COMPARISON OF SIMULATION-BASED DYNAMIC TRAFFIC ASSIGNMENT TOOLS

Ramachandran Balakrishna, Daniel Morgan, Qi Yang and Howard Slavin
Caliper Corporation

Introduction

Metropolitan planning organizations (MPOs) are increasingly seeing the need for traffic models with a temporal resolution that captures day-to-day and within-day dynamics, queuing and congestion patterns. These capabilities are necessary for short-term planning and operations management, and are largely beyond the scope of current static approaches tailored towards long-term processes involving significant changes in land use, residential location choices, auto ownership decisions, etc. Dynamic Traffic Assignment (DTA) is gaining popularity with its potential to accommodate changes in travel demand and network supply over very short intervals such as 5 to 15 minutes, and the ability to model the spatial and temporal results of their interactions. These interactions are often captured through behavioral models that predict individual drivers' route and lane choices. The advent of powerful computers is accelerating the interest in applying DTA to medium and large networks.

Several DTA approaches based on analytical and simulation techniques have been proposed, implemented and tested in both academic and commercial settings. Peeta and Ziliaskopoulos (2001) provide a comprehensive conceptual review of these approaches, several of which have been developed into tools that are available to modelers. These include DynaMIT (Ben-Akiva et al., 2002), DYNASMART (Mahmassani, 2002), DynusT (UA, 2009), Dynameq (Tian et. al., 2007), TransCAD (Caliper, 2009a) and TransModeler (Caliper, 2009b). However, examples of rigorous field tests are few and on various datasets that differ in their extent, structure, demand levels, etc. Further, the modeling differences and default parameters across tools make it difficult to objectively evaluate the results published in the literature. In this paper, we propose a conceptual analysis comparing the capabilities and modeling approaches of three DTA tools: DYNSMART-P, DynusT and TransModeler. We further propose a study applying these tools on a common dataset and similar parameter values so that their performance and outputs can be compared and evaluated. The study is expected to conclude in the next two months.

Simulation-based dynamic traffic assignment

As in static planning models, travel demand for dynamic models is specified through trip tables or origin-destination (OD) matrices. However, each matrix contains the trips that depart within a very short time interval, usually between 5 and 15 minutes. DTA packages designed for planning applications are built on the premise that a dynamic equilibrium exists in the real world. The definition of this equilibrium is a direct extension of Wardrop's principle along the temporal dimension. Consequently, all used network paths between an OD pair have the same, minimum travel time at equilibrium, *for a given departure time (interval)*.

In this paper, we focus on DTA packages that are based on traffic simulation principles. Such approaches are broadly classified as microscopic, mesoscopic and macroscopic depending on how they each represent network supply and the movement of vehicles. A microscopic model employs detailed models of a vehicle's interactions with those around it. Such interactions take the form of car following and lane changing maneuvers, with drivers determining their speed, acceleration and lane based on individual desired speed preferences and path choices. Macroscopic models either treat traffic as a fluid, or use volume-delay functions (such as those used in static assignment methods) to capture the interplay between congestion levels and link traversal times. Mesoscopic models provide a theoretical middle ground in which the link performance functions are based on the fundamental diagram typically through speed-density or speed-flow equations.

Most DTAs require the specification of time-dependent demand, usually as a series of origin-destination (OD) trip matrices. The demand is disaggregated into trips that are loaded onto the network through route selection logic based on either historical or updated travel times. At the end of the simulation, the outputs are aggregated and used to compute the input travel times for the network loading in the next iteration. This is essentially a fixed point problem of the form:

$$x = f(x) \tag{1}$$

where x are the desired congested travel times specified by departure time, and $f(\bullet)$ is the network loading. A detailed treatment of the solution of fixed point problems in the transportation context can be found in Bottom (2000).

Different DTA implementations can vary widely in many key modeling assumptions, features and capabilities. The remainder of this section briefly summarizes these differences for the three chosen packages.

DYNASMART-P uses a mesoscopic simulation approach in which vehicles are propagated on a link-node network representation. Routes are assigned to vehicles based on a k-shortest path algorithm, with a provision for some vehicles to make en-route switches. The software is based on the principle of bounded rationality (Simon, 1957), so that an alternative route must provide some minimum improvement in order for drivers to switch routes. Vehicles are propagated along their routes according to a queuing model with link output capacities acting as constraints. Vehicle speeds are set using aggregate speed-density relationships that follow a modified version of the Greenshields formula. The algorithm is expected to move towards a dynamic equilibrium by feeding the output travel times back into the k-shortest path algorithm, so that vehicles may re-evaluate their route selections.

DynusT is a mesoscopic DTA package that shares many modeling elements with DYNASMART-P. One of the key differences, though, is its Anisotropic Mesoscopic Simulation (AMS) for network loading. In this approach, a vehicle's speed is set as a function of the speeds of the vehicles in its Speed Influencing Region (SIR). This region is defined to include the vehicle immediately downstream of the current vehicle, and up to one vehicle in front of but on the adjacent lanes to the left and right. The AMS approach thus has a more microscopic focus than traditional mesoscopic models.

