 15 minutes) time of day representation of traffic conditions without going into the detail of microscopic models.

Mesoscopic models thus provide a bridge between the macroscopic and microscopic; developing an understanding of temporal network conditions without requiring the detailed data and analytic complexity of detailed network analysis.

Macroscopic, mesoscopic and microscopic models can be nested together, with macroscopic models providing high level demand information for input to mesoscopic network models, mesoscopic models then providing dynamic network conditions, still on a regional basis, and microscopic models using the output from mesoscopic models to provide detailed network conditions on a small area basis. This process is illustrated in a statewide modeling context in Figure 1.
Figure 1: Multi-resolution modeling framework

MACRO LEVEL - REGIONAL/STATEWIDE MODEL

**INPUT**
- Regional network (Highway and Transit)
- Demand
- HH and Emp. by TAZ

**Four-Step Planning**

**OUTPUT**
- Link Performance Measures
- Aggregate statistics
- OD tables

**TIME DEPENDENT REGIONAL/STATEWIDE MODEL**

**INPUT**
- Regional network (Highway and Transit)
- Time Dependent OD Tables

**TD Routing Information/DTA**

**OUTPUT**
- Time dependent link & path performance measures
- Time Dependent statistics

**MICRO LEVEL - SUBAREA/CORRIDOR MODEL**

**INPUT**
- Subarea network (Highway and Transit)
- Subarea dynamic OD Demand

**Dynamic Micro Simulation**

**OUTPUT**
- Time dependent link & path performance measures
- Disaggregate statistics
3.2 **Mesoscopic Models - DTA**

To provide a better understanding of traffic conditions by time-of-day on a statewide basis, the entire MSTM network must be represented. Since microscopic models are too detailed to represent a network of this size and macroscopic models do not provide time-dependent traffic patterns, mesoscopic models are most appropriate for consideration.

A number of different approaches have been developed to analyze the dynamic movement of vehicles through the network at the mesoscopic level. One of the first major applications of these was the Dynamic Traffic Assignment (DTA) techniques developed by Hani Mahmassani (Mahmassani and Herman, 1984; Mahmassani, 2001). The original term DTA referred to the work by Mahmassani but it has now evolved into a more generic term for models which capture the temporal effects of movement on the network. We will use DTA in that context for the remainder of the report.

DTA models are more advantageous for evaluating scenarios because of their enhanced ability to reproduce traffic congestion and to reflect changes in vehicle routes depending on changing temporal and network conditions (Chiu et al., 2010a). They emphasize the dynamic nature of the network under time-varying demand and try to capture the dynamics of traffic conditions such as congestion buildup and dissipation. Therefore, DTA models can yield useful estimates of state variables such as speed and delay to better understand the functional and environmental impacts of various projects in transportation planning and operations management.

Several DTA approaches have been proposed in the literature based on analytical and simulation techniques, which a comprehensive conceptual review of them can be found in Peeta and Ziliaskopoulos (2001). In this study, we focus on DTA models that are based on traffic simulation principles. Simulation-based DTA models use a traffic simulator to replicate the complex traffic flow dynamics, and have emerged because of the inherent mathematical intractability and challenging complexities of analytical methods. A number of these simulation-based approaches have been developed into tools e.g. DynaMIT (Ben-Akiva et al., 2002), DYNASMART (Mahmassani, 2001), DynusT (Chiu et al., 2011), DTALite (Zhou and Lu, 2013), Dynameq (Tian et. al., 2007), and TransModeler (Caliper, 2009).
3.3 REVIEW OF TOOLS

This section reviews major open source and proprietary tools which may be considered for representing temporal network conditions. This is not an exhaustive review of all available tools, but rather a review of software packages judged to be the most viable candidates. All of the tools reviewed, both open source and proprietary, are under continuous development so this review represents a picture of the tools in the late spring of 2013. The review covers a brief description of each tool, the capability of each tool to address person movements and transit, output and visualization, and describes a sample application of each tool.

3.3.1 Open Source tools

Three open source tools were selected for review; TRANSIMS, DynusT and DTALite. Each of these tools has been applied in a number of areas, has both a highway and transit capability, and was able to represent individual travelers and vehicles.

