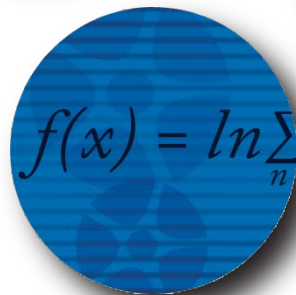
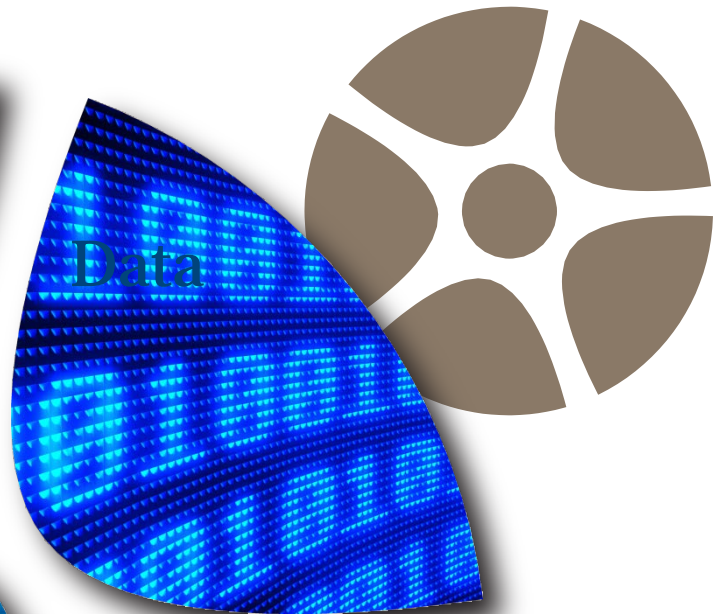


A Practical Guide on DTA Model Applications for Regional Planning

June 2016



U.S. Department of Transportation
Federal Highway Administration



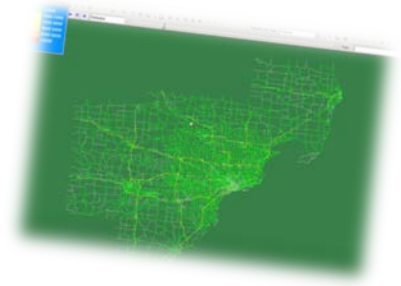
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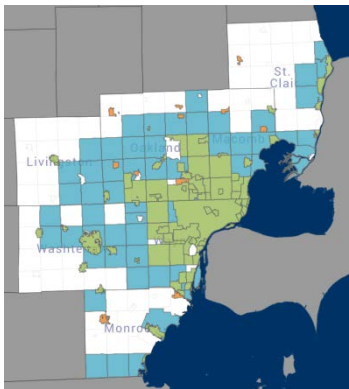


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16. Abstract This document is intended as a guide for use by Metropolitan Planning Organizations (MPO) and other planning agencies that are interested in applying Dynamic Traffic Assignment (DTA) models for planning applications. The objective of this document is to provide guidance on key practical aspects of working with DTA models, namely, information about model development, application, calibration and validation. This document relates to some experiences at the Southeast Michigan Council of Governments (SEMCOG).				
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1.0 Introduction and Background

This How-To document is intended as a guide for use by Metropolitan Planning Organizations (MPO) and other planning agencies that are interested in applying Dynamic Traffic Assignment (DTA) models for planning applications. The objective of this document is to provide guidance on key practical aspects of working with DTA models, namely, information about model development, application, calibration and validation. Relevant DTA modeling experiences gathered from interactions with the Southeast Michigan Council of Governments (SEMCOG) during the course of this project are also provided as examples in the main document and additional modeling information about SEMCOG is provided in Appendix A.

While the primary focus of this document is on the application of regional and corridor-based DTA models for planning purposes, readers are encouraged to peruse the *Guidebook on the Utilization of Dynamic Traffic Assignment in Modeling*¹ (“FHWA Guidebook”), and *Dynamic Traffic Assignment – A Primer*² (“TRB Primer”), for discussion on broader topics and readings pertaining to DTA. The reader is also encouraged to review a summary of the status of DTA modeling at MPOs³, which provides also provides the status of Activity-Based Models (ABMs) along with the status of DTA modeling at peer MPOs of the Metropolitan Washington Council of Governments (MWCOG).

In order to provide the reader with additional background and context, proceedings from an Association of Metropolitan Planning Organizations (AMPO) Travel Modeling Working Group’s meeting with emphasis on DTA⁴, held at the Atlanta Regional Commission (ARC) and by web conference on December 17-18, 2015, are provided in this chapter. The proceedings presented in this chapter are based on the discussions held at the AMPO meeting and are presented in the following sections:

- 1.1 Uses of DTA
- 1.2 Challenges in Using DTA
- 1.3 Research Needs

Additional details, such as the attendee list and complete meeting agenda are included in Appendix B and Appendix C respectively. This document benefited from the feedback on one its draft versions that were reviewed at this AMPO meeting, and attempts to address some of the concerns raised regarding DTA modeling.

1.1 Uses of DTA

DTA provides a way to examine the interaction between network performance and demand on a transportation system, at a much more fine-grained temporal and spatial resolution than is typically available in static four-step models. Participants discussed their experiences with DTA, and agreed that DTA is useful for assessing traffic management actions. It is also useful in situations where either supply or demand tend to be highly time dependent, and in situations where it is necessary to report on congestion and queuing in greater spatial and temporal detail than is possible with static models.

Traffic management actions that were mentioned include shoulder running (either for buses or general traffic) and any number of Intelligent Transportation System (ITS) improvements including dynamic pricing, ramp meters, transit signal priority, and signal coordination. Although tolls can be handled to

some extent in a static model, a time-sensitive model is needed to handle dynamic pricing, especially on a managed lane with a target speed. Similarly, the treatment of signals in an arterial system is inadequate in static assignment.

DTA is useful on congested corridors, where time-of-day choices, queue spill back and response to incidents need to be considered. In such an environment, static assignment is not detailed enough, but microsimulation may be more detailed than is necessary. A windowing approach may be helpful, with a regional DTA and increased refinement in a subarea.

Finally, DTA is useful where demand is highly time-dependent. This includes special event and evacuation planning.

With increasing computer capabilities and data availability, models are increasing in fidelity. The modeling of dynamic traffic phenomena is one example of this increase in fidelity. However, DTA is not the only approach. Microsimulation is another approach and some have argued that in a dynamic environment, it may not be necessary to run a model to equilibrium.

1.2 *Challenges in Using DTA*

Challenges in using DTA include:

- Ensuring that users understand the assumptions about travel and driver behavior, and traffic flow theory underlying a particular DTA model;
- The representation of transportation supply (the network and traffic controls);
- Representation of demand;
- Run times;
- Convergence; and
- Data needs for calibration and validation.

1.2.1 Transportation Supply

A DTA network and its associated traffic controls typically require more detail than the network used in static assignment models. For example, in its Second Strategic Highway Research Program (SHRP2) Integrated Dynamic Travel Model (C10) project that includes a DTA component, ARC has allowed one year for network development. They conflated an existing stick network with a NAVTEQ (now part of HERE) centerline file to obtain geometries, and also used NAVTEQ to add most of the signals. A variety of sources (Google maps, local jurisdictions, Georgia Department of Transportation) were needed to get to 100%; this involved substantial manual work.

Obtaining sufficiently detailed traffic signal information can be time consuming. Although the locations of traffic signals are often available, the challenge is in obtaining phasing, timing and progression information. This information is available from Synchro files, and DynusT has some defaults. ARC's model has more than 5,000 signalized intersections, and found coding the signals to be a four-month effort involving staff and three interns. Given this high level of effort to code the signals in a large network, a reasonable approach might be to focus detailed modeling efforts on the regionally significant

corridors, and accept approximations and defaults elsewhere. Without reasonably good signal plans, the DTA can struggle with convergence and networks can become overloaded with congestion. The degree of detail needed for the modeling of signals also depends on the model package being used, with a microsimulation model typically requiring more detail than a DTA model.

Networks that are used in static models may not have the detailed road geometries (turn pockets, multiple turning lanes) that are sometimes required in DTA models. Finally, although it was not discussed at this meeting, detailed information on transit services and access may not be readily available.

Future-year conditions can also be an issue. Heuristics based on population and employment forecasts may be used to synthesize traffic controls at future year intersections. In a 30-year horizon, potential technological and social changes (for example, shared autonomous vehicles), may make it impossible to simply extrapolate from existing conditions. A related question is that of updating the network from year to year. An MPO might be using a base map from a third party provider with annual updates. How does one merge the changes from a new base map into an existing network?

1.2.2 Transportation Demand

In a static model, the demand for transportation is typically represented in a zone-to-zone trip table for a particular time period that may last several hours. In trip-based static (four-step) models, entries in the trip table may be fractional, and often less than one. Dynamic models may be expecting integer trips, from one location to another location at a particular time. Three areas require attention:

- Translation of origins and destinations to the level of spatial detail required by the intended use of the DTA. For example, if a corridor analysis on an arterial is being performed, and the DTA can use locations on a street to introduce flow to the network, the zonal flow may need to be distributed among the locations on the streets in the zone.
- Assignment of departure times. If there is a certain number of trips during a particular time period (e.g., the AM peak 7 – 10 AM), these trips may need to be distributed to specific departure times.
- Creation of integer trips. Trip table entries often have fractional values. Techniques, such as bucket rounding, exist for making reasonable conversions from fractional to integer trips.

1.2.3 Convergence

Combined DTA / ABM systems can have significant central processing unit (CPU), memory and disk requirements, resulting in long run times when multiple iterations are executed in an effort to reach convergence. It may be helpful for DTA users to share their experiences, so that the appropriate hardware can be acquired at the beginning of a project.

Convergence of DTA models raises a number of other questions. Although static models may be reasonably expected to reach a 0.0001 or lower relative gap, it may not be possible to reach this point with a DTA model. With integer flows and no splitting of trips, too much oscillation might occur. With

this oscillation, there may be significant “noise” in the model, as total vehicles hours traveled (VHT) and other performance measures change from one iteration to the next. Dynamic tolls will also affect convergence, as the toll prices may change from one iteration to the next as the use of the facility changes. When DTA is used to assess a small project, the expected improvement in VHT might be small enough to be masked by this noise.

More fundamentally, we should be asking what level of convergence is needed, and what types of convergence we should be measuring. The answers may change depending on how the model is used. For example, aggregate numbers are fine when considering air quality attainment. On the other hand, more detail is needed when a ramp or specific road is being analyzed.

1.2.4 Calibration and Validation

How much data are needed to calibrate and validate a DTA model? A large region may need more than 5,000 traffic counts, which will come from a variety of sources: local, county and state DOTs. For example, the SEMCOG static assignment model uses about 7,000 daily traffic counts.

A number of agencies are looking at INRIX and AirSage data. AirSage is mostly used for origins and destinations, while INRIX provides speed and some volume information. One participant remarked that in the Washington DC region, the INRIX data covers nearly all of the freeways and many arterials. It is good at showing congested areas, but may not provide reliable free flow speed information.

1.3 *Research Needs*

Research needs fall into the following areas:

- Helping users to understand how DTA fits into a modeling environment, and why DTA is valuable
- Input data
- Convergence, calibration and validation
- Software and hardware

1.3.1 User Understanding of DTA

A potential user of DTA may be an MPO, State Department of Transportation (DOT), municipality, or other agency. They need to make the case for DTA by bringing well-documented applications and case studies to senior management. Case studies can help in demonstrating the potential benefit of DTA to regional planning.

Users also need to understand how DTA will fit into their modeling environment. An agency may have both static and dynamic models for different uses. For example, the static model may be used for air quality assessments while a dynamic model is used for corridor analysis. Finally, an agency needs to understand what level of staff resources will be required to develop a DTA model.

1.3.2 Input Data

What is the minimum amount of data needed to support a DTA model, at the corridor or subarea level? The answer to this question will depend on the planned use of the model, but for most models, the following data types should be considered:

1. Supply (network) data. Starting from a line network of roads, what additional data are needed? Do signal locations (without phasing, timing, and coordination) provide a reasonable starting point, or are detailed signal data needed? What network fidelity is needed (e.g., pocket lanes)? Is there value in providing a standardized representation of a routable network, to include links, nodes, intersection connectivity, pocket lanes and traffic controls? What tools would be most useful for converting supply data into a form usable by DTA?
2. Demand data. How detailed does demand data need to be in time and space. Many are now using a 15-minute temporal resolution for time-dependent trip tables and time-dependent shortest path. What are the implications of using 15, 30, or 5 minutes? What are the implications of using zone versus parcel data? How do we ensure consistency with existing trip tables?
3. Calibration data. How much count and speed data are needed to calibrate and validate a DTA model, and at what level of temporal resolution?

The treatment of traffic signals is particularly challenging in a large network, where there are insufficient staff resources to optimize individual signals and sets of signals on corridors. DTA models would become significantly more useful if they included the capability to synthesize good signal timing, phasing and coordination plans, based on inputs including projected traffic volumes, road functional classification, and policies (e.g., we will optimize flow on XYZ corridor).

Research is also needed on the treatment of traffic controls in future year models. It may be necessary to link travel forecasts to land use forecasts. In a long term (20-30 year) forecast, not only do we need to forecast future travel patterns and the resulting traffic volumes, we need to forecast what traffic controls will be put in place in response to the changed traffic patterns. We may also need to consider major technological changes, such as automated vehicles. One idea is to treat the control as an agent, with a predictive model of what it will do (e.g., if volume exceeds X, the stop sign becomes a signal). Perhaps such a model can be tied to traffic signal warrants.

1.3.3 Convergence, Calibration and Validation

In a static model, the number of trips on a particular route between an origin and destination is typically fractional, with travel time being calculated via a set of volume-delay functions. The travel time is an average over an entire time period, which is typically several hours. On the other hand, a DTA model will provide trajectories for individual vehicles (especially if it is a simulation-based DTA), with an integer number of trips. In such an environment, what is the best convergence that can realistically be achieved?

Related to this question is that of the stability of the solution from a DTA model. Will performance measures, such as VHT, remain the same from one run to the next, given identical inputs? Or will they vary enough to mask any improvement created by the project under consideration?

In an environment where both volumes and speeds vary with time, how is calibration done? The traditional count-based methods for static models still apply, but what about the newer data sources? How does one effectively use thousands of 15-minute counts or speed observations? What are the calibration criteria?

1.3.4 Software and Hardware

Participants mentioned a number of DTA products, including DTALite, DynusT, Aimsun, Dynameq, Cube Avenue DTA, TransModeler, TRANSIMS, TransDNA, DynaMIT, VISTA, DynaSmart and DIRECT. Although obtaining details from the vendors of proprietary software can be challenging, it may be helpful to compare DTA platforms to identify strengths and weaknesses, including technical support and data needs.

Given the run time issues that sometimes occur, participants would like more support from DTA providers on what equipment to acquire, and how to set it up.

Finally, it was noted that a mix of open source and commercial DTA software products are available. Which business models for DTA software support can most effectively meet user needs going forward?

1.4 *Report Organization*

The remaining part of this report includes the following chapters:

- ✓ 2.0 Development and Application
- ✓ 3.0 Calibration
- ✓ 4.0 Validation
- ✓ 5.0 Conclusion

Chapter 2 provides some of the “wisdom” gathered as part of prior DTA applications. This chapter provides insights that would help ensure useful results and more efficient applications, thus **it is highly recommended that the reader not skip Chapter 2**. Chapters 3 and 4 provide a plan for calibration and validation and key checks to help verify the accuracy and usefulness of the model results. Chapter 5 provides concluding remarks.

2.0 Development and Application

Often MPOs taking a plunge into large-scaled dynamic traffic assignment (DTA) modeling face challenges in the absence of experienced outside support. This is not uncommon because over the decades, agencies have become quite comfortable working with static traffic assignment (STA) as part of their four-step trip-based travel models, or through activity-based models (ABM) that employ STA for assignments and the preparation of skims. In comparison, DTA is more complex and requires additional

considerations because it works at a finer temporal resolution and a more disaggregate spatial level. Many of these considerations require additional know-how and more intensive checks on network and travel data, model setting and computing resources.

The purpose of this chapter is to first provide step-by-step guidance on applying DTA analysis to regional and corridor level networks and then highlight several practical considerations involved in applying the DTA models. These considerations cover a wide range of topics, from software and hardware setup to questions that help validate results. It is recommended that modelers become familiar with the points that are raised in this chapter and treat them as a “checklist” to help ensure that the DTA model is properly applied.