TRANSIMS

The TRansportationANalysis and SIMulation System (TRANSIMS), is a modular, integrated set of tools designed for a comprehensive regional application of travel simulation. It was originally developed to address all aspects of travel forecasting, from the estimation of households, individuals and employment to the detailed second-by-second simulation of people and vehicle movement. TRANSIMS tracks the location of individuals and vehicles as they move through a 24 hour day. It can track an individual through multiple locations throughout the day and track the individual through the use of different modes; drive, walk and transit. While TRANSIMS was initially designed as an integrated package with both demand and network components, this review focuses on the two components of TRANSIMS used in network analysis; the Router, which develops travel plans for individuals and vehicles to pass through the network, and the microsimulator, which simulates the movement of people and vehicles through the network (TRANSIMS Documentation).
Router

After generating highway and transit networks, and associated demand input (either by population synthesizer module or from trip tables), TRANSIMS network analysis begins by using the Router module. The Router module develops travel plans for each individual to be at various locations at specific times during the day. Plans may include multiple stops and transfers between modes (e.g. walk to transit) in order to complete the plan. The plans identify the time spent traveling by each mode and the time spent executing activities. The Router then tracks the location of the individual throughout the day. If the individual is using a vehicle, the time and location of the vehicle are also identified. In the case of movements by transit, the time to move from one location to another is derived from the transit network. For highway movement the time is derived from the highway network. Router movements are typically based on 15 minute intervals and travel times for each 15 minute time slice are based on the BPR curve. While the Router does not include detailed intersection, signal and queuing information, nevertheless it does provide a much better picture of travel time than classic static assignment methods. The output from the router is a set of plans including routes and times for each person or vehicle to follow during the course of the day.

Microsimulator

Once plans have been developed they are used as the basis for detailed microsimulation. The microsimulation is a detailed second by second cellular automata based model which tracks individuals and vehicles as they move through the day. In this approach, the network lanes are is divided into grid cells. Each cell either contains a vehicle or is empty. Simulation is carried out in discrete one second time steps. For each second, the vehicle decides whether to accelerate, break or change lanes in response to nearby vehicles in the grid. This guarantees each vehicle makes decisions based on the state of every other vehicle in its surroundings at the same time and vehicles move from cell to another on a second by second basis. The speed of the vehicle results from the number of cells moved (TRANSIMS Documentation).

The framework of TRANSIMS and Router/Microsimulator modules are shown in Figures 2.a and 2.b below.
Figure 2.a: General structure of TRANSIMS

Source: SimTravel Web site
Figure 2.b: TRANSIMS Router and Microsimulator Modules

Source: TRANSIMS Training Material

Feedback
Once travel plans have been made and the plans simulated in the network, feedback between the simulator and router can occur. The purpose of feedback procedure is twofold: eliminating the problems incurred at routing and microsimulation steps and achieving a routing and microsimulation result which is can represent normal day trips and congestion realistically. Note that traveler’s mode choice is not determined by the model but by the travel surveys. The feedback mechanism tries to find an equilibrium, typically by iterating between the router and microsimulator (Note: the user specifies the type of equilibrium or convergence used). The estimates of travel time, delays and time of completion of the plan can be fed back to the Router for route adjustment, destination adjustment or change in departure time.

While feedback between the router and microsimulator is the typical way of finding a user equilibrium traffic pattern, Router output alone may also be used as input to successive iterations of the Router to adjust paths and departure times to more realistically distribute traffic (Router Stabilization) without using microsimulation. This process allows for closer approximation of travel patterns without requiring the computation burden of the microsimulator.

**Transit**

Transit representation is an essential part of the TRANSIMS system. In addition to walking and driving, TRANSIMS can represent multiple transit modes including bus, trolley, street car, and several classifications of rail. External demand models may be used to estimate traveler choices in response to changes in network performance (SimTravel Web site). Transit demand may be input as individual transit trip tables or as tours which have transit components. In either case the time of departure must be included as input. The transit network input includes route paths, stops, schedules and vehicle properties. The router module finds the best route given the mode or combinations of modes. A trip plan contains all the information about a trip from origin activity location to destination location including sequence of modes, routes, transfer points, and planned departure and arrival times at the origin and destinations.
Output and Visualization

TRANSIMS can interface with a number of visualization packages, some proprietary, some open source. Examples of open source visualization tools include original TRANSIMS visualization tool developed by TRACC that use GIS output to represent link delays and other aggregate information in time-dependent bar graphs form on top of network links; NEXTA (Network EXplorer for Traffic Analysis Graphical User Interface (GUI) designed to visualize transportation networks (e.g. node and link properties and lane configuration) and time-dependent traffic simulation results (e.g. density, speed, queue length, and vehicle locations); Metropolis developed by NCSA (the National Center for Supercomputing Applications) allows users to navigate in three-dimensional space (and time) while showing moving vehicles, dynamic link performances, and other dynamic network features; ArcSnapshot is a script that creates traffic animation through generating GIS shape files second-by-second, and TransimsVIS which has been prepared specifically for TRANSIMS users (TRANSIMS Training Material).

Figure 3: 2D data (congestion, lateness or waiting) plot of Chicago model in TransimsVIS

Source: TRANSIMS Training Material (Presentation 17)
Sample Application – Chicago

The Argonne Transportation Research and Analysis Computing Center (TRACC) and the Illinois Terrorism Task Force developed a comprehensive DTA model for the Chicago metropolitan area in TRANSIMS. The basic purpose was to model different scenarios for emergency evacuation of the Chicago Business District.

Demand data for this application is primarily based on data and previous models from Chicago Metropolitan Agency for Planning (CMAP). In collecting the required network data, the main focus was on topology, especially connectivity, number of lanes, functional classes, and coded length. For instance, satellite imagery, aerial photography, and direct observations were employed to improve the accuracy of the road network in the model, which also helped to enhance the visualization. Gathering complete information about the transit systems in the area and correctly integrating transit links and stations in the network was another issue faced in this application. Additional software utilities were developed to manage the available data and to run different evacuation scenarios on high-performance computing cluster.

The final simulation model covers 10,000 square miles and encompasses 40,000 links and 14,000 intersections. It also includes 26.5 million vehicle trips and 1.5 million transit trips. Trip tables are broken down by purpose. The reported runtime for this network changes from 48 hours for one CPU to 0.378 hours for 127 CPUs.

One of the main challenges of this project was performing a second-by-second microsimulation in such an extremely large network to track every single individual during the evacuation. This high level of accuracy was required to provide more efficient evacuation plans by city officials and, potentially to save more lives. Microscopic dynamic traffic assignment was utilized in this study to model the dynamic effects of no-notice events on the multimodal regional transportation system in the Chicago metropolitan area. The model also has full functionality for transit and full functionality for Activity-Based trips.
DynusT

DynusT (Dynamic Urban Systems in Transportation) is one of the latest Dynamic Traffic Assignment models, which has been used in a number of areas. DynusT is person based with the capability of tracking both individuals and vehicles as they move through the system. This model, which is based on mesoscopic simulation, seeks dynamic user equilibrium (DUE). As shown in Figure 4, DynusT consists of two main modules: traffic simulation and traffic assignment. Iterative execution of these two modules is employed to solve for dynamic user equilibrium.

In the first module, vehicles are generated and loaded onto the network. The traffic simulation is performed based on an Anisotropic Mesoscopic Simulation (AMS) method (Chiu et al., 2010b). In this approach, the vehicle’s speed is a function of the speeds of the other vehicles in front of it. More specifically, a Speed Influencing Region (SIR) is defined for each vehicle and the density of vehicles inside the region is used by the speed density curve to determine the corresponding speed at each simulation interval. Once the simulation is finished, required measures of effectiveness such as time dependent link travel times and delays are transferred to the traffic assignment module. This module consists of two algorithmic components: time-dependent shortest-path algorithm and time-dependent traffic assignment. The assignment component uses the Method of Isochronal Vehicle Assignment (MIVA) which is a temporal decomposition scheme for large scale DTA (Nava and Chiu, 2012). In this method, the analysis period is divided into Epochs and the vehicles are assigned sequentially in each Epoch, thus improving model scalability and computational efficiency. Computational efficiency is provided by a self-tuning scheme that adaptively searches for a run-time-optimal Epoch setting during iterations (DynusT website). The simulation-assignment iteration continues until a convergence criterion for dynamic user equilibrium is satisfied. It is also worth mentioning that methods included in DynusT to improve the computational efficiency of different components make it possible to conduct large scale simulation and assignment for long time periods e.g. 24-hour or greater (DynusT website).
Figure 4: General structure of DynusT

Source: Chiu et al., 2010c, available online at http://www.michigan.gov/documents/mdot/MDOT_DTA_DynusT_Overview_Chiu_8_11_10_334886_7.pdf
Transit

DynusT dynamic transit assignment capability has been under development. The capability is provided by integrating DynusT with FAST-TrIPS, a simulation based dynamic transit assignment model developed by University of Arizona. The transit assignment procedure in the integrated DynusT-FAST-TrIPS model can consider wait times at stops, transit vehicle capacity, transfers, stops, walk and bike access and intermodal assignment. FAST-TrIPS tracks person trips as they move through the transit system. It initially derives transit vehicle paths and schedules from Google transit or by input from the user. Based on the initial information, person trips are then assigned to vehicles and the vehicle movements are simulated using DynusT. Within DynusT the transit vehicles adhere to a schedule with specific routes and stops. The final transit travel times are then estimated based on the DynusT simulations. DynusT-FAST-TrIPS integration is expected to be completed in 2013 as part of SHRP 2 C10 project. Thus it is not currently available and has not been extensively tested in practice as of this writing.

Visualization

Most of the outputs of DynusT are in ASCII text format. Among them, there are three data files which play a more prominent role: Vehicle Trajectory Data, Vehicle Data, and Vehicle Route Data. The Vehicle Trajectory Data file is generated by DynusT in each iteration, including records of individual vehicle attributes, start time, end time, origin and destination zones, path nodes, and delay associated with each node. When the DynusT run is complete DynusT stores the resulting vehicle data and vehicle route data for future use or for visualization. The Vehicle Data file contains individual vehicle descriptions, including origin TAZ, vehicle entrance link, destination TAZ, vehicle exit node, and vehicle departure time. Vehicle Route Data file stores the route each individual vehicle chosen in the last iteration of DynusT run. Using the vehicle trajectory data, Nexta has been used to visualize the movement of vehicles in the network and to illustrate the link performance measures. Toll revenue and summary statistics are among the other possible outputs of DynusT.