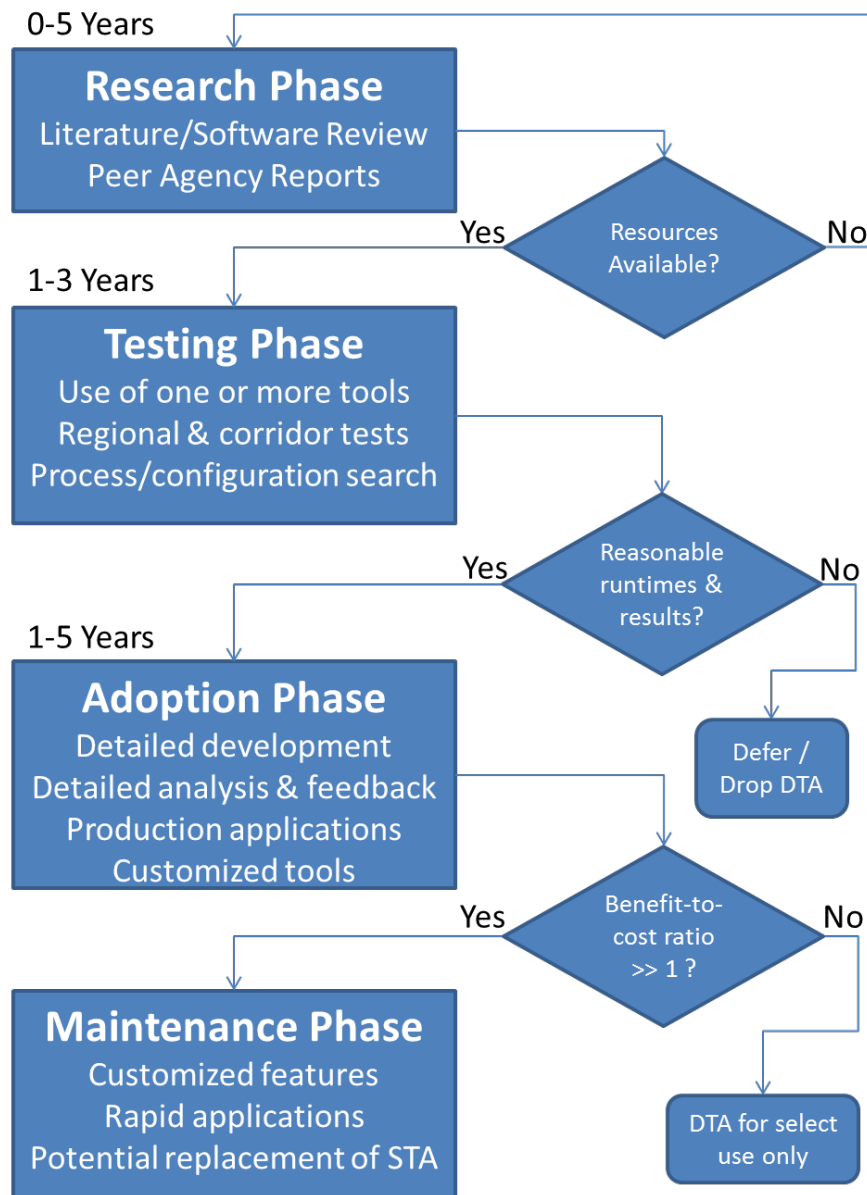
It is recommended that modelers become familiar with the points that are raised in this chapter and treat them as a “checklist” to help ensure that the DTA model is properly applied.

In addition to the topics presented here, readers may also find it helpful to review the PSRC Case Study⁵ (“PSRC Case Study”), which describes the integration of DTA in a regional four-step modeling framework.

Figure 1 presents the phases an agency is likely to pursue when developing a DTA model. The amount of time spent in each phase varies widely between agencies due to many factors, such as the level of congestion in the region, the push from decision makers to answer questions that can’t be answered sufficiently or at all by static assignment, etc. Nonetheless, estimated time durations are provided for each phase to help orient the reader. Note that these time periods need not necessarily be additive, especially if a lot of effort has been spent and a lot has been learnt in the earlier phases. In such cases, the efforts in the subsequent phases become relatively easier and have a higher chance of success. On the contrary, bad decisions or insufficient efforts in initial phases can have long lasting impacts and also prove to be expensive.

The first phase is the *research phase*, when an agency begins exploring publications to learn more about DTA. In this phase, the staff may utilize surveys and literature to learn about the strengths and weaknesses of DTA and to examine the potential feasibility of DTA applications in their region. Preliminary software decisions, implementation strategies, and desired results are formed during this stage which is largely influenced by what peer agencies have been able to successfully achieve.

Figure 1: Conceptual Phases of DTA Application



The second phase is the *testing phase*, where some resources are committed to performing hands-on experimentation using local datasets, either with or without experienced external support. This phase is very influential in charting out the next steps for DTA implementation in the region. If the experiences from the testing phase are unfavorable, such as poor model runtimes or laborious setups, the agency is likely to delay or even abandon the pursuit of DTA for the time being.

If the agency achieves desirable results, the process may lead to the *adoption phase* with actual production applications to help answer policy questions that require DTA capabilities. Adoption may be incremental: an agency may use DTA for special stand-alone studies before integrating the tools to

include traditional or activity-based models. In addition, the agency may develop custom tools to support DTA and may include feedback to their demand model.

Continued success in the *adoption phase* is envisioned to lead to the *maintenance phase* where an agency might replace its STA model with a DTA model and take steps to support the customized application of DTA for their region.

2.1 *Start with Realistic Expectations*

One of the key aspects of an agency's "user-experience" with DTA is how easily the DTA model can be executed and how quickly it returns results. These early "user-experiences" can be quite influential, which can significantly affect the agency's scope and timeline for adoption of DTA. While this experience can vary depending on various factors such as the type of analysis being performed, the software in use, etc., starting with realistic expectations and applying the software in an optimal computational configuration can help avoid situations that adversely affect this experience.

Compared to STA models, DTA models may take about 10 times longer to complete.

The data requirements and model execution times are the primary reasons agencies have been reluctant to adopt DTA methods. DTA modeling is an order of magnitude more complex than traditional equilibrium assignments. Modelers, agency leaders, and decision-makers need to clearly understand the implications of the complexity before embarking on a DTA project. They also need to be told that there are a significant number of transportation improvements and management strategies that can only be evaluated realistically using dynamic methods.

As a general rule of thumb it will take 10 times longer to develop networks, calibrate models, and complete DTA model applications than it does to perform similar tasks using static assignment tools. This is partly due to the fact that DTA tools are less mature and most modelers have little experience or training in the fundamental concepts and challenges of dynamic modeling. A useful metric for gauging if a DTA model is configured and running appropriately is to estimate how long the static user equilibrium assignment will take for the same time period and network size (using a conventional STA software package) and multiply that run time by 10 to estimate the DTA run time.

Given this expectation, an ideal DTA application design will attempt to match the computer processing time to real-time conditions. Thus, each hour of simulated time should be processed in at most one hour of real time: an all-day (24 hour) assignment should take about 24 hours or less to complete. If the size of the network or the simulated time period requires more than a one-to-one relationship to compute, the tool is likely to be impractical for typical planning studies. Potential solutions to long run-times include reducing the study area or investing in a more powerful computer system.

2.2 *Gain Familiarity with DTA Concepts*

The essential difference between STA and DTA is the added "time" component in path-building and facility throughput. With this added temporal dimension, the network is usually enhanced by the addition of operational details such as pocket-lanes, signals, lane-connections, and dynamic lane use

restrictions (e.g., HOV operations). The added network details primarily depend on the capabilities of the chosen DTA software, the availability of operational data, and computer resource limitations given the size of the region. Due to the increased network details, the level of efforts for implementation could be significant.

Nevertheless, it is critical for the modeler to gain familiarity with the DTA concepts such as time-dependent paths, diurnal distributions, and analytical vs. simulation-based DTA, to better understand and appreciate the workings of the DTA model. The FHWA Guidebook and the TRB Primer mentioned earlier are excellent resources. In addition, the modeler may simply want to go through the accompanying documentation of their chosen DTA software to discover key functionalities in the software relevant to their application.

DTA software can generally be classified as either analytical or simulation-based. Analytical DTA packages adopt some form of flow-density relationship to propagate traffic through the network and estimate travel times. Simulation-based DTA packages model traffic propagation through algorithms that capture realistic individual vehicle maneuvers and traffic phenomena. These simulations could be either event-based, that is the positions of individual vehicles or platoons of vehicles are updated at every change in state (or event) of the system, or be time-based, where at predefined intervals of time (e.g., every 6 seconds) the positions of the vehicles or platoons are updated. Analytical DTAs will typically run faster, but may not model queuing and spillbacks accurately, therefore under-estimating congestion. Simulation-based DTA applications generally take much longer to model a given network demand, but they often require fewer iterations to reach a converged solution. Understanding the needs of the planning effort is helpful in selecting the most appropriate DTA methods.

2.3 *Ensure Correct Software and Hardware Installations*

Since DTA software packages are relatively new and less mature than traditional travel demand software, modelers should ensure that a stable version of the software is installed and software updates and bug fixes are tracked. New versions of a given software package may generate different results or introduce new problems that the DTA software provider has not anticipated. Two-way communication and a good working relationship with the DTA software provider are important for successful implementations.

Most regional or corridor-based DTA applications will require 64-bit versions of the hardware and software to avoid the memory limitations associated with 32-bit software and hardware and a relatively powerful and modern workstation, with the following minimum configuration. The hardware specification needs can vary with the particular DTA software under consideration. The hardware solutions can be broadly classified into two categories, 1) high-end computing server-based solutions, and 2) high-end computing workstation-based solutions. The difference between the two is whether a server(s) is used or a workstation(s) is used. In simple terms, servers are generally designed to handle a large number of relatively smaller tasks, and workstations are generally designed to handle a few relatively intense tasks. Usually servers come in “rack” cases and are stored in a climate-controlled environment, whereas workstations come in “tower” cases and are placed in the regular office workspaces. While this is true, the line of demarcation between what hardware can be called a server

and what hardware can be called a workstation is constantly changing because computers have been continually getting more sophisticated and capable. However, the operating systems used on a server and a workstation are always different. Servers allow two or more simultaneous interactive user sessions while workstations are generally limited to a single user. When specified with ample computing power, a server-based solution can be used to run not only a relatively larger regional DTA application, but also multiple subarea DTA applications or traditional regional models. On the down side, server-based solutions cost usually 2 to 4 times more than workstation-based solutions. Additionally, server-based solutions will most likely require remote-access which may introduce some limitations on usability such as screen-lag, as opposed to direct access for workstations. So the pros and cons of the two solutions need to be weighed, especially keeping in mind future expansion needs, to arrive at a hardware solution that can be included in the current and future year budgets.

While a minimum configuration can't be specified across all DTA software and their intended applications, the following is a typical minimum hardware configuration that is also applicable to SEMCOG:

- A 64-bit processor, with at least six-cores (12 threads with hyperthreading enabled),
 - Clock speed and cache sizes should be maximized to the extent affordable
- 24 Gigabytes (GB) RAM, with at least 2:1 ratio of RAM in GB to the number of threads,
- Dedicated hard-disk for modeling data with at least 500 GB storage,
 - A Solid State Disk (SSD) drive is preferable,
 - Otherwise, the disk should be a high-performance disk with at least 10,000 RPM.
- If multiple hard-disks are utilized, RAID 0 ("striping") should be avoided to minimize the chances of data losses due to disk-failure(s). RAID 5 provides a good balance of speed and reliability.

In addition to the workstation configuration, it is also desirable to provide a fast "gigabit" LAN connection (1 Gbps or better) to this workstation so that the data transfers and remote access sessions perform efficiently.

The model execution times are directly dependent on how efficiently the DTA software uses the available hardware. CPU utilization is a key indicator of how efficiently the model is executing. Analytical DTA applications tend to show higher CPU utilization than simulation-based DTA applications because they do not need to process vehicular-interactions and therefore can be more "parallelized". For instance, in the SEMCOG DTA model, the "thread" and "epoch" settings have a direct impact on the stability and execution speed of the model. The "thread" parameter defines the number of threads used by the assignment and simulation modules of the DTA. This value should be set to a number equal to or just less than the number of CPUs available on the machine. An epoch in the SEMCOG DTA defines the number of sub-time-periods that the software should take into account when simulating a given time-period. The number of sub-time-periods helps the software better estimate how much demand should be handled in each sub-time-period and helps it run more efficiently.

Memory utilization should also be watched to guard against “page-faults”. Paging is an operating system (OS) phenomenon where programs requesting more memory (RAM) than is currently freely available are managed by the OS using a combination of hard-disk storage and memory. In this process, a portion of the memory needed by programs is stored in a page-file. As and when the program needs to access the portion of memory that was stored away in the page-file, the OS reloads that portion into memory, while storing away other portions. Page-faults occur when programs have a working memory requirement that exceeds the available free memory. When page-faults are occurring, the OS is constantly shuffling portions of memory back and forth between the hard-disk and memory. In the meantime, the CPU idles. Therefore, page-faulting can cause excessively prolonged runtimes, while diminishing the life of the hard-disks due to excessive disk I/O. This can be overcome by making use of memory-management features of the DTA program, reducing the number of programs that are executed simultaneously, or increasing the memory on the workstation.

Work with your software provider to understand the impacts of tradeoffs in computing environment on model run time and stability

Another factor influencing the model execution times are the format and quantity of produced outputs. ASCII (text) files are more readily human-readable; however large outputs of text files can significantly slow down model execution. Large outputs, such as snapshots of vehicle positions, traveler paths, skims, also tend to slow model execution due to the computation involved to generate that data and to perform file storage operations.

So, essentially the modelers should work with their DTA software providers to understand the impacts of tradeoffs in computing hardware elements, such as CPU, memory, storage, etc., and also understand the performance influence of various DTA software settings on model run time and stability.

2.4 Building a DTA Model

The general process of building a DTA model at a regional or corridor level is outlined below. The procedure is usually applied in an iterative fashion, since later steps usually reveal errors and insufficiencies of previous steps.

- **Step 1: Network coding.** The static model network can be converted to a network representation that can be used for DTA application, but it is vital to ensure the dynamic components of the network, such as managed lanes operations, are adequately captured. Many DTA packages provide functionality to convert static networks in common travel modeling package formats and shapefiles, into their native format. These tools may also synthesize the operational elements that are needed for dynamic modeling, but are typically not included in regional models (e.g., traffic controls, lane connections, access points). If the dynamic elements are not operational for the whole time period (e.g., an HOV lane restriction for 2.5 hours of a 4 hour peak period), manual adjustments and additional control records will need to be included to model dynamic impacts realistically.

- **Step 2: Demand conversion.** Trip tables from the static model can be converted to DTA model demand by using a diurnal distribution by trip purpose and orientation (e.g., converting from production-attraction trip tables to origin-destination trips by time-of-day). The daily travel demand for DTA applications is usually disaggregated into dynamic OD matrices in 15-minute time intervals. DTA modeling also typically requires zone-based trip data to be distributed to many network entry and exit points within the zone to avoid artificial bottlenecks in loading and unloading vehicles from the network.
- **Step 3: Traffic assignment parameters.** Dynamic assignments tend to require more parameters than their static counterparts. It is a good practice to ensure the parameters for traffic assignment (e.g., value of time, flow-density relationships, etc.) fall within sensible ranges. Parameters can be compared to other similar models. These parameters typically need to be calibrated to reproduce local travel behavior, and in particular travel speed. Most regional travel models are calibrated to reproduce daily or peak period traffic volumes, but the resulting speeds are only a minor consideration. Dynamic models typically need to be calibrated to generate realistic volumes and speeds in 15 minute time increments. Half-hour or hourly calibrations may be sufficient for large networks.
- **Step 4: Initial traffic assignment.** The dynamic traffic assignment can be executed with the initial network, demand and parameters, to “debug” the conversion. This assignment will highlight locations where the simplified coding used in many static models will break down in dynamic models. Most static models include links with very high volume-to-capacity ratios that result in extremely low speeds, but the trip will eventually get through and reach their final destination during the modeled time period. The trip completion does not happen in a dynamic model. Simulation-based dynamic models are truly capacity constrained and will not push through more traffic on a link than can be accommodated by the link capacity. Capacity constraints result in queues that backup onto other links and generate cascading network failures. Finding and fixing the source of these cascading queues is an important step in refining the dynamic network or demand profile.
- **Step 5: Checking the initial assignment results.** After the network “bugs” are fixed, the assignment results should be checked against existing validation data sets and local knowledge. Generally, the modeler should check the high-level results and then examine details on specific roads. The high-level analysis should focus on checking the overall vehicle-miles and vehicle-hours of travel by facility type and screenline volumes against the regional model and traffic counts. In general, a dynamic assignment should generate comparable results to a static assignment at an area-based, peak period level. The detailed check on facility-based results should focus on volume and speed profiles by time-of-day. The cause of unrealistic results is likely attributed to network coding or demand conversion issues. Reviewing or

It is important that the modeler be aware of how the algorithm works to know which parameters will affect the results.

refining intersection configurations and traffic signal timing and phasing plans may be the best way of addressing a localized problem.

- **Step 6: Model parameter calibration.** After debugging and refining the network coding and demand profiles, a full run of the DTA model can be executed. This is an iterative process of convergence similar to a static equilibrium assignment, but the temporal dimension and true capacity constraints make the process considerably more difficult to identify a stable solution. The modeler should start with relatively few iterations or minimal convergence criteria and check the results to make sure the network hasn't "crashed" (e.g., cascading queues, excessive congestion, a significant number of "lost" vehicles, etc.). If the network has unrealistic congestion, the model parameters *can* then be adjusted based on comparison with observed data. Several runs may be necessary before a final set of the parameters is determined. These parameters typically focus on flow-density relationships for different facility types. In some DTA models, intersection capacity is an input, while in others capacity or maximum throughput is an output. It is important that the modeler is aware of how the algorithm works to know which parameters will affect the results.