DynusT has another upcoming visualization tool developed by RST International Inc., named DynuStudio®. DynuStudio® trial version allows users to prepare DynusT networks from GIS based planning networks, edit and improve
networks, develop and manage scenarios, run DynusT and visualize DynusT simulation results for debugging and analysis purposes. The major features of DynuStudio® include dynamic output animation in bandwidth plots, diagrams for departure/arrival profiles and time-of-day statistics, dynamic vehicle trajectory animation with modes and delays highlighted in colors, dynamic vehicle trajectory plots for selected links and vehicle IDs, bandwidth plots for selected links and zones, demand OD flow plots and advanced data manipulation with embedded Python scripting and APIA (DynusT website). A sample screenshot of a DynusT model in DynuStudio® is seen in Figure 5.

Figure 5: DynusT in DynuStudio for SACOG

Source: SHRP2 C10 video published on March 31, 2013 available online at https://www.youtube.com/watch?v=XusLse-uN7o

Sample Application

North Carolina’s Triangle region is modeled in DynusT (Williams et al., 2011). This region is delineated by the cities of Chapel Hill, Durham, and Raleigh. The main focus of the study is on the I-40 corridor and its increasing problems due to
rapid growth in the region. I-40 corridor includes I-40, I-85, I-440, I-540, NC147, and US-70 highways and plays a crucial role in economic vitality of the region and the entire state. A calibrated DynusT model is prepared in this study for the Triangle region as a tool to evaluate the system performance impacts of different operational strategies, including High Occupancy Toll (HOT) lanes, congestion pricing, ramp metering, signal coordination, work zone management, and expanded traveler information. The impact of each scenario is also summarized at different levels such as regional network, different parts of I-40 corridor, key origin-destination pairs, and critical links.

In this study, 2015 is used as the baseline year for scenario analysis and the DynusT model is developed based upon 2015 Regional travel demand model (TRM) network, zonal structure, and O-D trip matrices at the full scale. The resulting model has 2,389 zones, 9,527 nodes, and 20,250 links. This model also contained 7,610 intersections with no control and 1,915 intersections with actuated signal control, in some of which the signal plans are based on the field data. Two steps are taken to calibrate the baseline model. First, the default freeway traffic flow models are modified to match the observed flow characteristics. Second, the estimated traffic flows in 2015 are compared to field measured flows in 2009, on the links where traffic demand is unlikely to witness significant changes during this time.

Two time periods are applied in this study for traffic analysis: AM peak (4 hours) and PM peak (4 hours). More than one million vehicles are generated in the model during the AM peak while more than 2 million vehicles for the PM peak. The time dependent O-D demand distributions are also derived using traffic count data distributions from an Automatic Traffic Recorder (ATR) station in the network. It is reported that the model can be run in a reasonable amount of time, when sufficient memory resources becomes available.

**DTALite**

DTALite (Light-weight Dynamic Traffic Assignment Engine), an open-source dynamic traffic assignment model, has been developed at the University of Utah, in collaboration with Kittelson& Associates, Inc. and North Carolina State University. DTALite is designed as a light-weight dynamic assignment tool to
allow utilization of dynamic traffic analysis capabilities for medium to large scale networks which require significant data and computational resources. DTALite uses an agent-based simulation-based mesoscopic dynamic traffic assignment framework with time dependent origin-destination matrices (DTALight White Paper, 2013). DTALite utilizes simplified traffic flow models with capacity constraints and queuing models (point/spatial) to capture within day and day-to-day traffic flow dynamics. The major modeling components include: (1) dynamic network loading (DNL) simulator, (2) various day-to-day and user equilibrium-based dynamic traffic assignment procedures and (3) computationally efficient time-dependent shortest path algorithms that can utilize parallel computing power (Figure 6).

**Figure 6: General structure of DTALite**

The minimum required input data are network data used in static assignment and a time-dependent demand profile for travelers. Two main components of the tool are routing engine and traffic simulation, which join together in an iterative procedure. The route choice behavior of users is modeled in the former component and the selected paths are used as an input for traffic simulation. Travelers choose their routes according to the experienced and predicted travel times. After running mesoscopic simulation, the travel times are fed back into the route choice model for the next iteration. At each iteration, a certain percentage of travelers switch to alternative routes using the updated travel times. This iterative process could be interpreted in terms of a day-to-day learning mechanism.

At the traffic simulation module, Newell’s cumulative-count based traffic flow theory (Newell, 1993a, 1993b, 1993c) is used to simulate queue formation, dissipation, and spillback. Applying this theory, flow volume, travel time, and average speed can be determined for each link based on corresponding entering and exiting flow rates. DTALite does not directly simulate the effects of signalized intersections, stop signs and yield signs. Instead, it employs a point queue model that uses a single outflow capacity value (typically available from the BPR functions) that reasonably capture the effect of traffic congestion at major bottlenecks but cannot take into account the queue spillback and the resulting delay due to storage capacity. This allows avoiding unrealistic and unnecessary gridlock at the first few iterations due to use of “all-or-nothing” assignment at first few iterations.

Transit

DTALite can accept transit network form Google Transit Feed or user specified transit networks. DTALite considers transit routes (including bus, light rail and metro transit) and park& ride routes in its intermodal routing engine. Given the bus schedule, DTALite reads the arrival and departure time at each stop, and constantly compares the bus travel time vs. the driving only travel time for a given origin-destination pair. With different driving travel times at each iteration, DTALite can determine and adjust the route/mode selection for each agent with his/her own route/model choice utility functions. As a light-weight simulator, DTALite takes directly the travel times of public transits given by either published transit schedules or the users’ input for future-year scenarios, and it does not simulate the interactions between buses and passenger cars. This simplified
approach may not be able to capture the complex dynamic congestion effects between different types of vehicles on an arterial street network, nevertheless it is still a valid approach for modeling metro transit mode with its own right of way and the resetting of transit times based on congestion. In addition, a published bus schedule typically has reserved sufficient buffer time to take into account the congestion impact on the road (Interview with Dr. Xuesong Zhou).

Output and Visualization

The major outputs of DTALite are grouped into three: (1) time-dependent link MOEs such as density, speed, volume and queue length, (2) vehicle trajectory with path and travel time sequences, (3) bottleneck identification and point-to-point travel times. DTALite utilizes NEXTA (Version 3) for visualization of the output. The Version 3 of NEXTA has following capabilities: (1) Create, import, edit, store and visualize transportation network data, (2) Spreadsheet based applications for trip generation, trip distribution, and mode choice model calibration, mostly for educational purposes, (3) Perform and visualize static and dynamic traffic assignment/simulation results, (4) Import and visualize network-oriented train timetables and provide basic scheduling functionalities, (5) Import multi-day traffic measurement data and provide multi-criteria path finding results (mobility, reliability and emissions) (DTALite website). Figure 7 illustrates a sample screenshot in NEXTA.
Sample Application

The Triangle Regional Model in North Carolina is one of the large-scale applications of the DTALite. This regional network has 2,389 zones, 20,259 links and about 2,000 signalized intersections. The DTALite model is developed using the morning peak-period demand matrix (from 6AM to 10AM) with about 1.06 million vehicles. The model is validated against a total of 120 hourly link count data. These counts were collected from freeway (from 16 sensors) and arterial links (from 14 sensors). The experiments were performed on a PC with 16 GB memory and 8-core processors running at 2.70 GHz. The running time is about 2 min and 45 sec per iteration. The running time increases to 5 min and 3 sec per iteration with the additional path flow adjustment process is uses. The model run converged after 140 iterations, in a total of 12 hours of CPU time. The validations results showed that the average absolute link flow deviations are 435.15 and 212.21
vehicles per hour per link, respectively, on freeway and arterial links (DTALite White Paper)

DTALite was also used to model the entire Portland, Oregon metropolitan area network. This model included 2,013 zones, 9,905 links, 22,748 links and 1.2 million trips for a four hour time interval.

3.3.2 Proprietary Tools

Two proprietary tools were considered, CUBE Avenue and TransModeler. These tools have wide application throughout the United States and are the most likely tools to be available at planning agencies.

Cube Avenue

Cube Avenue is a vehicle based mesoscopic simulation. Cube Avenue uses the same input as Cube Voyager including O-D travel demand, the roadway network, link properties (e.g. length, capacity, and number of lanes), and traffic signal locations and configurations.

The modeling period in Cube Avenue is divided into small time segments during which the demand is assumed to be constant. Then, for all O-D pairs, demand is needed at each time segment as an input. Time segments could be in the order of minutes or hours depending on the level of detail that is required. Demand is disaggregated by Cube Avenue into packets of traffic, which can be of any size, from an individual vehicle up to relatively large platoons. Each packet is assigned a random continuous-time departure within the corresponding time segment. Cube Avenue loads the vehicle packets according to these departure times and tracks them throughout the network.

This dynamic network loading can be done iteratively to achieve dynamic user equilibrium. For this purpose, Cube Avenue finds the lowest-cost path for each packet, based on its departure time and dynamic traffic conditions. Dynamic Traffic Assignment is implemented using the Method of Successive Averages. To reduce the required computational resources, a probabilistic interpretation of MSA is employed. In this method, a trip between a given O-D pair has a specific probability of switching to a new minimum-cost path at any given iteration and given time segment. This probability is reduced as iterations proceed. Another
assignment method is available in Cube Avenue, in which users are allowed to perform additional iterations of route choice for a given time segment before the model goes to the next time segment. This method is called Incremental DUE assignment and could reduce required number of iterations and runtime. Problems in early segments also have a better chance to be fixed before they impact the entire model.