After following the above six steps, a working DTA model should be constructed at this point. Depending on the nature of the analysis, the modeler can code alternatives and make additional runs to determine the benefits of the DTA approach in quantifying the impacts of proposed transportation projects. Subsequent sections will provide more information about the issues that might arise in the DTA application.

2.5 Perform Robust Network Checks

Ensuring that the network is valid, integrated and complete is one of the most important checks throughout the DTA process. The utility of the DTA applications usually stems from the enhanced network details. Therefore, it is essential to maintain a complete and accurate representation of the network. As in the static models, it is important to check basic network attributes and geometric representation such as length and number of lanes, link connectivity, and free-flow speed and capacity. In the DTA network, the modeler should pay special attention to checking the time-varying components of the network, such as dynamic lane use on managed-lane facilities, tolls and signal configurations. A thorough network check could help subsequent modeling steps.

The modeler should pay special attention to checking the time-varying components of the network.

The chosen type of DTA application (i.e., analytical DTA or simulation-based DTA) determines the level of effort required for network development. Since a simulation-based DTA application operates at a higher fidelity than an analytical DTA, the network should be realistic at a higher level of "precision".

Typical network preparation begins with converting the regional MPO network. If this network does not have curvature (i.e., is a "stick network"), it is likely to include unrealistic approach and departure angles at a number of junctions. Without realistic approach and departure angles, the lane-connections can be incorrect or missing in many instances. For example, without proper curvature, a right-side on-ramp can

be interpreted by the DTA network conversion tools as a left-side on-ramp, which would result in different traffic behavior: left-side on-ramps merge into the highest-speed lane, whereas right-side on-ramps merge into the lowest-speed lane.

However, many agencies that have stick networks try to represent curvature on links by adding “shape nodes” with multiple split-links. While this approach makes the geometry of their network easily recognizable, the direct translation causes performance issues in DTA software. Every additional link and node in a DTA model increases the memory and computing requirements, potentially slowing down the overall DTA runtimes. To overcome this “shape nodes” issue, some DTA software can collapse the “shape nodes” to form larger curved links. If the links are not sufficiently “curved” to represent the realistic approach and departure angles, lane-connectivity problems can arise, as described earlier. Additionally, if the split links create short links (less than 100 feet), they can cause computation problems in some DTA software packages. This is because, when using Simulation-based DTA, the link length should be greater than the longest assigned vehicle to properly calculate its contribution to the link performance. In addition, the distance traveled by a vehicle traveling at the fastest assigned speed in the smallest simulation time-increment, should also be greater than the link length, so that the vehicle does not skip over multiple links in that time-increment without impacting the link performance. If proper care is not given to such minimum link length guidelines, the DTA software may have difficulty in tracking vehicles and accurately computing link performance measures.

Another potential issue with network conversion is when the MPO network nodes consolidate real-world intersections, such as a couple of closely-spaced intersections, with all approach and departure links connected to a single network node. Due to this artificial representation of intersections, the lane-connectivity, pocket-lane creation, and synthetic signal timing and phasing plans are significantly affected in the DTA network. In simulation-based DTA applications, this can cause unrealistic congestion due to unrealistic intersection representation and traffic controls.

The processing of zone-connectors is also an important consideration in the creation of the DTA network. A number of analytical DTA packages, such as Dynust, use zone-connectors to load traffic from zones to nodes. In such DTA models, zone-connectors are not physical links, but the beginning and ending points of trips. This makes the turning movements at intersections less useful for intersection level-of-service analysis. Simulation-based DTAs are much more concerned with intersection operations and require that trips loaded to links rather than nodes. In these DTA packages, zones and zone-connector concepts are typically replaced with a distribution of trips to link locations within the zone. If zone-connectors from the regional model are preserved in the DTA network, they should be connected at mid-block locations rather than controlled intersections. In some cases, zone-connectors are converted to local streets to enhance network density. In such cases, the zone-connectors should be connected at mid-block nodes. Lane-connectivity and traffic controls need to be added to properly represent traffic behavior.

Operational details of the signalized and unsignalized intersections are required for simulation-based DTA for moving vehicles through the intersections realistically.

2.5.1 Properly Code Signal and Sign Controls

The intersection controls are usually approximated in analytical DTA models using traffic flow functions. However, operational details of the signalized and unsignalized intersections are required for simulation-based DTA for moving vehicles through the intersections realistically. While signals and signs both define the right-of-way for conflicting vehicle paths, signals require more attention than signs due to the complexity involved in their coding. Signs are easier to code because they remain static throughout the course of the day. They can either be coded based on real-world data or synthesized using rules or warrants based on the area-type and facility-type of the intersecting roadways. Sign data is typically maintained in shapefiles by the public works departments, making it somewhat straightforward to transfer that information to the DTA modeling network using GIS processing.

Similarly, the signals can either be coded according to the real-world signal timing plans or synthesized using intersection control theories, such as Webster's equation or the Greenshields-Poisson method⁶. When signals are coded and used, the free-flow speeds should be adjusted to *exclude* the intersection delay on arterials with signals, so that the path-builder does not double-count the intersection delay. Typically, the free-flow speeds in the regional MPO networks *include* the effect of signals on arterials, simply because signals are typically not modeled in the regional STA models. However, it must be stated that nowadays "intersection modeling" concepts are gaining popularity. When "intersection modeling" is performed, the intersection geometries are coded realistically but not used, typically as a preparation for DTA modeling. The intersection signal timing is also coded in detail, but it is only used to compute delays for different movements, given traffic flow. In any case, the free-flow speeds transferred to DTA models should consider whether signals are modeled within the DTA or not. If signals are modeled, the free-flow speeds on arterials should separate the delay associated with signals from the uncontrolled travel time on the link. Coding arterial speed limits is one option, though actual uncontrolled speeds are generally up to five miles per hour faster than speed limits.

In the real-world, the signal timing data are stored in the signal controller next to the intersection. These controllers are either isolated or centralized. Isolated signals require physical maintenance by signal engineers, whereas centralized controllers can be monitored and controlled from a Traffic Management Center (TMC) located remotely. The most commonly used signal optimization software used by TMCs is Synchro⁷®, which also acts as a repository for maintaining signal timing data. Another example of signal timing software is QuicNet⁸. Synchro timing plans can be obtained for different times of day from the traffic departments. Synchro timing plan conversion is supported by many DTA packages. Data from other isolated signals are usually obtained in non-electronic formats that need to be manually coded in to the DTA models.

Signal conversion is not a trivial process even with automated or assistive signal processing routines. Care must be taken in considering several factors that can have a significant influence on the DTA model execution and results. The first step is matching the intersection representation in traffic control model to the intersection representation in the DTA model. Typically the traffic control model network is very detailed and may include more approach links than what is being modeled in the DTA network. For example, in a dense urban area, an exit from a parking garage, major employer, shopping center, or

school may have a traffic light with a three-legged intersection in the traffic control model. This intersection would typically not be included in the DTA network. In such cases, it may be helpful to either code a “stub link” to provide access to the special land-use, convert the intersection control to include an “all-red” phase, or drop the signal if the delay is not significant. If the stub link is added, the corresponding demand should be added to this link and removed from other zone access points.

An additional complexity arises when the intersection approach links are represented with different compass angles between the traffic control model network and the DTA network. Some traffic control model conversion tools allow the modeler to define special-geometries to address these situations by forcing a match between the approach links of the two networks. Also, the traffic control model timing data might include demand actuated exclusive pedestrian-related phases, which may not be applicable to the DTA software. Another potential issue is the mismatch between the possible movements at an intersection and the controlled movements at that intersection. If there are movements that are not signal controlled, then, depending on the DTA software, vehicles making those movements may not be given a change to move or may run free. In the former case, they will cause excessive congestion and possibly cascading queues. In the latter, they will cause one or more of the following situations: simulated vehicles run over each other, delays are underestimated, and/or congestion is inappropriately transferred downstream. All of these issues need to be addressed during the signal conversion process. As a general rule of thumb, it may take anywhere between 5 minutes and one hour to resolve signal conversion issues at a given intersection. In regions involving hundreds or thousands of signals, this task can easily become extremely labor intensive. It should be noted that most of this complexity can be overcome if both the traffic control model-network and traffic control model-timing data are being converted; however, more often than not, the traffic control model-network is fragmented and not usable for modeling purposes.

Typically, actual signal timing data is coded and used for corridor or subarea analysis because of the level of effort required in coding, checking and maintaining the signal data can be cumbersome. For regional DTA applications and for forecasting applications, agencies might be better off choosing to synthesize signal data. Synthetic signals eliminate the conversion time and make the network more responsive to future network changes.

Coding actual signal timing plans can be very time-consuming. It may be best to use a combination of synthetic and actual signal timing data.

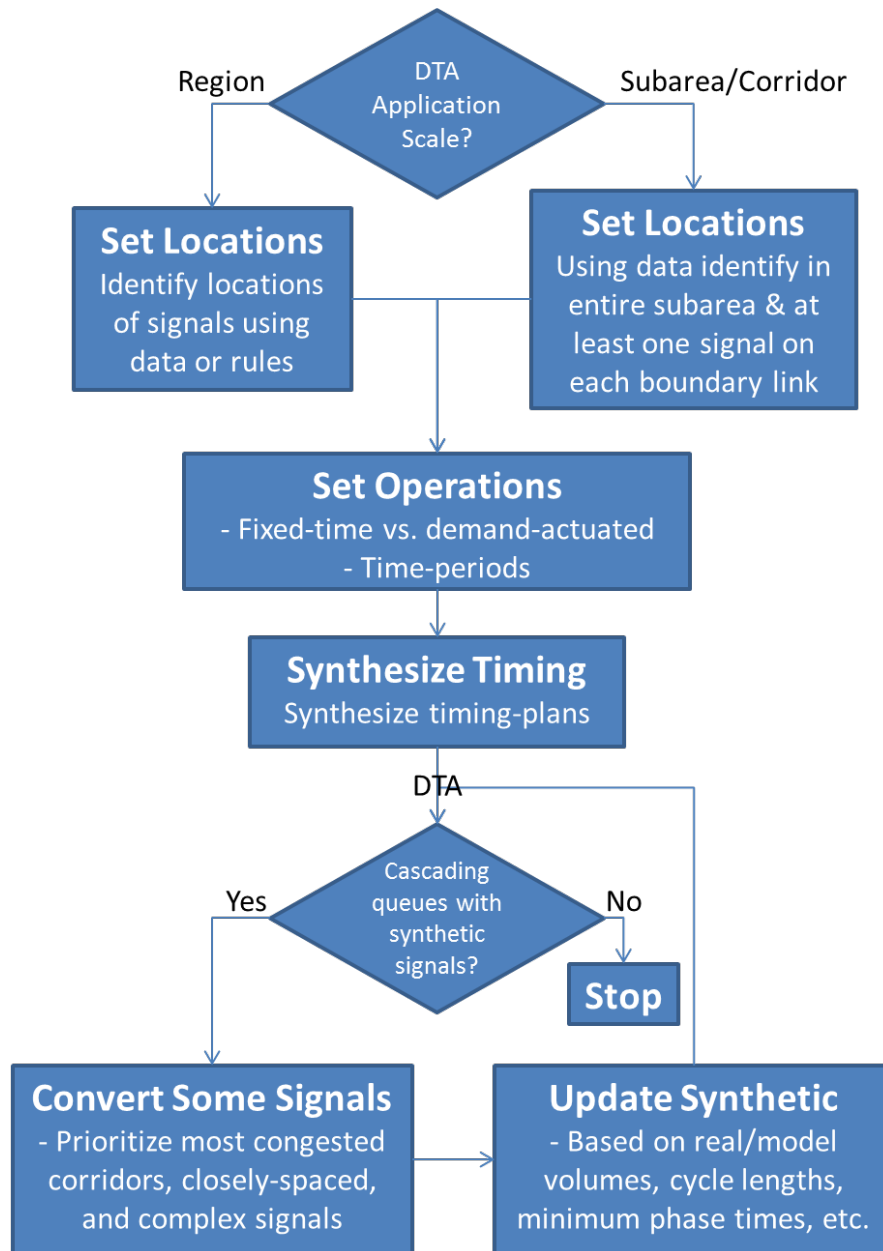
Synthesizing signals is much faster and less error prone than importing actual signal timing data. However, care must be taken to make sure that the synthetic signal data reasonably replicates real world conditions, and that it follows the general principles that a traffic signal engineer might follow when generating the signal timing plans.

Since signals are always customized for every location or corridor, similar care should be taken in developing DTA traffic controls. Closely-spaced intersections are typically coordinated and act as a group. Such signals must be synthesized respecting their real-world behavior to avoid unrealistic traffic congestion at these intersections. One compromise is to use the actual signal timing plans in conjunction with the synthetic signals. It is probably most beneficial to have actual timing plans for the most congested corridors and complex intersections in the region, while using synthetic signals in other parts

of the region. This approach of mixing actual signals with synthetic signals should help with the goal of using signal data throughout the region, while avoiding excessive or unrealistic congestion at key locations and the time required to convert the Synchro signals into a format suitable for the DTA model.

Given all these considerations, often DTA modelers seek to know the 'optimal effort' that they can dedicate. As agencies perform their own modeling, through experience they will develop their own procedure based on their situation (scale of the network, network detail, level of congestion, etc.) and experiences. While a single procedure may not always be optimal for all situations, Figure 2 presents guidelines based on the author's prior DTA experience, to optimize the signal conversion effort.

Figure 2: Guidelines for Optimizing the Signal Conversion Effort

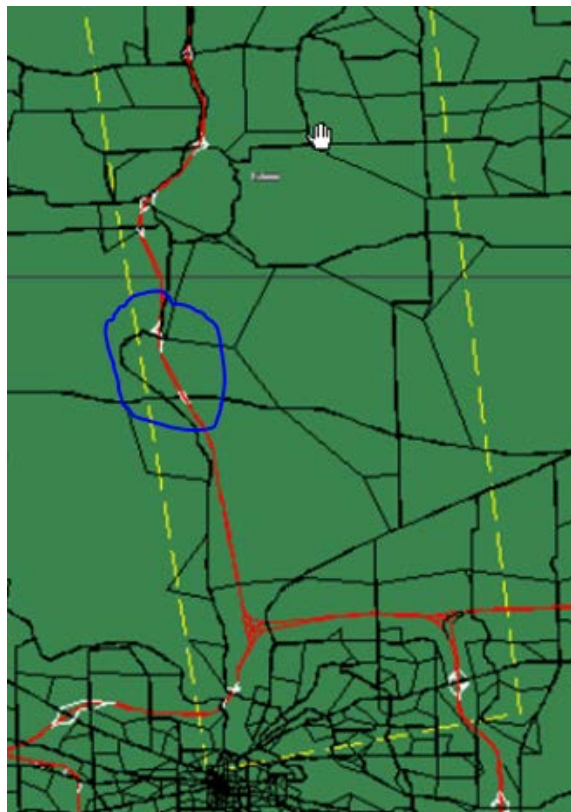


2.5.2 Define Subareas Effectively and Efficiently

Subareas and corridors should be defined carefully so that the primary purpose of doing a subarea analysis (e.g., saving computer processing time) is not hampered. Major entry and exit roadways should be included in the area or corridor along with additional “micro-coding” to represent all roadways with intersections. The parallel facilities that provide alternate paths or detours should be included. The estimates of congestion levels and network performance can be significantly affected by the subarea definition. If the subarea does not include parallel routes, the DTA models will tend to overload the primary facilities without balancing the distribution of traffic on logical alternate paths. In choosing the location to “cut” the roadways, care must be taken to avoid short-links and multiple-cuts on the same roadways. Short-links, as mentioned earlier, can cause problems in some DTA software packages, whereas multiple-cuts will cause unnecessary and artificial boundary conditions. Multiple-cuts, as shown in Figure 3, also will prevent the DTA models from properly loading traffic on that roadway.

The estimates of congestion levels and network performance can be significantly affected by the subarea definition.

Figure 3: Subarea boundaries should avoid double-cutting streets



An important distinction between a DTA model and a traffic operational simulation is that a DTA seeks to equilibrate the distribution of traffic to multiple routes, while a traffic simulation typically loads a fixed set of trips to relatively few routes. From this point of view, a DTA will generally perform many more assignment iterations than a traffic simulation application to calculate a result. The iterative

convergence process can be significantly accelerated by excluding the areas that should not be impacted by the subarea of interest. Including such areas may introduce noise into the model, which affects a fair evaluation of the network performance within the subarea and causes the convergence process to spend additional computational time refining volumes and speeds in areas of little concern to the area of interest.

It is usually best to define subareas where the path options are minimized, such as bridges and between intersections on arterials and between interchanges on freeways. Using this method allows for the entry and exit traffic flows to be verified using traffic counts and metered into and out of the subarea at fixed points (i.e., points with fewer path alternatives). For example, if a freeway is cut, the modeler may define the approach and departure speed of vehicles based on observed data to create more realistic entry and exit behavior of vehicles in the subarea.