Queue formation at bottlenecks is evaluated by applying first-in-first out (FIFO) queuing discipline at nodes. In Cube Avenue, link storage constraints can be considered in addition to flow capacity constraints and therefore if storage constraints are exceeded, queues spread backwards from link to link. On the contrary, in many other simulation packages, storage constraints are not truly enforced. Cube Avenue is also capable of representing the existing geometrics at intersections and traffic control systems.

Figure 8 illustrates information flow in Cube Avenue. Different levels of aggregation are used in this process regarding the temporal details. After the simulation of vehicle packets through the network, flows and queues are analyzed at continuous time which is the most disaggregated level. Finally, link costs are calculated for using in the next iteration based on the queue and flow data, applying macroscopic flow-delay relationships.

Figure 8: Information cycle in Cube Avenue
Transit

With Cube Avenue, it is possible to integrate any static or dynamic tool with Cube to account for transit. For example, the Cube Voyager transit model can be interfaced with these assignment tools. In this way, while a dynamic model is used for the highway network, a schedule-based static assignment model can be used for the transit network. While it is not possible to create dynamic transit model within CUBE, this provides an interim solution for including transit (Hadi et. al, 2012).

Output and Visualization

The main output file that Cube Avenue generates is a text file that includes the complete results of simulation in a format that is ready for additional processing. Using this pseudo-XML format file, it is possible to postprocess results e.g. to identify which trips pass by a particular point in the network at a particular time. This information is essential to implement advanced analyses like select node/link analysis, computing queue for specific user groups, and peak spreading. The network file is another important output file that provides different performance measures on all road segments. Volume, queue length and speed are among the default outputs that Cube Avenue provides. It also reports LOS and operating conditions for intersections. Most of these measures are defined time-dependent and so outputted separately for each time segment during the simulation run.

Cube utilizes a built-in ArcGIS engine to visualize the results. Thus the visualization of the output available in CUBE Avenue is very similar to visualization for other simulation packages, with the exception that packets of vehicles are visualized using the packet log file (Figure 9). Using the network file, the CUBE user can code the road segments over time by defining bandwidth and color charts based on different measures. By this way, users can see how a particular value changes over time. Dynamic intersection LOS can also be visualized in Avenue.
Sample Application

Brown et al. (2009) developed a hurricane evacuation model for the Greater Houston, Texas, area, which investigated the performance of major evacuation routes before the disaster. Dynamic traffic assignment was employed in this study using Cube Avenue. The main objective was to identify bottlenecks in the transportation network and accordingly establish appropriate policies to effectively evacuate people during the natural disasters.

The model in Cube Avenue was integrated with the regional demand model. The regional model, had 3000 zones and 43,000 links, more than 10 million daily trips, and covered 7,700 square miles. However, to save running time and memory usage, the number of zones was reduced from 3000 to around 570 zones in Cube Avenue through a zonal aggregation process (Lam et al., 2009).

In this model, the base case was developed based on the observed traffic conditions within the region during the evacuation response to Hurricane Rita in
2005. Evacuation trip tables were built on the data collected shortly after this event and mesoscopic simulations used to model queues on evacuation routes. Policy analysis tools were also used to test the effects of supply-side scenarios such as facility closures and contra-flow lane reversal timing as well as demand-side controls such as scheduling evacuation trip departures.

**TransModeler**

TransModeler (Caliper, 2009) is a microscopic vehicle traffic simulation package which simulates vehicle movement through the car-following, lane changing and gap acceptance models. It also provides detailed description of vehicle interactions at various conflicting points (e.g. intersections, merging areas). In addition, it models various control devices/strategies, including stop sign, signal control, ramp metering, and High-Occupancy Vehicle lanes. Traffic signal timing plans for multiple scenarios and multiple times of day can also be stored and simulated. In addition, it handles different ITS applications like electronic toll collection and traffic detectors.

TransModeler routes vehicles through a learning-and-switching logic. At the first iteration, any available travel time estimation (congested or free-flow) is used in the route choice model. Afterwards, TransModeler begins to simulate vehicle movements iteratively. In each iteration, based on the travel times in the last run, time-dependent demand is assigned to paths. Travel times on all experienced paths between the same O-D pair will be same. Taking this knowledge into account, vehicles along the non-shortest path will switch to the shortest path according to a specific probability. The resulting path flows are simulated on the network and the experienced travel times are used in the next iteration after applying a travel time averaging strategy like Method of Successive Averages (MSA) or Polyak averaging. This procedure is repeated until all but a small number of vehicles have incentive to change their routes. In this case, the relative gap between input and output travel times falls below a predetermined value. Final network performance measures can then be generated. General structure of TransModeler is presented in Figure 10.
As another feature, TransModeler can execute microscopic, mesoscopic and macroscopic simulation-based DTA on the same network database. It can also do hybrid simulation, where the user can decide which links are microscopic, which are mesoscopic and which are macroscopic. All links are then simulated simultaneously and vehicles moving seamlessly from one modeling environment to another. In this way, large networks could be simulated without scaling down to reduce the computational needs. In the mesoscopic approach, speed is calculated through speed-density relationships defined for each facility types (e.g. freeway, arterial, and ramp). In the macroscopic approach, speed is calculated from the volume-delay functions (VDF).

A customized GIS tool has been included in TransModeler to store traffic data such as traffic counts and speeds, that can be analyzed, modified, and directly used in traffic simulation. This GIS tool also makes it easier to build large networks in TransModeler. It should also be noted that TransModeler provides a set of Application Programming Interfaces (API) and allows users to extend the software capabilities beyond the available features in the package.

**Transit**

TransModeler can simulate bus and rail transit systems with frequency or schedule-based service. It provides a network editing environment that can create,
edit and maintain transit routes and stops in a geographic database. Route headways and headway variability for simulating frequent, headway-based transit services or transit schedules for simulating schedule-based service can be defined. It is also possible to specify dwell time parameters, seating and standing room capacities to transit vehicle classes, simulating exclusive bus lanes, signal priority, and queue jumping for transit vehicles. TransModeler can report schedule adherence, reliability measures and ridership statistics (TransModeler Brochure).

**Output and Visualization**

During the simulation, TransModeler gathers a wide variety of detailed data. When a simulation run is complete, the Output Manager in TransModeler can be used to generate reports and maps conveying the results of the simulation. TransModeler also includes a visualization tool that produces animation of complex traffic systems by displaying traffic flows, signal operations, and overall network performance. Resulting animations can be saved for later viewing. Furthermore, TransModeler easily work with GIS data to generate informative maps and charts that could further improve the presentation of the results. Another key benefit of Transmodeler is the ability to show the model operations in 3D view. Figure 11 presents a sample screen shot in TransModeler.
TransModeler provides disaggregate vehicle trajectory data for all vehicles in the network, which can be post-processed to estimate required results. For instance, using trajectory data, emission of various air pollutants can be estimated by common microscopic emission models, without additional programming. In TransModeler, it is also possible to export subareas of large networks to be simulated on a more localized scale. Comparing output results from multiple simulation runs is another capability of this simulation package.

Sample Application

Chang et al. (2012) developed a model in TransModeler for a before and after study of the Inter-County Connector (ICC) in Maryland, which is a tolling facility. The model is employed to evaluate the base-year (2010) network and the after-ICC scenario that includes the new ICC freeway. The aim was to prepare an effective...
tool for traffic analysis and travel forecasting in the study area. Moreover, with a microscopic level model, the study is able to replicate detailed traffic dynamics and impacts of traffic operation strategies.

The simulation model includes all freeways, major arterials, most minor arterials, and some local streets along the I-270/I-495/I-95 corridor in the North Washington D.C. metropolitan area. The simulated network includes 7121 links and 3521 nodes. Furthermore, a route diversion model and a departure time choice model are developed in this study and integrated to the model in TransModeler to more realistically predict behavioral reactions to network changes (Zhang et al, 2012).

4 TOOL SELECTION (TASK 1.C)

This section builds on the review conducted in the previous section, synthesizing the information gathered to make an informed and targeted decision for selecting the tool to achieve the objectives of the project. The functional specifications of the software, previously described in section 1, are repeated below. Table 1, provides a summary of the capabilities of each package to address the model functional specifications.

- Vehicle based analytic capability
- Person based analytic capability
- Transit routing and path finding capability
- Capability to run the entire MSTM network
- Subarea analysis capability
- Flexibility to modify software
- Simplified network modeling
- Visualization
- Technical and computational support
Table 1. Comparison of capabilities of each software tool considered

<table>
<thead>
<tr>
<th></th>
<th>TRANSIMS</th>
<th>DynusT</th>
<th>DTALite</th>
<th>CUBE Avenue</th>
<th>Trans-Modeler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Based</td>
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<tr>
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<td>✓</td>
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<tr>
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<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>Subarea model generation for focused analysis capability</td>
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<td>✓</td>
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<tr>
<td>Flexibility to accommodate user modifications</td>
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<td>✓</td>
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<tr>
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</tr>
<tr>
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<td>✓/-</td>
<td>✓/-</td>
<td>✓/-</td>
<td>–/-</td>
</tr>
</tbody>
</table>

The software packages reviewed have varying degrees of capability and user friendliness. However, some general comments can be made about the differences between commercial packages and open source packages.