2.6 *Ensure Proper Demand Preparation*

Both, the Activity-Based Model (ABM) demand and the STA demand can be converted to create DTA demand. The ABM demand, in comparison to STA demand, is relatively easier to convert to DTA demand because it requires lesser disaggregation and file-processing. Where the ABM demand is complemented with special market models in STA models, the special market demand needs to be processed similar to the regional STA model demand. The conversion of STA model demand is essentially disaggregation of trips. This disaggregation is performed at the temporal level, and, depending on the DTA software, also at the spatial level. It is essential to check that the demand conversion is properly executed. The static model demand is usually converted to DTA model demand (e.g., demand matrices in 15-minute intervals) using diurnal distributions. A general procedure for converting the static model demand to DTA model demand may include the following steps:

Step 1: Prepare zonal demand. Most regional modeling procedures generate, distribute, and select travel modes. The mode-specific, purpose-specific vehicle trip table in origin-destination format can be used as inputs to generate matrices that are immediately ready for DTA application. However, most regional models create fractional trips. Especially when working with simulation-based DTA models, it is important to convert these fractional trips into integer trips to represent whole vehicles in the simulation. The fractional trips also indicate a key difference between STA and DTA. In STA, a single trip can be divided amongst different paths in the resulting assignment, while contributing fractional volumes to the link paths. In DTA, a trip always chooses a single path and contributes to the demand on the link at the time the vehicle enters the link.

Especially when working with simulation-based DTA models, it is important to convert these fractional trips into integer trips to represent whole vehicles in the simulation

When converting from fractional trips to integer trips, a bucket rounding method is most commonly used to minimize the distortion to trip distribution while also minimizing the differences in trip totals. With bucket rounding, at most one trip per zone may be lost or gained, while simple rounding may lose or gain one trip per zone to zone combination. Alternatively,

trips could be rounded using a Monte Carlo approach (i.e., rounding based on random numbers). If the network includes sequential zone numbers in geographic areas, the bucket rounding approach may create less geographic distortion than the Monte Carlo approach, because in the bucket rounding approach the rounding error is accumulated and utilized sequentially. Therefore fractional trip adjustments are likely to be more relatively more geographically contained.

As part of this stage, the decision about the orientation of the input trips is also made (i.e., trip tables in OD or PA format). If trip tables in PA (production-attraction) format are used, then the trip tables are usually split into two orientations – one with P-to-A orientation (trips leaving home) and another with A-to-P orientation (trip returning home). The P-to-A trip table is obtained by dividing the original trip table in PA format by 2, and the A-to-P trip table is obtained by taking the P-to-A trip table and transposing it.

While the regional demand is usually specified by travel modes (e.g., SOV, HOV2+, HOV3+, HOV4+, Light-Trucks, Medium-Trucks and Heavy-Trucks), the modeler should determine which of these travel-modes is modeled in the DTA package and treat them appropriately. If the DTA model does not differentiate between the various occupancy levels, they may be combined. This situation might arise if there are no supporting facilities for certain modes.

These trip tables are usually prepared in this manner for each of the time-periods specified by the regional model before applying further temporal disaggregation. Some DTA software packages can directly interface with the native formats of the regional trip tables, which are typically stored in custom binary formats. Modelers might find it convenient to take advantage of this interface and do all trip table (matrix) manipulations in their native formats. However, being able to work in the native format of the regional trip tables requires the availability of the regional modeling software's license for trip table or matrix operations. In situations where such a direct native interface is not available, or to avoid reliance on the software license, the modeler may export the trip tables, either before or after manipulations, to standard ASCII formats such as tab-delimited or comma-delimited text files for further processing. The modeler can also consider using the recently developed Open Matrix (OMX) format ⁹ for matrix manipulation. Matrices stored in this format can be accessed using Application Programming Interfaces (APIs) in different programming languages and several commercial travel modeling software plug-ins.

When processing ABM demand, which represent demand in integer person trips between zones or sub-zonal activity locations, this step becomes quite simplified. The trips in this case simply need to be compiled with the orientation, mode and purpose identified.

Step 2: Prepare temporal distributions. Temporal distributions are derived from observed travel patterns within the region or from travel surveys. The diurnal distributions are paired with the trip tables for disaggregation of demand to detailed time periods. The input time period determines how the diurnal distributions are utilized. If the diurnal distribution is a 15-minute

distribution for all 24 hours of the day, but the trip-tables belong to a peak-period, such as AM peak, only the portion of the diurnal distribution for the AM peak period is used.

If OD trip tables are used, the diurnal distribution need not be split by orientation. However, if PA trip tables are used, the diurnal distributions should be split to match the orientation of the trips. Depending on the corridor or subarea location, regional diurnal distributions may need to be adjusted to reflect local time-of-day patterns – 15-minute traffic counts can be used to make these adjustments. Depending on the quality of the count and survey data, the modeler may need to smooth the distributions with the help of moving-averages or other techniques to remove the irregularities in the source data. Figure 4 and Figure 5 provide examples of home-based-work (HBW) 15-minute diurnal distributions by orientation. Figure 7 shows the P-to-A or home-to-work trips with a morning peak and Figure 8 shows the A-to-P or work-to-home trips with an evening peak.

Multiple diurnal distributions can also be used to distinguish the arrival/departure patterns of various geographies, downtown areas versus suburban activity centers.

Figure 4: Input diurnal distributions for highway trips going to work by geography

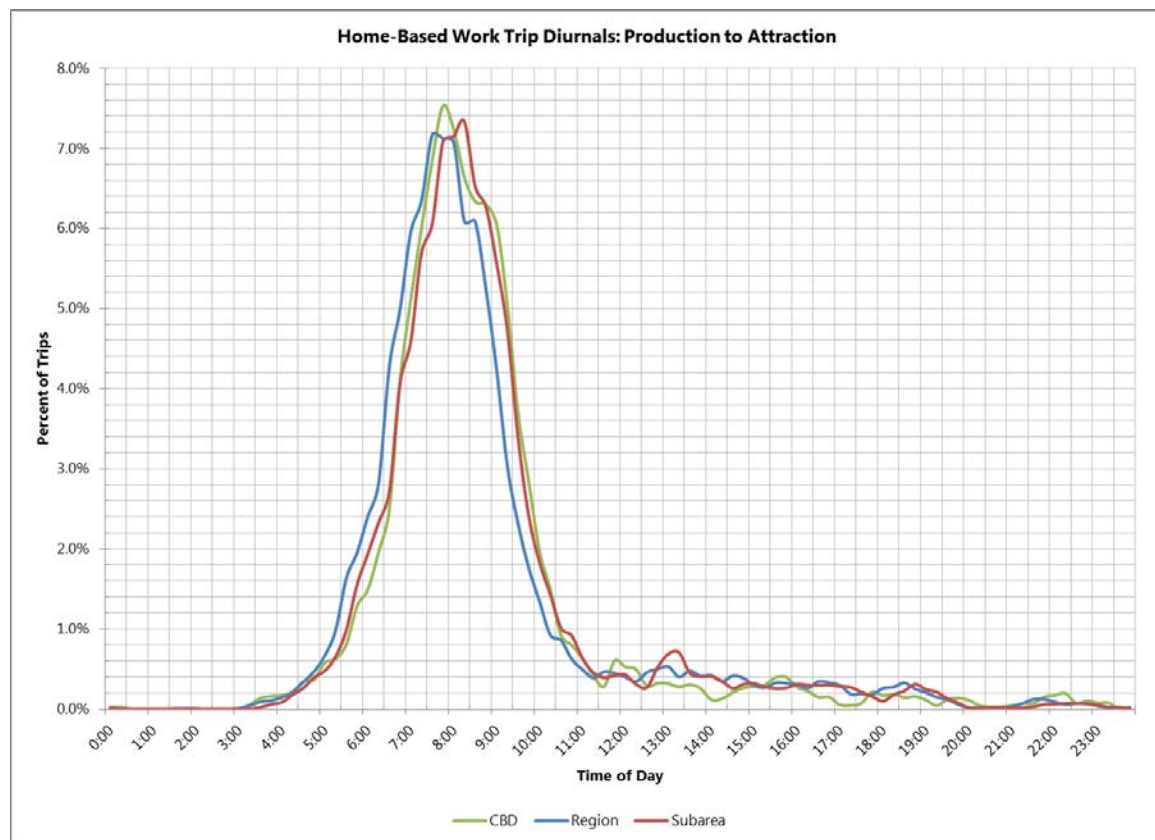
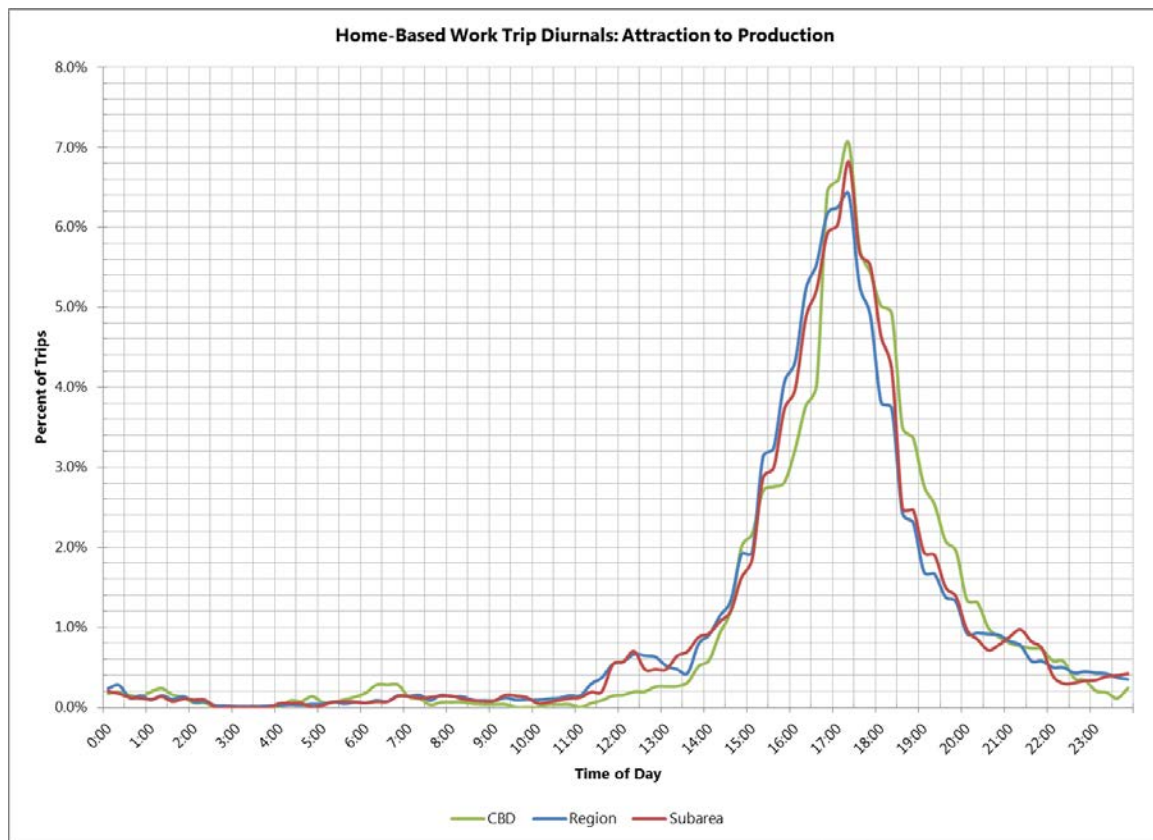


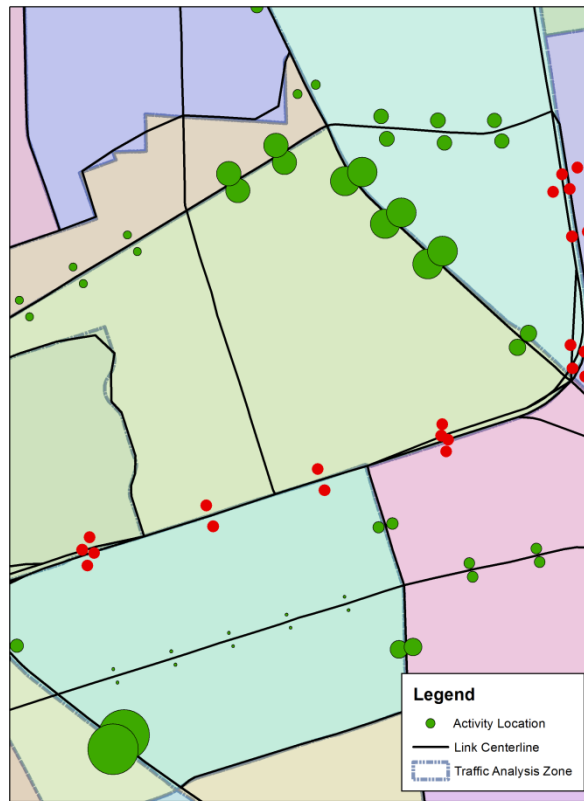
Figure 5: Input diurnal distributions for highway trips returning from work by geography



Step 3: Prepare sub-zonal allocation weights. For DTA packages that model trip-ends at mid-block locations without zone connectors, the demand conversion process also involves specifying how the zonal trips are spatially allocated among the links in the zone. Sub-zonal allocation weights may consider several factors such as the presence of water bodies, parking garage entrances, airport terminals, building footprints, mode-specific access considerations, transit walkability, etc. At boundary locations, it may also be necessary to specify weights depending on the direction of travel. For example, if a freeway is cut at the boundary and is represented by a pair of one-way links, the weights should be set appropriately to avoid assigning originating trips to the outbound link. Similarly, weights should be set to prevent trips from ending on a one-way inbound link. Figure 6 shows an example from a DTA study, illustrating sub-zonal weights for highway trips (shown in red) and transit trips (shown in green). The red dots indicate locations (“activity locations”) where truck trips are prohibited from starting or ending. The size of the green dots indicates the propensity of allocating transit trip-ends based on the proximity to transit service.

At boundary locations, it may also be necessary to specify weights depending on the direction of travel.

Figure 6: Weights for sub-zonal spatial distribution of trips



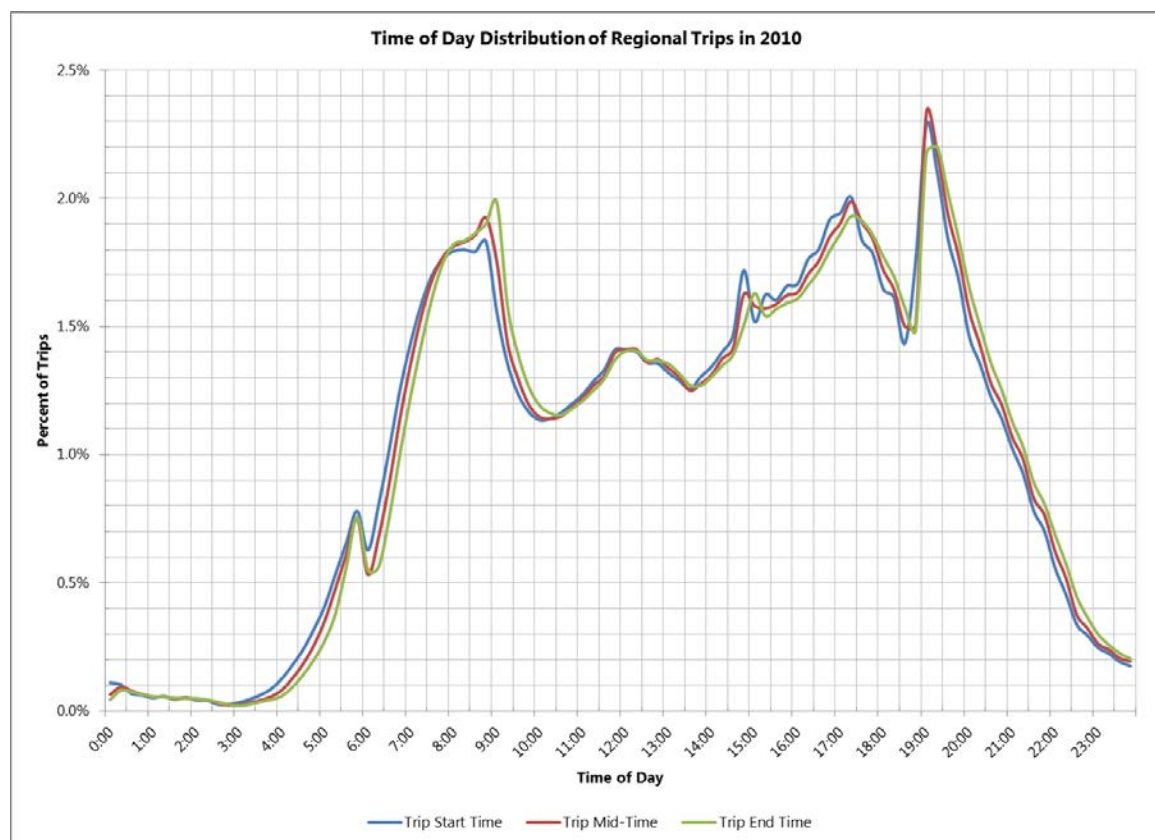
Step 4: Prepare and check DTA demand. The time-period zonal trips are converted into spatially and temporally disaggregated trips by combining the trips with diurnal distributions and subzone weights. This demand conversion process usually takes about an hour or less. However, it can take a few hours depending on factors such as the number of trip tables, the resolution of the diurnal distribution curves and the complexity of the logic for spatial disaggregation. Depending on the software package, the resulting DTA model demand is represented by either one single trip table or many smaller trip tables. The output format depends on whether the trips are specified as OD records or as OD matrix entries. The packages that work with ODs as records can work with a single trip file containing multimodal DTA model demand. Such trip files have columns corresponding to travel mode, departure time, and arrival time of trips, so it can be used to represent a continuous day. The records in these files are usually sorted in ascending time, however, this sort order may not matter if the trip file is entirely read into memory for processing. The other type of representation of trips is the conventional format of using OD matrices. To represent a DTA model demand, a separate OD matrix is used for each time-period increment. Each OD matrix represents a single mode of travel, hence separate OD matrices are

Depending on the software package, the resulting DTA model demand is represented by either one single trip table or many smaller trip tables.

specified for each modeled mode. Thus, total DTA model demand is represented by a set of several individual OD matrices corresponding to a specific time period and mode.