Commercial packages generally have the advantage of being more user friendly with customized, high quality graphical display capabilities within the package. The commercial packages are therefore easier to set up and apply. However, commercial packages, at this point have limited capability to represent person
flows and do not handle transit person trips. Commercial packages also typically have proprietary methods in the software and the user cannot see internal algorithms which lead to convergence. Also users cannot modify commercial packages to address issues which are beyond the capability of the current version of the package.

On the other hand, open source packages are not as user friendly as commercial packages and can be more difficult to initiate. In addition they may require that the results be linked to visualization tools not part of the package. However, open source packages have the advantage of allowing users to see the algorithms and understand the internal procedures. They also allow users to modify the code should that be necessary to address new issues. Finally, open source packages are available free of charge and do not require a licensing fee. Therefore, we recommend narrowing down the software tools considered to open source packages.

Of the open source packages reviewed, DynusT, DTALite and TRANSIMS, all have strengths and weaknesses. Our review did not identify one package which was clearly dominant. All packages are person based. Also, all packages have further development either planned or underway. Because of these factors, the final selection is a judgment call based on information available in early 2013.

**Computational Requirements** - One important factor must be considered in software selection, computational requirements. Due to the large size of the MSTM network (more than 167,000 links) and large number of vehicle trips (31,894,070) and households (4,490,547) to be analyzed, any package selected will have significant computational requirements, likely requiring very fast computers and/or a multiprocessor and multithreaded environment. In addition to expertise on simulations, expertise on this type of computer environment will also be required.

**Software Selection**

The final software selection was based on two factors; transit capability and, computational support
Transit Capability

The proprietary packages, even though they are more user friendly, were not selected due to the lack of adequate transit capability and the lack of a person based modeling capability. While discussions with package developers indicated that transit capabilities are planned, as yet there has been no active development.

All of the open source packages were person based or had plans to become person based and had a transit capability. However, the transit capability in TRANSIMS has had more extensive testing and requires less development for this application.

Computational Support

As stated earlier, given the size of the network and the number of trips and vehicles to be included, advanced computational support will be required. This may include the acquisition of high end computers to run applications in a reasonable amount of time and also the expertise to run problems in this type of environment. The Argonne Labs TRACC center has large scale multiprocessor computing capability and has installed TRANSIMS on this system. The labs offer free access to the system and technical support to users of TRANSIMS. Support of this type is not available for other packages.

**Recommended approach – TRANSIMS**

While microsimulation is the typical method for moving individual travelers and vehicles through the network, micro-simulation is also computationally intense and requires detailed network information, including intersection and signalization detail. In addition, an extensive network cleaning and debugging process, with multiple runs required to fully develop the network. Given the size and extent of the MSTM network, microsimulation would be computationally prohibitive.

Based on the information above, as well as other factors, we recommend the use of the TRANSIMS Router for the following reasons:

- The TRANSIMS Router has the capability of running at 15 minute time intervals using the BPR curve to adjust link travel times, simplifying the computational requirements
- The transit capability in TRANSIMS is more mature than that of DynusT or DTALite.
- Software support will be available for TRANSIMS from the Argonne National Laboratory as well as training on the use of TRANSIMS.
- Staff from AECOM, who have extensive experience with TRANSIMS applications, will be available for informal technical support.

The TRANSIMS Router will be used for this study. The Router component of TRANSIMS can be run at 15 minute time intervals, updating link travel times using the BPR curve at each time step. This approach eliminates the need for detailed signalization and intersection data and the process of detailed cleaning of the network. TRANSIMS, of all the open source packages reviewed, has the most mature and tested transit capability, both in representing the movement of transit vehicles and in tracking individuals through the network as they access and depart transit. The Router will be used as a stand alone tool, with feedback from one iteration of the Router providing input to the next iteration, allowing for a stable solution.

Through the feedback process between consecutive router runs, TRANSIMS provides capability to find a stable solution without going into microsimulation. While this is not precisely a Dynamic User Equilibrium solution; for large scale statewide networks, the Router Stabilization process (by using Router output as input to succeeding iterations of the Router) adjusts paths and departure times so that traffic is distributed more realistically. This process allows for closer approximation of travel patterns without requiring the computation burden detailed intersection analysis.

Using the TRANSIMS Router will allow the inclusion of time dependent network analysis within the MSTM, providing a clearer picture of the time of day characteristics of the network performance without getting into the complex intersection and signalization details of an extremely large network. It will greatly improve the ability to understand the temporal aspects of freight movements, travel characteristics at different times of the day, peak spreading and the routes of individual vehicles. In addition, by tracking transit vehicle movements through the network the results can be used to compare travel times from transit skims to travel times based on congested networks.

Based on the analysis we recommend TRANSIMS for this project. This recommendation is based on the specific project needs and is not a general
recommendation for TRANSIMS. Other projects, with different needs, may use other software packages.
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