After conversion, the general demand pattern for different trip purposes may be assessed by professional judgment or compared to known distributions if available. The trip duration for certain purposes should also be evaluated to ensure the diurnal curve is valid. The resulting cumulative demand profile, as shown in Figure 7, normally follows the profile of the vehicle counts by time-of-day. Depending on the size of the region and the complexity of the operations of the roadways, this resulting curve might not be representative of any single facility; however, it should give a clear indication of the timing and intensity of peak demands, and the operations in the region. For example, if the HOV restriction ends at 6:30 PM, there will likely be a surge in SOV demand at about that time, corresponding to trips that waited until the HOV restriction expired. This particular example reveals a diurnal distribution problem at 8:00 PM where there is a spike in demand. This was caused by allocating too many trips to the evening time period and not enough to the early morning hours.

Figure 7: Resulting Temporal Distribution of Trips



2.6.1 Define Subarea Demand Correctly

The subarea demand is generally extracted from the regional demand based on paths from a regional assignment. The travelers that enter the subarea should be included in the subarea demand. If a static regional assignment is used to extract subarea trips, the demand at the subarea entry and exit points will still need to be distributed by time of day. Traffic counts at the subarea entry points can be used to define the temporal distribution of trips entering the subarea. Traffic counts at subarea exit points should be used with caution. From a dynamic modeling perspective, traffic counts are the result of a time-dependent trip, but may not represent travel demand by time-of-day. Trips between a given origin-destination pair should be assigned to a demand time period based on when the trip starts. It may take the trip several DTA time periods to reach its destination.

Trips spanning multiple periods have additional implications for how the analysis time period is defined and data are summarized. For a large subarea or corridor, it may take vehicles a significant amount of time to travel from one end of the corridor to the other. If the study is interested in network performance during the peak period, this travel time should be taken into consideration to ensure that all of the traffic that travels on links of interest in the peak period is included in the model. This typically means that the model demand needs to include trips that start prior to the peak period so that the network includes trips that are in-route when the peak period starts. Thus the analysis should exclude performance measures from the pre-peak time periods because these periods typically don't include all vehicles.

Some DTA packages provide the functionality of identifying subarea travelers and generate corresponding demand.

2.6.2 OD Matrix Estimation Using Counts.

OD matrix estimation (ODME) is essentially a matrix manipulation process using a set of target observed data points so that the resulting OD matrix produces assignment volumes similar to the target observed data points. This process starts with an initial or “seed” matrix and involves repeated model assignments with varying adjustments until a desired level of match between the target and results is achieved. Since this ODME process modifies the trip-distribution, care must be taken in its use. Modelers need to understand how a particular ODME algorithm works in order to avoid using it inappropriately or as a black-box. It is important to know that while ODME process may almost always generate a better fit to the input target data, it has the potential to also introduce undesirable distortions when run improperly. The better the quality and the more the extent of the coverage of the observed data, the less wiggle room the ODME process has to make changes. So the extent of the observed data indicates the degrees of freedom that the ODME process has available to it. If the trip-patterns in the input seed matrix are good, then it would be better to use the assignment volumes resulting from that matrix while replacing subsets of it with observed counts, so that the distortions would be limited.

While ODME process may almost always generate a better fit to the input target data, it has the potential to also introduce undesirable distortions when run improperly.

ODME can be largely divided into two types, namely, time-dependent or dynamic-ODME¹⁰ and time-independent or static-ODME. Since MPOs usually maintain conventional four-step models, static OD matrices need to be converted to dynamic ones using diurnal distributions. Static-ODME procedures can help refine these distributions within a subarea based on observed traffic. The inputs for static OD estimation include a target OD matrix, usually the current static OD matrix, and a set of traffic counts. Traffic counts are usually collected using conventional loop detectors but turning movement counts can also be used in combination or alone. Generally, the counts only cover a subset of links in the network but the coverage needs to be sufficient to produce relatively good OD estimates as discussed earlier. Most commercial travel modeling packages provide integrated functionality for ODME using traffic counts; modelers can refer to the software packages' user manuals for more information. When using ODME techniques it is best to have the same configuration for assignment in ODME as it is set in the regular model assignment so that all the assignment considerations such as link-use restrictions, turn-penalties, volume-delay functions, etc. are properly used. While the details of the various ODME algorithms are beyond the scope of this document, it is important to review how travel patterns from the seed matrix are modified in the ODME process. ODME procedures can significantly reduce trip lengths in generating a solution. The algorithm will typically find it easier to converge on a solution by adjusting trips that travel through fewer count locations. Since longer trips typically travel through multiple count locations, the adjustment direction is often contradictory (e.g., low on some counts, but high on others).

The primary difference between static-ODME and dynamic-ODME is how travel time between traffic counts is considered. A static-ODME assumes that the counts for each 15-minute time period are independent of any other 15-minute time period. In other words, travel time is not considered. The process balances the OD flows based on the observed counts for each time period. If the travel times between origins and destinations are less than the size of the demand time period, this may be acceptable. If the travel times are significantly larger than the demand time periods, a dynamic-ODME is more appropriate. This algorithm uses estimated link travel times or observed speeds by time of day to relate the count on a given link in a given time period to counts on other links in other time periods.

2.7 Convergence

Almost all equilibrium-seeking DTA algorithms balance the demand assigned to multiple paths using an iterative procedure. The Dynamic User Equilibrium (DUE) definition dictates that, for each departure time, a user equilibrium solution is reached when there is no substantial incentive for a user to shift routes, i.e., a traveler won't improve his or her travel time by selecting another alternate route. But sometimes, a full DUE is not practically possible given the computing resources and time limitations. Usually, pre-specified convergence criteria are used to guide the assignment. The trade-off between the computation time and model convergence needs to be carefully contemplated to strike an appropriate balance. Several iterations of model runs with different convergence criteria may be necessary identify the setting that generate acceptable results within a reasonable time and cost.

The user-equilibrium in the context of STA is typically defined based on changes in vehicle hours of travel on links. In STA, all trips are assumed to be completed in the specified time period. In other

words, all trips contribute to all links on their path options at the same time such that a change in link performance has a direct correlation to a change in trip travel times. However, in DTA, since both the demand and network are disaggregated, the relationships between link performance by time of day and trip travel times are not straightforward. From this perspective, dynamic user equilibrium should primarily focus on changes in trip travel times rather than changes in link performance. On the other hand, the primary reason for doing a

DTA assignment is to measure detailed link performance. This suggests that the DUE convergence should be concerned about link convergence in addition to trip convergence. In most cases it is more difficult to stabilize link volumes and speeds by time of day than it is to stabilize trip travel times.

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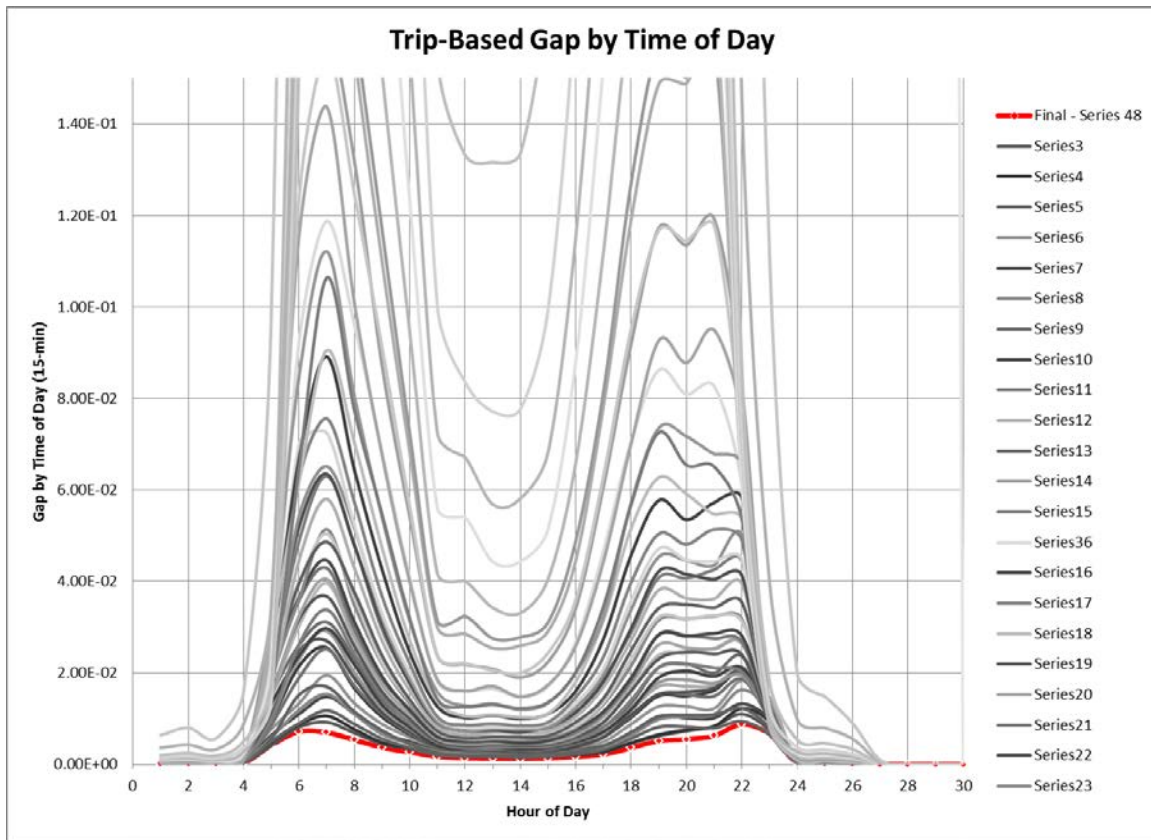
It is also helpful to review link or trip convergence measures by time of day. Figure 8 shows an example of tracking trip-based relative gaps by time of day across iterations. Earlier iterations are shown in light

The definition of gap measures can vary between DTA softwares.

colors and the final relative gap profile is shown in red. This type of analysis helps to highlight the magnitude of the congestion issues the algorithm is attempting to address. It is worth noting that the definition of gap measures can vary between DTA softwares, so the modeler should read the software documentation and understand

how it is defined for their particular DTA software. Sometimes the gap is defined to capture the difference between successive iterations, whereas at other times it is defined to capture the true distance from dynamic equilibrium solution. While the former type, i.e., the difference between successive iterations, could potentially mislead a stable solution for an equilibrated solution, its use may be warranted by the practical considerations of available computing resource and time.

Figure 8: Trip-based Relative Gap by Time of Day



The trip-based relative gap measures the difference between the current trip schedule and the all-or-nothing (AON) trip schedule. It is defined as follows for a given time-period.

$$\frac{|\sum n_c t_c - \sum n_c t_{AON}|}{\sum n_c t_c}$$

Where,

n_c and t_c are number of trips and their travel – times in the current iteration

t_{AON} is the trip – travel time from an AON assignment using the current iteration

The link-based relative gap measures the travel times and demands on links by time of day. It is defined as follows for a given time-period.

$$\frac{|\sum v_c t_c - \sum v_{AON} t_c|}{\sum v_c t_c}$$

Where,

v_c and t_c are link volumes and travel – times in the current iteration

v_{AON} is the link volume from an AON assignment using the current iteration

Ideally, both of these measures should provide the same information and be identical, but due to the impacts of true capacity constraints on link travel times, link-based flows and speeds by time of day can be extremely volatile. In many cases, an increase in congestion at one location will result in improved travel conditions beyond the bottleneck. This tends to even out during the course of a trip and makes the overall change in trip travel time less significant. As a result, the trip-based relative gap is usually less than the link-based relative gap.

For checking closure, modelers may choose to use one or both of these measures by defining minimum thresholds, however, the closure criteria should be used consistently across all applications of DTA. Link-based performance measures, such as vehicle/person miles traveled (VMT/PMT), and vehicle/person hours traveled (VHT/PHT), are typically used for defining measures of effectiveness (MOEs) and are more directly relatable and comparable to similar performance measures from the STA models, therefore focusing on link-based relative gap for convergence may be of greater interest.

Achieving a reasonable convergence in the context of DTA is usually difficult because it is influenced by several factors, such as the network coding accuracy and processing times. Especially in simulation-based DTA models, extreme congestion may occur in the initial iterations when the initial paths are AON paths based on free flow conditions. For simulation-based DTA models, it is usually helpful to perform some analytical DTA iterations upfront to provide a better starting point for the simulation. If a regional analytical DTA model exists and the simulation based DTA is being applied with the same network and extents, then the upfront analytical DTA iterations are not necessary in that case and therefore may be skipped. If the analytical DTA iterations are being performed, it also helps to start with estimated travel times as opposed to free flow travel times. This starting point is even better if the analytical DTA considers intersection delays in the initial iterations. While this step helps to improve the initial simulation, it is also important not to overdo these initial iterations. A few iterations, typically at most 5 to 10, are sufficient to initialize a simulation-based DTA. An analytical DTA will typically require twice as many iterations to generate useful initial results.

Even with a better start, relative gap measure may not converge after many iterations. Such situations are usually associated with bottlenecks (gridlocks in simulation) at one or more locations. Severe or extreme congestion can significantly distort the assignment and convergence process, so it is better to address the source or problem that causes extreme congestion before running a full set of convergence iterations. More iterations are only likely to make the problem worse and create congestion problems in large sections of the network that should not be adversely affected.

One of the ways of addressing major congestion problems is to review and adjust any link, intersection or demand attributes that generate the problem. Usually, the network problems are systemic, so identifying the source of one issue will fix many problems. Keeping track of the number of simulation

It is better to address the source or problem that causes extreme congestion before running a full set of convergence iterations.

or path-building issues by problem type and attempting to understand and address the most significant problems will help a great deal in reducing the overall number of problems and improving convergence.

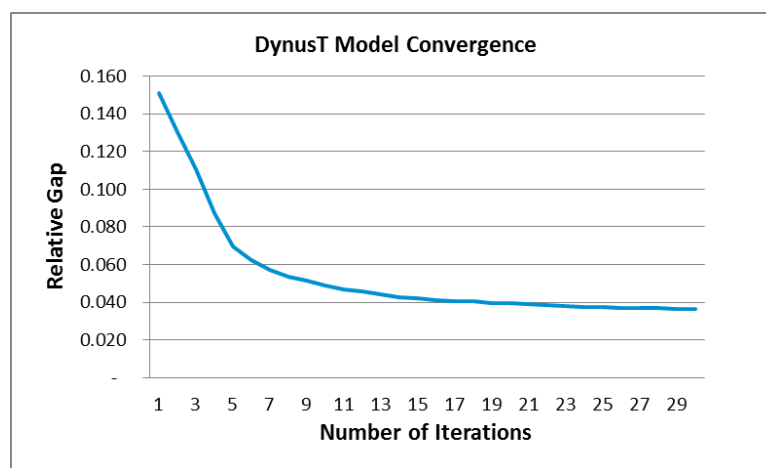
The relative gap threshold in STA is usually maintained at $0.001(10^{-3})$ or $0.0001(10^{-4})$, however, such a high level of convergence is extremely difficult or impossible to achieve in the DTA realm due to integer trips, and stochasticity such as signal operations. Typically, a relative gap of $0.01(10^{-2})$ in the peak period is considered acceptable.

The tests SEMCOG performed to date were all based on 30 iterations with 1% (0.01) gap. The gap closure was not reached at iteration 30 and the model runtime was considerably longer than SEMCOG would like. Figure 9 shows the convergence gap by iteration from a DTA model runs. The minimum gap that model could achieve at 30 iterations was 3.7% or 0.037.

In the static assignment, floating point OD tables are often used, so the path alternatives in the assignment can be performed using fractional trips. This enables the convergence gap to be set to 10^{-3} or even 10^{-5} without generating oscillation problems. Based on the observation, SEMCOG thought that the integer-based DTA assignment might need a different method to achieve a reasonable convergence.

The number of trips in path alternatives needs to be at least 1 in an integer-based assignment. With this constraint, it would be difficult to set the convergence level that is similar to the static assignment. If a convergence gap is set too low, the assignment may oscillate between paths and never reach the convergence target.

Figure 9: Convergence and Number of Iterations



As shown in Figure 9, SEMCOG thought that a 4 to 5% relative gap with a maximum of 15 iterations would be appropriate under the current setting of the SEMCOG's DTA software. As a result, SEMCOG plans to perform all future tests with a maximum 15 iterations and a relative gap at 5% or 0.05. With this setting, the PM assignment model SEMCOG is currently using could be finished within 20 hours. These settings balance the running time with an acceptable gap closure.

Since the gap and run time will change when system congestion levels change, SEMCOG staff plans to monitor the convergence measures during model calibration and future year applications and adjust the closure criteria accordingly.

2.8 *Stability and Sensitivity*

Simulation-based DTA models usually have stochasticity associated with the traffic modeling. To ensure reproducible results, the modelers should keep the random seeds identical in the model building and application process. The TRB Primer suggests the locality of impacts can be used to check the stability of the model. Specifically, the TRB Primer states “a minor change in the network should generally not typically have large impacts on flows or conditions far from the location of the change. Existence of significant nonlocal impacts may be evidence of a poorly computed DTA solution. For example, a minor change, such as a speed limit change on a particular link, would not be expected to significantly affect flows and conditions far from the link in question; DTA model outputs that showed such effects should be closely examined.”

To ensure reproducible results, the modelers should keep the random seeds identical in the model building and application process.

The parameters used in the DTA models may be compared to other similar models if there is one.

2.9 *Forecast-ability*

The DTA models are typically built and calibrated to current conditions. However, their primary purpose is to analyze long-term impacts of scenarios with 10 to 20 year horizons at a finer resolution. A major feature of DTA is the ability to model traffic operational conditions realistically, such as using lane use restrictions and intersection controls. Since there is more knowledge about current conditions than the future conditions, there is greater confidence and available sources for operational inputs to the DTA model in the current year. However, for future scenarios it is impossible to be equally certain about those operational inputs, especially with regards to signals. These inputs to the DTA model come into question especially when the future scenarios experience extreme congestion.

Unlike static models, simulation-based DTA cannot accommodate unlimited demand. Since demand invariably increases with future scenarios, its impact is not modeled realistically when it results in extreme congestion. However, before ascertaining that the demand is the problem, which could possibly be a valid answer, it is desirable to ensure that the process used to build the DTA model is revisited. For example, if the network elements such as pocket-lanes, lane-connectivity and signal timing data were synthesized using rules, then it may be necessary to revise these elements given the future configurations.

If the network is coded correctly and extreme congestion still exists, a more realistic analysis may be to reduce demand to a level the network can reasonably accommodate rather than report performance measures based on total gridlock. In other words, report a demand constraint to decision-makers. Alternatively, major bottleneck locations can be tested and adjusted to avoid total gridlock conditions. It is often more helpful to report performance measures based on “enhanced” network assumptions than to report “doom and gloom” based on total gridlock conditions.

3.0 Calibration

The credibility of the results and advantages of DTA capabilities are easily undermined by failing to adequately replicate existing traffic conditions (i.e., a poor calibration). It is ineffective to use a model with ‘default’ or ‘borrowed’ parameters from another region without verifying suitability for the current effort. Also, performing future alternatives analysis to measure the “delta” or “impact” will be inaccurate without adjusting travel behavior to local conditions. This is because the “state” of a model – its calibration – defines the magnitude and direction of this “delta” or “impact” as observed from model application. For instance, if an uncalibrated DTA model is used to estimate the usage of a future managed lanes project, the answers can vary significantly depending on how well the model represents current traffic conditions. If the values of time are too high in the model, it may result in over-estimation of the usage, and vice versa.

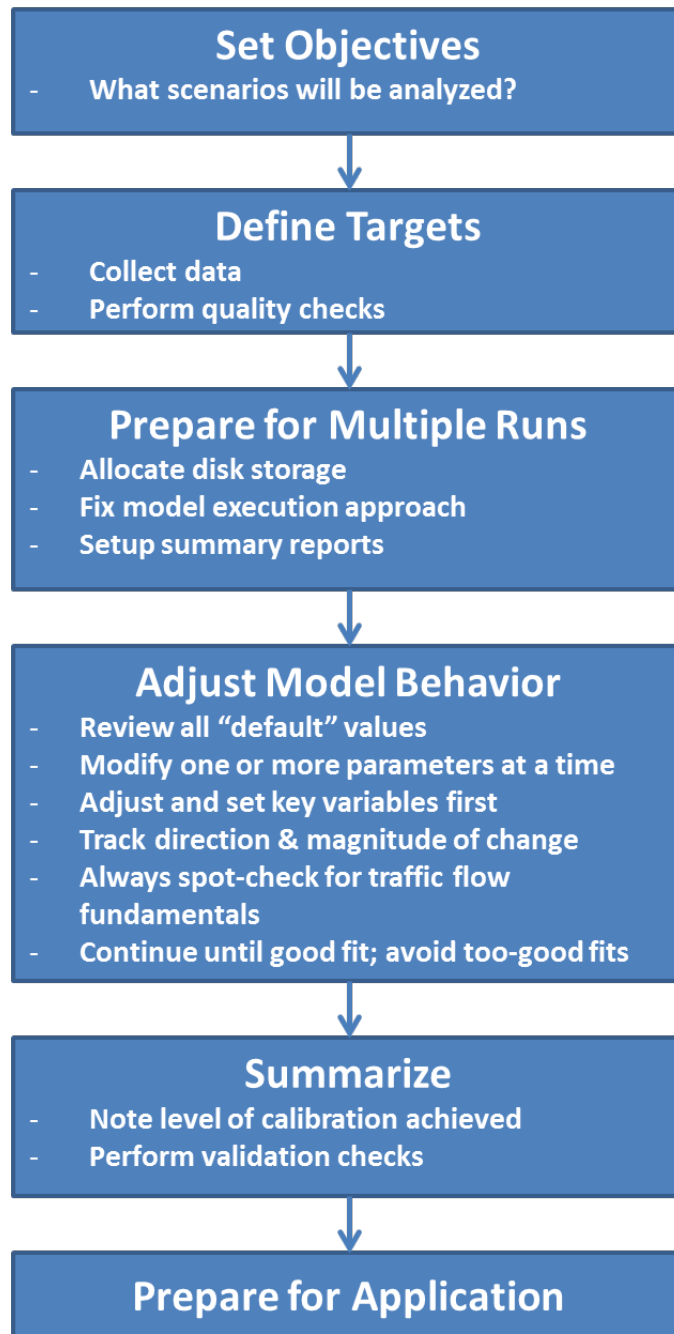
Calibration, especially in the context of DTA, can often appear to be a daunting task due to a variety of reasons, such as unfamiliarity with the modeling software, the complexity of the model, and lack of clarity on what the calibration targets should be. Fortunately, there are several resources available to the modeler to help them get organized and follow a methodical approach to calibration. Some of these resources are listed below:

1. Chapter 8 (“Model Calibration”) of the FHWA Guidebook.
2. Page 35 (“Model Validation and Calibration”) of the TRB Primer.
3. Chapter 5 (“Calibration”) of the PSRC Case Study.
4. Chapter 9 (“Assignment Procedures”) of the Checking Manual¹¹.

This chapter is intended to provide an overview of the calibration step, and highlight the aspects that have the most influence on the usability of results. Since calibration also applies to STA, this chapter focuses on what *additional* considerations are required when calibrating a DTA model, hence modelers should also keep in mind the calibration aspects they would consider with respect to a STA. The reader is also encouraged to go through the aforementioned resources to supplement the information presented here.

Figure 10 shows the various stages of the DTA calibration effort. These stages are discussed further in this chapter.

Figure 10: Calibration Steps



3.1 *Set Objectives*

Before embarking on calibration, it is good to remind ourselves of the scenarios that will be analyzed using the DTA model. This will help identify aspects of the model to pay particular attention to in the calibration process. For example, if the DTA model will be applied to study pricing strategies, then the value of time tradeoffs in the model will require special attention. If the DTA model will be used to study urban arterial corridors including freeway segments, it may be necessary to focus on the movement of disaggregate vehicle classes. Also, if a multi-modal corridor is being studied, modeling transit vehicles and their loadings will be required.

While the details of all the scenarios may not be available, the modelers may be able to know the type of scenario. Using a combination of the full range of planned applications, the modeler should develop one or more objectives for the calibration exercise based upon the type of scenario. Below are some examples of these objectives:

- Calibrate the model for highway and/or transit travel.
- Calibrate the model for peak period(s) and/or a continuous 24-hour day.
- Calibrate the model for the region and/or subarea applications.
- Calibrate the model's pricing, demand management, and/or operational sensitivities.

The objectives help focus on the extent of calibration efforts, and the extent to which they can be met define the scope of appropriate applications of the model.

3.2 *Define Targets*

The next step is to identify the performance measures, identify data needs, assemble data and define the acceptable threshold values for the evaluation metrics. Regarding data, it is important for modelers to recognize the distinction between calibration and validation efforts. Calibration is defined as adjustments to model behavior to meet a desired level of realism. Validation is evaluating the results of a calibrated model. For proper validation checks, the datasets used for calibration should be separate from those used for validation, because the model will naturally compare well against the data that was used to calibrate it.

3.2.1 Data Collection

The following is a listing of some of the data sources used in DTA model calibration, grouped into demand and supply categories. Not all of the data sources are usually available, needed or used.

Demand

- 15, 30, or 60 minute diurnal distributions of trip start times to create/refine dynamic OD
- Bluetooth data
- Cell-phone based OD data, such as AirSage® data
- License plate recognition
- Electronic toll collection readers

Supply

- Vehicle counts in 15, 30 or 60 minute intervals over multiple days to account for variability
- Vehicle class identification (SOV, HOV, Truck, Bus, etc.)
- Speed data, preferably by vehicle class in 15 minute increments, usually obtained from INRIX® or collected in the field
- Travel times by corridor
- Turning movement counts by 15 minutes
- Queue lengths and duration by location--in large regions, SkyComp® provides reports containing such information
- Transit ridership by line
- Transit dwell times--these can also be extracted from the Automated Passenger Counters (APC) systems. In some cases, the Automated Vehicle Location (AVL) data can also be parsed to obtain transit dwell times.

The easiest and most cost-effective approach to assembling these data is to make use of existing datasets, such as those collected for similar studies, or those from published mobility reports. However, it is important to ensure that those datasets are still relevant and have not become obsolete with respect to the base year of the model. Often times, past data from a few years ago is readily available; this data can be used as long as conditions have not changed drastically from when the data was collected.

Quite often, data collected from multiple sources or time-periods are not synchronous. For instance, if volumes were collected from the field whereas speed data was obtained from INRIX®, the two data sources may not show the speed-volume traffic flow relationship. Thus, the modeler will need to prioritize one data source over the other. The collected data almost always needs to be reviewed for quality and accuracy. If the quality related issues can't be addressed and no alternative sources are available, the data should be used with caution.

To the extent possible, it is best to obtain data over multiple days instead of a single day, so that the day-to-day variations in the traffic conditions can be better understood. The model can then be calibrated to the “average” conditions within the range of observed conditions. The model should produce results that fall within the 85th percentile minimum and maximum range of observed data.

To the extent possible, it is best to obtain data over multiple days instead of a single day, so that the day-to-day variations in the traffic conditions can be better understood

3.2.2 Set Criteria

At this stage, after the observed data has been collected and processed, targets should be noted corresponding to each data set when comparing to the model outputs. These should become the minimum threshold values for comparison. For instance, the volumes by time period should fall within 5 percent of the ground counts with a percent RMSE of 40 percent or better, or the 15-minute speed profile should fall within the range of observed speed profiles.

The Checking Manual, mentioned in the introduction of this chapter, provides a valuable list of checks that can be performed on various parts of a model including its inputs. Chapter 9 of the Checking Manual covers the checks and guidelines involved with assignment. While DTA procedures and products were less mature at the time the Checking Manual was written than they are now, several parts of it can be extended for aiding the calibration and validation of DTA models. As a starting point, the DTA model results are expected to be at least as good as the STA model results in representing reality. However, extending those guidelines to the lowest time-resolution of the DTA model may not be practical. For instance, a DTA model working at the 15-minute time-increments may not be able to meet the %Difference, %RMSE and R-squared criteria in every time increment, but it should do so in larger time-periods that are comparable to those in the STA model.

An alternate source could be the guidelines provided by the local state DOTs regarding criteria for calibration and validation. For example, Virginia Department of Transportation (VDOT) publishes a manual called TOSAM¹² that specifies calibration thresholds for microscopic simulation models in Table 5 on page 33. While these thresholds established for near-term, microscopic traffic simulation models are generally more stringent than those for the DTA models, they provide a good reference for consideration.

3.3 *Prepare for Multiple Runs*

Often this step is either ignored or skipped over. As evident model calibration may require scores of model runs, which frequently involves running models several times while pursuing one target, and then pivoting from the original target to pursue another one. So it is important to prepare for multiple runs.

While experienced modelers may be able to manage this in their head by continually overwriting the outputs and not saving copies along the way, the relatively inexperienced modelers will benefit from preparing for multiple runs so that there is some ‘method in the madness’, as the proverbial saying goes.

The following is a list of items that the modeler may consider as part of this preparation:

- Estimate the number of model runs that may be required. Depending on the complexity of the model and the strictness of the specified targets, this may range from 5 to 35 runs.
- Compute the disk space required for each full and partial model run and allocate adequate disk space.
- Establish a nomenclature for identifying different model runs. For example, if the driver reaction parameter is being experimented with, the model names could be, “BaseDR05”, “BaseDR12”, corresponding to driver reaction times of 0.5 seconds and 1.2 seconds.

- Create a workbook to gather model outputs and reports to display and/or compare them to the observed data. This output may be refreshed with each model run.
- Review the documentation of the chosen DTA modeling software to gain familiarity with the various parameters and methods. This will help the modeler develop a preliminary plan.

3.4 *Adjust Model Behavior*

Adjusting model behavior is the core of calibration effort. Both the demand and supply aspects of the model are adjusted so that the base year DTA model results match the observed data at the desired threshold levels. The details of the steps and the level of effort involved here can vary considerably depending on the software being used, however the points discussed below should be applicable generally. Model behavior and parameters corresponding to demand conversion, path building and simulation are discussed below.

3.4.1 Demand Profile

The original dynamic OD trips may have been converted at the regional level using regional temporal distributions. If a subarea demand was prepared from this data, the demand profile should be checked against the count profile at the subarea boundaries. This may be done using the external zones or external links at the subarea boundaries. The overall temporal distribution of the trips, whether the model is for a subarea or the whole region, should be checked against the aggregate count profiles, especially noting the peaking time-periods; appropriate adjustments should then be made. These temporal profiles should not coincide, however, because the time period of *counts* corresponds to when the vehicles are on the road, whereas the time period of the *demand* typically corresponds to the departure time. The temporal distributions of the demand can also be verified against any available sample/subarea OD data from the data sources listed earlier.

The converted dynamic trip tables should also be checked for trip lengths and duration. If necessary, the demand conversion steps should be revisited to improve the demand conversion, using information from the various data sources. One area for improvement may be the spatial distribution of trips. If additional micro-coding was performed in preparation to study a corridor, the sub-zonal distribution of trips can be refined based on any newly split zones or additional activity locations. Other GIS data such as building footprints and parking lots can be used to refine the location of trip ends.

3.4.2 Paths and Driver Behavior

The defining capability improvement of DTA models over STA models is the added dimensionality of *time* to paths. In DTA, the paths are time-dependent. The checks and adjustments to the path-building component of the DTA model can't be overstated, especially in the context of analytical DTA models, which rely heavily on the path-builder to estimate the experienced travel times. Again, depending on the software being used, the names and lists of parameters will vary; however, all of them deal with the three basic attributes of a path: time, distance and cost. These attributes are weighted in a generalized cost function (GCF), which is minimized by the path-builder to obtain the "best path" for a given set of constraints, such as a given OD or a fixed departure or arrival time. Depending on the software,

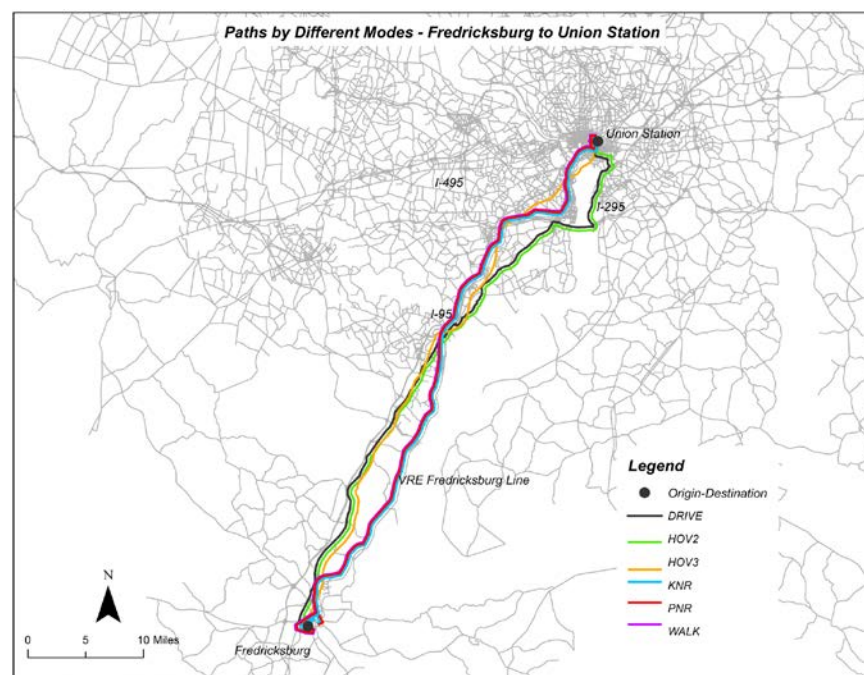
modelers may be able to specify weights by traveler or vehicle-types for further customization. Unless the modeler can make an educated guess, it may be advisable to start with the software-recommended or default values. These weights have a significant influence in the results and therefore should be experimented with early and can then be set for fine-tuning of other parameters later.

In analytical DTA models, the VDFs may be refined to fit available count and speed data for different facility types. It may be necessary to specify upper and lower limits, or caps, on applicability of the VDFs. In simulation DTA models, the path-builder settings should ensure that the outputs from simulation are properly being incorporated, and are not being overwritten by the internal delay computations within the path-builder. Modelers should perform spot checks on paths between select origins and destinations at different times of day and with all the modes being modeled. These test paths should be built under free-flow and congested travel times to study the impact of modifying various parameters. This will often highlight network coding issues that may be preventing the path builder from selecting the expected path. Some of the network coding issues may be related to the dynamic operations of the roadway. Besides testing along the most congested corridors of interest, if applicable, modelers may find it helpful to check their own commute paths in the model. The resulting paths should also be examined carefully for changes in the path attributes along the path.

Modelers should perform spot checks on paths between select origins and destinations at different times of day and with all the modes being modeled.

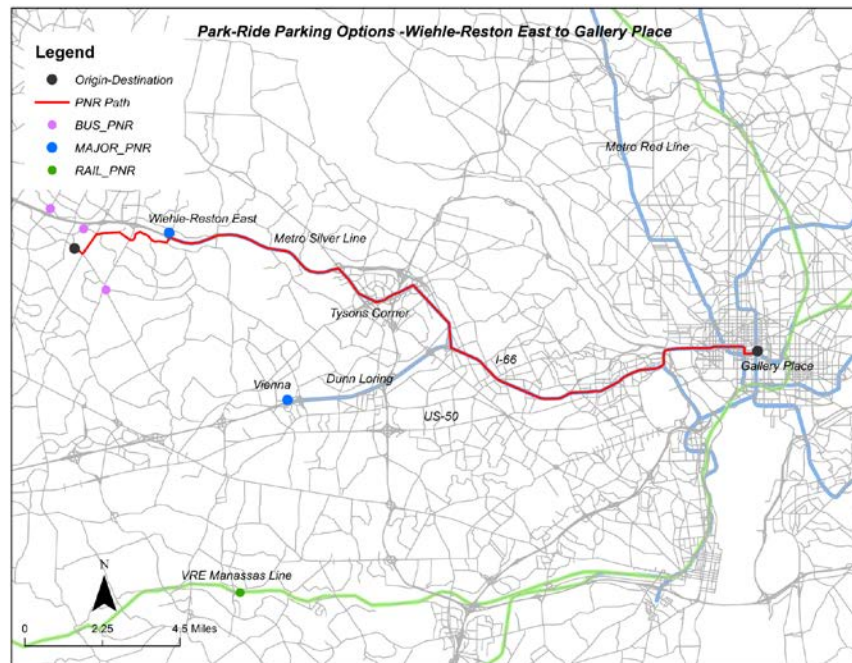
Figure 11 shows an illustration of how multimodal paths were checked along a major freeway corridor with dynamic HOV and Express Lane operations.

Figure 11: Checking Path Builder Paths (Source: AECOM/VDOT)



Similarly, Figure 12 gives an example of the choice of parking lots considered by the path builder when building a transit path using a park-and-ride travel mode. In each of these examples, modelers should look for the reasonableness of the paths under the study's traffic conditions.

Figure 12: Checking Multimodal Paths (Source: AECOM/VDOT)



3.4.3 Simulation Parameters

While the path-builder treats each trip independently, in simulation, the interaction between trips or vehicles provides the estimate of congestion and experienced travel times. The type of simulation and the extent of modeled vehicular interactions can vary considerably between DTA software. Most DTA software uses either macroscopic simulation resolution or mesoscopic simulation resolution. Microscopic simulation is usually not performed due to high processing times. Even within mesoscopic simulation resolution, the vehicles may either be treated as platoons or as discrete vehicles. Depending on the representation of vehicles, the interactions between them, such as merging and lane-changing, are appropriately adjusted. Some DTA software also allow for dynamic multi-resolution modeling for either the whole region or subarea(s). Regardless of these distinctions, the modeler should become familiar with the methodology and parameters of the chosen software, however, the following discussion should be generally applicable to all simulations.

The following is a high-level list of parameters that have the most influence in matching the observed data:

- **Simulation time increment.** Some simulations are event-based and some are time-based. In the time-based simulations, this setting defines how often the calculations are performed or how often the vehicles are updated. Lower values will increase the processing time but may be required for modeling highly congested corridors. Note that the changes to this value may also affect the throughput of roadways, and therefore may require other adjustments to replicate observed throughput.
- **Driver reaction times.** This is perhaps the most influential parameter in simulations and has a direct impact on the level of observed congestion. Obviously, lower values will increase the throughput and vice versa. Some packages specify driver reaction time by facility whereas others specify driver reaction time by traveler or vehicle types. The latter types tend to represent a more consistent driver behavior throughout a trip. These values should be set to represent the local driver characteristics, and should not be set outside of the reasonable range: 0.25 to 1.5 seconds.

Driver reaction time is perhaps the most influential parameter in simulations and has a direct impact on the level of observed congestion
- **Lane-change permissibility.** This parameter determines how the merging and weaving vehicles will yield and give way to other vehicles.
- **Vehicle specifications.** The physical and propagation characteristics, such as the maximum speed, maximum acceleration, comfortable speed etc., of vehicles are specified in the model. These specifications have a direct impact of vehicle movements within the simulation.
- **Tolerance thresholds on delays.** These thresholds tell the simulation how to handle the vehicles that are delayed in either starting their trip, arriving at the destination or in traffic. Some vehicles may get “stuck” in traffic or waiting in long queues at intersections. As discussed earlier in this document, it may be better to remove such vehicles to avoid unrealistic congestion.
- **Plan-following and Look-ahead.** These parameters correspond to how the vehicles change their lanes along their path with regard to where they are currently in their path and what the traffic conditions are upstream of their current position.

4.0 Validation

Two types of validations can be performed with both the STA and DTA models: static and dynamic. The terms ‘static’ and ‘dynamic’ have a different meaning in this context, as compared to STA and DTA. Static validation refers to comparing the outputs of the model to observed field conditions, including comparing multiple time-periods or profiles. Dynamic validation refers to evaluating the change in outputs caused by changes in inputs to the model. An example of static validation is comparing the 15 minute volume profile on a given link to the 15 minute field observed count profile on that link. An example of dynamic validation in a similar context would be to compare the change in 15 minute volumes by time of day given a change in the inputs that impact the observed link, such as, reducing lane throughput with traffic-calming or road-diet techniques. The dynamic validation is similar to performing a sensitivity analysis, but different from it in that the change is judged, not just measured.

As mentioned earlier, the validation is performed with different datasets than those used in calibration, so that the model’s behavior can be verified with similar but different data. The data sources for validation are the same as calibration, so the modeler may either choose to divide data source for each purpose. If a comparable regional model exists, its outputs can also be used for validating the DTA model for aggregate level measures, such as VMT and VHT.

4.1 *Volume, Speed and Ridership Comparisons*

The most important validation reports involve comparison of estimated versus observed volumes and speeds. Some of the validation comparisons that can be performed may include the following.

- Total volume comparison by facility type, jurisdictions and screenline;
- 15 minute volume and speed profile comparisons at key locations;
- Travel time validation along major corridors and between important OD pairs;
- Ridership comparison by transit modes; and
- Ridership at transit stops.

In addition to these comparisons, often just comparing the volumes and speeds together provides insights into the dynamic capacity of the roadways. The following are a few example tables showing the various comparisons.

Figure 13 shows sample validation tables with statistics by volume level and facility type. In the both these tables, the percent difference and the percent RMSE is

observed first, showing overall modeled volumes that are 10 percent over the observed counts, with about 62 percent RMSE and 0.8 R-squared. The results do not indicate a good match and suggest calibration should continue to be improved. However, examining the records closely can help give indicators as to the specific issue. In this case, at the lower volume levels we see that

the estimate is much higher than the observed data. This could potentially be a count tagging issue, for example, if the arterial or ramp counts were accidentally tagged to neighboring freeway links, the

Comparing the volumes and speeds together provides insights into the dynamic capacity of the roadways.

counts will always be lower than the freeway assignments. Looking at the records by facility type in the table below, the higher facility classes are oversubscribed whereas the lower facility types are undersubscribed. This indicates that the bias or weights for line-haul facilities need to be reconsidered. One of these considerations may be to reduce any bias towards higher facility types, either alone or in combination with reducing the weight for distance component of path-building to prefer shorter, more direct paths, over longer paths. Modelers may also want to check if the loaded speeds on the freeways are close to what can be observed. The coded freeway free-flow speeds and speed limits can

The coded freeway free-flow speeds and speed limits can significantly influence the results.

significantly influence the results. The analytical DTA models rely more on the free-flow speeds and the simulation-based DTA models rely more on the speed limit values. If the free-flow speeds are set too high, (i.e. to the highest observed speed from overnight field data), the models can overestimate the capacity of the roadway due to excessive speeding during the period of data collection. On the other hand, if the speed limit is coded as the posted speed limit, typically 55 mph in urban areas, vehicles will not exceed this speed ceiling in the simulation, which would also be unrealistic, thereby resulting in underestimation of the capacity of the roadway.

Figure 13: Sample Volume Validation Tables

Daily Volume by Volume Level								
Volume Level	Links	Estimate	Observed	Diff.	% Diff.	% RMSE	R. Sq.	
0 to 1,000	410	898,365	187,990	710,375	377.9	1,076.3	0.004	
1,000 to 2,500	489	1,879,430	853,957	1,025,473	120.1	279.2	0.016	
2,500 to 5,000	805	4,206,964	3,043,433	1,163,531	38.2	109.7	0.003	
5,000 to 7,500	803	6,095,696	4,976,631	1,119,065	22.5	96.7	0.012	
7,500 to 10,000	561	5,493,336	4,874,646	618,690	12.7	53.1	0.024	
10,000 to 25,000	1,594	25,741,308	24,662,465	1,078,843	4.4	44.1	0.175	
25,000 to 50,000	397	13,085,357	13,362,116	-276,759	-2.1	39.0	0.308	
50,000 to 75,000	148	10,556,788	9,059,101	1,497,687	16.5	33.0	0.124	
75,000 to 100,000	47	3,579,355	3,916,467	-337,112	-8.6	33.9	0.033	
100,000 to 500,000	13	1,417,967	1,536,291	-118,324	-7.7	23.0	0.050	
Total	5,267	72,954,566	66,473,097	6,481,469	9.8	62.4	0.787	
Daily Volume by Facility Type								
Facility Type	Links	Estimate	Observed	Diff.	% Diff.	% RMSE	R. Sq.	
Freeway	490	24,817,364	21,780,296	3,037,068	13.9	46.2	0.591	
Expressway	103	3,060,235	2,364,882	695,353	29.4	38.3	0.840	
Major Arterial	1,222	20,211,117	19,031,032	1,180,085	6.2	37.4	0.535	
Minor Arterial	2,028	17,996,241	16,487,356	1,508,885	9.2	40.4	0.676	
Collector	1,196	5,002,042	4,176,844	825,198	19.8	89.4	0.440	
Local	15	77,038	119,075	-42,037	-35.3	104.1	0.860	
Ramp	213	1,790,529	2,513,612	-723,083	-28.8	109.3	0.179	
Total	5,267	72,954,566	66,473,097	6,481,469	9.8	62.4	0.787	

Figure 14 illustrates an example of comparing 15 minute volume-count profiles. In this example, the 15 minute modeled volumes track reasonably well with the 15 minute count profile. At the daily level, the volumes and counts appear close because the area of the purple line above the blue line seems to get compensated by the area of the blue line above the purple line. However, there is an abrupt spike in the morning peak period, at about 6:30 AM, and a late evening spike at around 8:00 PM. Both of these observations indicate issues in matching the distribution of traffic throughout the day. The morning abrupt spike could be related to operations on the roadway, such as the time when HOV restrictions begin. It could also be due to excessive congestion and subsequent flow breakdown. In such situations, it is worth examining the temporal distribution of demand and the input diurnals for sharp demand spikes, examining the simulation or the delays closely, and inspecting the time-of-day operations on the roadway. The late evening spike seems to be an outlier. Some non-work trip purposes, such as shopping, tend to peak after the normal PM peak period. The number of trips associated with these types of trips, however, should not be greater than those in the normal PM peak period. Similar to the issue in the AM period, checks on the network operations, demand conversion and inspection of simulation traffic or delays can help identify the source of the problem.

It is worth examining the temporal distribution of demand and the input diurnals for sharp demand spikes, examining the simulation or the delays closely, and inspecting the time-of-day operations on the roadway.

Figure 14: Sample 15 Minute Volume - Count Profile comparison

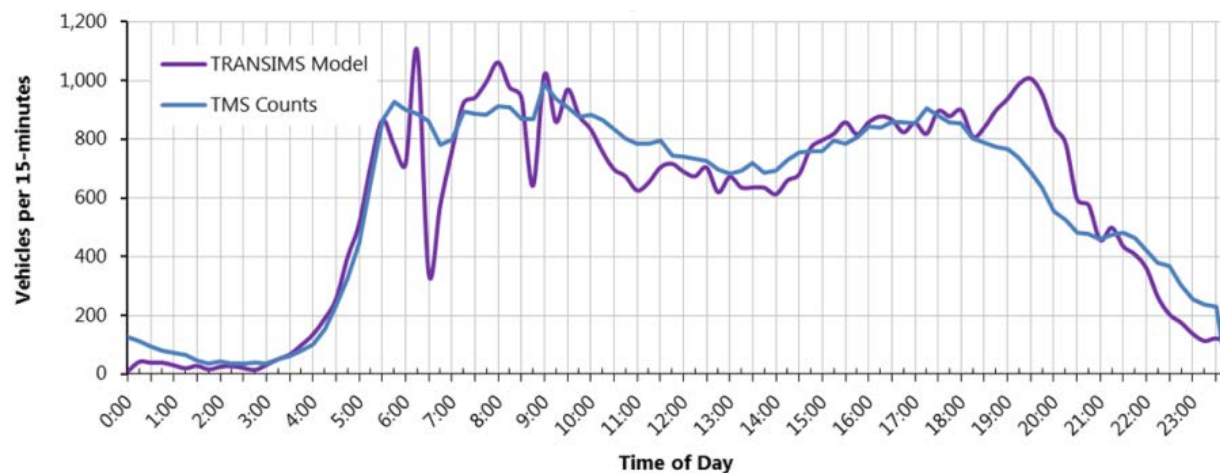
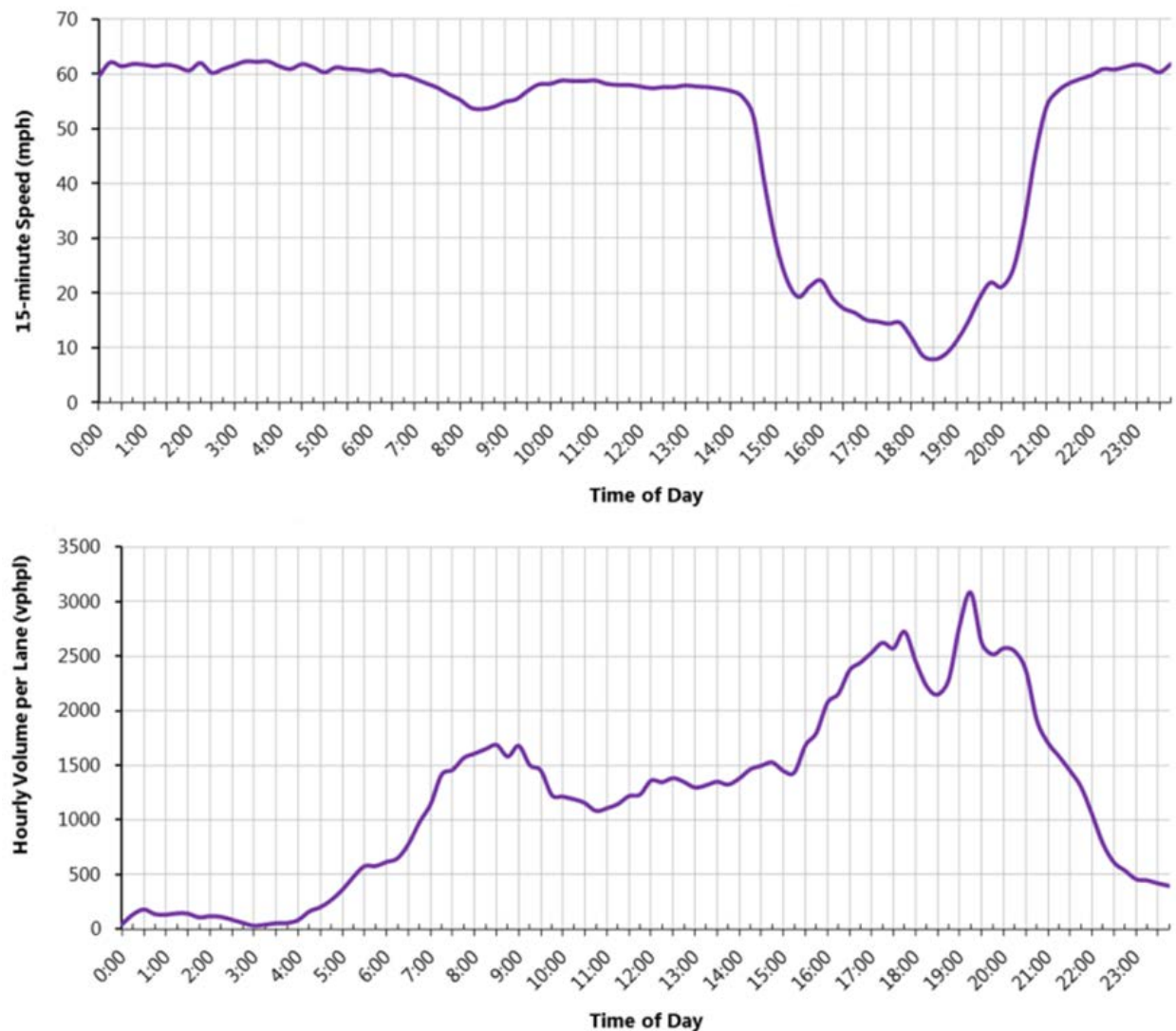


Figure 15 displays an example location where the 15 minute volumes and speeds can be studied together. Such side by side comparisons of modeled volume and modeled speed profiles help to perform quick checks on the roadway traffic loading. In this example, it can be ascertained that PM is the peak time period. The speeds and volumes are correlated with each other throughout the day. However, calibration can be fine-tuned in this case. In the PM peak period the speeds drop to 15 mph or lower, with a maximum peak throughput between 2,500 vehicles per hour per lane (vphpl) to 3,000 vphpl. These are very high throughput numbers and potentially indicate a calibration issue. If it is an analytical DTA model, the VDFs may need to be adjusted to increase the delay as throughput

approaches capacity of 2,400 vphpl. If it is a simulation-based DTA model, then the issue is potentially larger because simulation-based DTA models will likely exhibit lower throughput on roadways due to their modeling of vehicular interactions, which the analytical DTA models either do not consider or approximate. In a simulation-based DTA model, the modeler can examine the traffic flow animation during the apex of the peak period. The modeler can check to see if the vehicles are moving appropriately, the acceleration and deceleration rates are reasonable, the lane-change behavior is reasonable, and the reported link speeds correspond to the vehicular speeds.

Figure 15: 15 Minute Volume vs Speed comparison



4.2 Comparisons with the Static Model

In addition to comparing the model results at the network level, it is also helpful to compare the results at the aggregate level between the DTA model and the available STA model. The two models are bound to have differences in their results due to their nature and extent; however, some performance measures should be comparable between the two, as both models were built to represent the same

reality. The modelers can assess the total vehicle miles traveled (VMT) and total vehicle hours traveled (VHT) and may compare these metrics to those obtained in the static model. Any unexplainable large differences should prompt closer inspection of the DTA model's calibration as well as the STA model to the extent feasible.

The travel time skims can be compared between the two models. Both models should show the same pattern of congestion and should ideally generate similar loaded speeds. However, not all differences necessarily indicate poor performance of the DTA model. There may be the areas where the STA model does not capture speeds well, especially for trips along extremely congested corridors. Success at this level of validation can pave the way for a potential integration of the DTA model into the larger regional modeling.

During the model validation process, SEMCOG found that there were links near the centroid connectors that were overly saturated. This situation was discovered in the static assignment as well. However, due to the nature of the DTA assignment, these conditions cause more serious problems. The "artificial" congestion can lead to unstable assignments. SEMCOG plans to review all of the centroid connectors (CC) that are associated with localized congestion, and make adjustments to minimize their impact on the assignment. These adjustments include:

1. Reallocating the CCs to more evenly distribute traffic,
2. Adding additional CCs based on real world access locations.

Upon finishing the adjustment, the DynusT model will be rerun, and the statistics will be updated. SEMCOG hopes, with a better control on CC plus a realistic level of convergence, the overall performance of the DTA model will be improved, and, in turn, this would provide a better base for further model calibration.

5.0 Conclusion

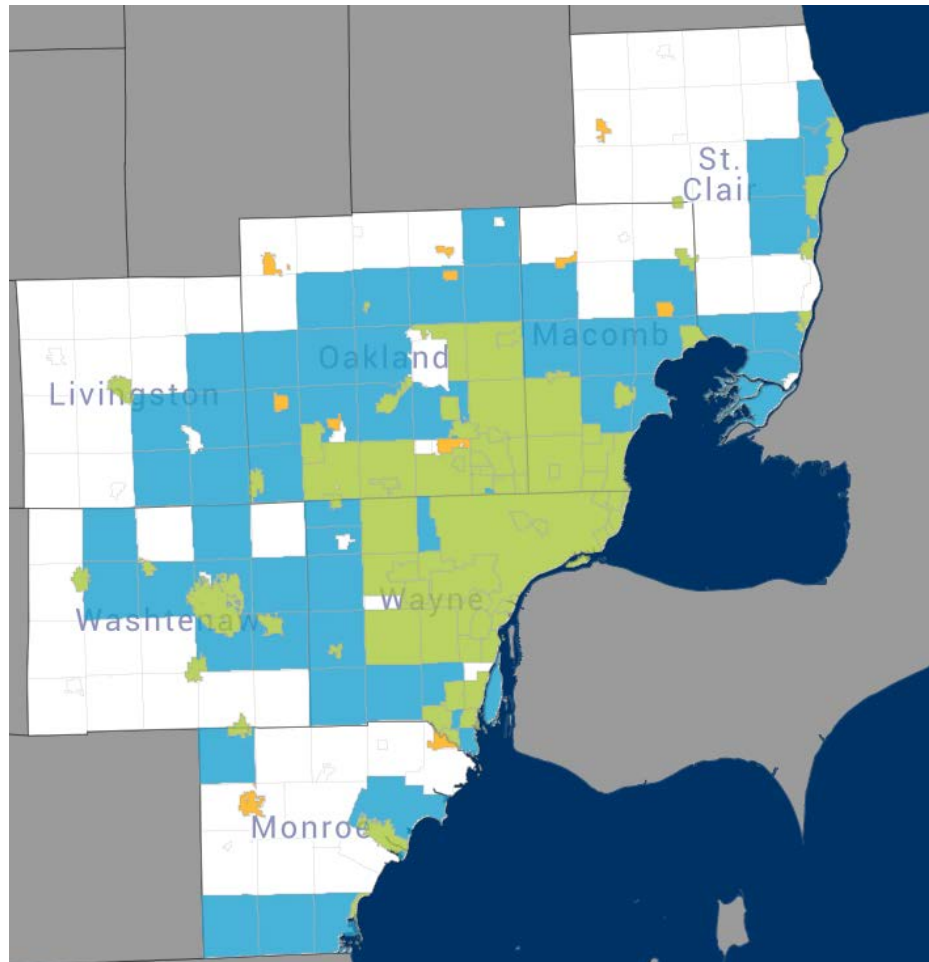
Practical and successful DTA applications are quite possible. Building a DTA model is time-consuming and can be tricky, so it should be well thought out before embarking on the effort. All agencies need to understand the benefits of DTA so that they can decide when and where DTA can add value to their planning efforts. If an STA model is able to adequately answer all the policy questions, then there is no need to invest resources in the application of a DTA model. Increasingly, however, policy questions are emerging that necessitate the use of DTA, because DTA can provide greater insights into the impacts of peak spreading, travel-time reliability, dynamic operational changes, dynamic pricing scenarios, and traveler behaviors. When compared to an existing STA model, DTA applications definitely require higher levels of effort, so they will likely prolong the timeframe required to analyze policies, however, they also facilitate answering questions that can't otherwise be answered with STA. The advantages of DTA can be leveraged when it is implemented appropriately and effectively.

Appendix A Modeling at SEMCOG

A.1 Conventional Modeling at SEMCOG

The SEMCOG is the MPO for the seven-county Southeast Michigan (Detroit) region as shown in Figure 16 and maintains the travel demand model for the region.

Figure 16: Seven Counties of SEMCOG (Source: SEMCOG)



SEMCOG's current regional travel demand forecasting model is versioned "E6" at the time of writing this document and has the following characteristics:

- Four-step trip-based model applied using TransCAD modeling platform
- Number of travel analysis zones (TAZs): 2811 internal and 88 external
- Model calibration year: 2005
- Model validation year: 2010
- Incorporates nested-logit mode choice model

- Time of day is modeled with five time periods for highway trips and four time periods for transit trips.
- 5 highway speed feedback loops are performed using the Method of Successive Averaging (MSA).
- Static Traffic Assignment (STA) is performed with six vehicle classes
- The land use inputs and socioeconomic data are generated with the help of the UrbanSim¹³ software – an open source urban simulation system.

Additional information about SEMCOG's traditional four-step trip-based model can be found at the following website, which also includes SEMCOG's Travel Model Improvement Plan and SEMCOG Travel Model Document, version E6.

<http://semcog.org/Plans-for-the-Region/Transportation/Travel-Forecast>

A.2 DTA Modeling at SEMCOG

One of the major concerns for the SEMCOG staff has been that their regional travel model underestimates delay. This is a common concern because traditional four-step trip-based models employ static traffic assignment (STA) procedures that estimate delay for large time periods using volume-delay functions (VDFs). These VDFs do not accurately estimate queues, spillbacks and bottlenecks under excessive traffic congestion. Certain corridors in the SEMCOG region experience significant congestion, although the SEMCOG region does not rank very high relative to national congestion levels.

The following is a list of modeling needs with respect to DTA that the SEMCOG staff has felt:

- Model execution times should be at most 16hrs.
- the software manual should provide enough guidelines on model calibration;
- The results should be stable across various hardware and be replicable, and
- The GUI should be stable and user-friendly.

In 2009, SEMCOG embarked on building a DTA model at the regional level in response to technical assistance requests from the constituent local agencies. The plan was to use this model for corridor and subarea analysis to estimate congestion impacts more accurately. This effort was also envisioned as a prerequisite for the planned move towards Activity-Based Modeling (ABM) in the region.

SEMCOG began exploring DTA using DYNASMART, TransCAD and later TransModeler. The TransCAD DTA was applied in a subarea and was found to be relatively easy to implement without needing too many additional resources. This TransCAD DTA was able to model queues and spillbacks by defining storage capacity for the links. However, it had difficulty converging on a stable condition. The TransModeler DTA was applied in a 98 square mile subarea within the region (Novi-Farmington). The exercise involved developing trip tables using Origin-Destination Matrix Estimation (ODME) techniques and was found to generate more realistic results compared to the regional STA. It was found to be effective for subarea

analysis, but it required additional resources for model preparation and the model took a long time to apply.

After two years of initial testing, SEMCOG began assessing other available DTA software packages (DTALite, DynusT, TransCAD DNA, etc.) for application at the regional level. The goals of this effort were to find software that could model relatively large networks (25 to 30 thousand links), handle a larger number of vehicles (16 to 19 million) and perform well under congested conditions with reasonable model execution times. The evaluation effort lasted for three years before the agency focused on using DynusT for testing in 2014.

The updated SEMCOG DTA model used the regional modeling network and trip tables for the year 2010. The following are the characteristics of this model:

- Peak periods are modeled: AM peak period (6:30-9:00) and PM peak period (3:00-6:30)
- Signal locations were identified and intersection nodes were marked
 - All signals were synthesized and assumed to be fully demand-actuated
- The model was tested at both the regional and US 23 corridor levels

Appendix B Agenda: AMPO Travel Modeling Work Group Meeting

AMPO Travel Modeling Work Group Meeting - Final Agenda

December 17-18, 2015

Atlanta Regional Commission

40 Courtland Street, NE

Atlanta, GA

December 17: Harry West Room “B” – Main “C” Level

2:00 pm Welcome and Introductions

Opening Discussion – Meeting purpose and desired outcome

Status of Activity-Based Models and Dynamic Traffic Assignment at Peer MPOs – Mark Moran, MWCOG-NC RTPB

Experiences with DTA – Roundtable Discussion

- Success stories and lessons learned from current DTA work
- General DTA modeling procedures and modeling issues
- Policy issues and transportation application agencies address using DTA
- Transportation applications that DTA could be useful for
- Agencies planning to undertake DTA in the near future
- Other issues

Comments on TMIP draft report – *How to Calibrate and Validate a Regional DTA Model for Planning Applications* (draft report to be emailed to participants prior to the meeting)

AMPO Research Foundation Common Modeling Platform Development Status – Guy Rousseau, ARC

5:30 pm Adjourn

December 18: Chattahoochee Room, Level 2

9:00 am SHRP2 ABM/DTA Integration

- Maryland Integrated Travel Analysis Modeling System (MITAMS) – Carlos Carrion, University of Maryland
- Atlanta Regional Commission – Guy Rousseau, ARC

Facilitated Discussion - Development of DTA Research Needs Statements

- Detailed research recommendations

Modeling Updates – Roundtable

- Current and planned modeling initiatives

Future Meetings

12:00 pm Adjourn

Appendix C Attendees: AMPO Travel Modeling Work Group Meeting

In person participants included:

- Charles Baber, Baltimore Metropolitan Council
- Carlos Carrion, University of Maryland (December 18th only)
- Hamideh Etemadnia, Denver Regional Council of Governments
- Liyang Feng, Southeast Michigan Council of Governments
- Bill Keyrouse, AMPO
- Guy Rousseau, ARC
- Steve Lewandoski, ARC (December 18th only)
- Lubna Shoaib, East-West Gateway Council of Governments
- Scott Smith, Volpe Center, US DOT

Telephone/web participants included:

- Denise Bunnewith, North Florida Transportation Planning Organization
- Rick Curry, San Diego Association of Governments
- Rich Denbow, Cambridge Systematics
- Craig Heither, Chicago Metropolitan Agency for Planning
- Ron Milone, Metropolitan Washington Council of Governments (MWCOC)
- Mark Moran, MWCOC
- Dzung Ngo, MWCOC
- Arash Mirzaei, North Central Texas Council of Governments
- David Ory, Metropolitan Transportation Commission
- Sarah Sun, FHWA

Attendee contact information:

Organization	Name	Email
ARC	Guy Rousseau	grousseau@atlantaregional.com
ARC	Steve Lewandoski	slewandowski@atlantaregional.com
BMC	Charles Baber	cbaber@baltometro.org
CMAAP	Craig Heither	cheither@cmap.illinois.gov
DRCOG	Hamideh Etemadnia	hetemadnia@drcog.org
DVRPC	Matthew Gates	mgates@dvrpc.org
EWGCOG	Lubna Shoaib	lubna.schoaib@ewgateway.org
Jacksonville TPO	Denise Bunnewith	dbunnewith@northfloridatpo.com
MTC	David Ory	dory@mtc.ca.gov
MWCOC	Mark Moran	mmoran@mwkog.org
MWCOC	Ron Milone	rmilone@mwkog.org
MWCOC	Dzung Ngo	dngo@mwkog.org
NCTCOG	Arash Mirzaei	amirzaei@nctkog.org

Organization	Name	Email
SANDAG	Rick Curry	rick.curry@sandag.org
SEMCOG	Li-yang Feng	feng@semcog.org
University of Maryland	Carlos Carrion	carrion@umd.edu
FHWA	Sarah Sun	sarah.sun@dot.gov
Volpe	Scott Smith	Scott.Smith@dot.gov
AMPO	Bill Keyrouse	bkeyrouze@ampo.org
For AMPO	Rich Denbow	rdenbow@ampo.org
For AMPO	Janet Oakley	janetoak@aol.com

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- ³ Page 25, “Status of Activity-Based Models and Dynamic Traffic Assignment at Peer MPOs”, prepared for MWCOC / National Capital Region Transportation Planning Board (NCTPB), prepared by Cambridge Systematics, Inc., August 27, 2015: <http://www.mwcog.org/uploads/committee-documents/aVxfXVhW20150827091119.pdf>
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- ¹² Traffic Operations and Safety Analysis Manual (TOSAM), Virginia Department of Transportation, released November 2015, <http://www.virginiadot.org/business/resources/TOSAM.pdf>
- ¹³ UrbanSim: <https://en.wikipedia.org/wiki/UrbanSim>

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