TransModeler is a 4D geographic information system (GIS), in which the temporal dimension is added to a 3D representation of the transportation system. The network, vehicles and other infrastructure (including control devices, message signs, etc.) are stored as geographic layers that are updated as the simulation progresses. Vehicles are propagated in cells of similar space headways. Cells may split if the headways within it become less homogeneous, or merge if the gap between cells drops below a threshold. TransModeler is unique as a hybrid simulation that allows sets of segments to be modeled at different fidelities (i.e. microscopic, mesoscopic or macroscopic) *within the same simulation run*. Large networks at the regional scale may therefore be simulated without having to scale back the study area for computational reasons. TransModeler's microscopic loading is based on car following and lane changing logic. The speed calculations in the mesoscopic fidelity are captured through speed-density relationships defined for various facility types (e.g. freeway, expressway, ramp, urban street). A vehicle's speed in the macroscopic fidelity is calculated from a volume-delay function (VDF) similar to those deployed in regional planning models. The DTA functionality can be based on any fidelity desired by the modeler, including hybrid simulation.

All three packages outlined above employ an iterative algorithm to attempt to solve for dynamic equilibrium. Typically, the outputs from one iteration feed back into the next after an update of either route flows or network travel times. For illustrative purposes, the travel time updating mechanism in TransModeler is shown in Figure 1.

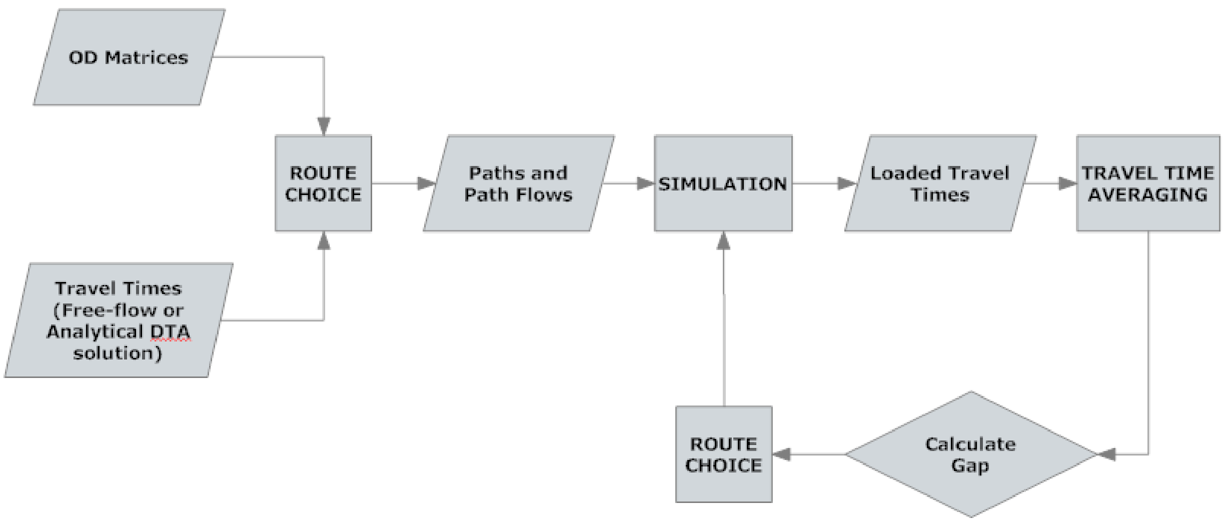

Figure 1. Travel Time Updating in the TransModeler DTA

In the above flowchart, a time-dependent series of OD matrices and any available travel time estimates (congested or free-flow) are input to a route choice model that splits the OD flows into path flows. These flows are simulated on the network and the experienced (loaded) travel times are logged. A travel time averaging function is then applied before re-evaluating drivers' route choices. If the travel times have not converged (i.e. a solution to the fixed point problem has not been identified), the new route choices (and hence path flows) are simulated in the next iteration. The process is repeated until the relative gap between the input and output travel times for the iteration falls below a user-specified value. The following travel time averaging scheme is used:

$$x_{i+1} = (1-\alpha_i)x_i + \alpha_i f(x_i) \quad (2)$$

The choice of the factor α_i will determine the type of averaging, such as the Method of Successive Averages (MSA), Polyak averaging or fixed-factor averaging (see Balakrishna et. al. (2009) for details).

Methodology

The comparison of different DTA packages is complicated by several factors. First, the modeling approaches and (default) model parameters often vary widely across the packages. Second, the results of existing applications as reported in the literature are largely not directly comparable since they are obtained from different networks, datasets and input parameters. Third, it is not obvious if sufficient model calibration has been carried out in each case, using real-world traffic data. Finally, the definition of performance measures and convergence thresholds can vary across packages and studies. In this study, we propose to reduce the effects of many of the shortcomings outlined above.

A key aspect of our methodology is the selection of a common network location for testing purposes. A set of links from a real-world location will be delineated, and the corresponding computer representation will be coded in each software package. Care will be taken to ensure that the representation is as true as possible, accounting for the capabilities of each package. Several candidate locations are currently being analyzed based on calibration data availability to ascertain the best test candidate.

Since the different DTA packages may employ different model paradigms to capture the same real-world traffic phenomena, the default model parameters provided with each DTA package will be analyzed and compared to check if they represent similar processes. For example, two mesoscopic traffic simulation models can differ in their link performance model component, one being based on a speed-density formula while the other uses a speed-flow equation. Even more significant is a comparison across fidelities, with a microscopic model using explicit driver behavior mechanics to capture effects such as car following and weaving, while a mesoscopic model relies on more aggregate relationships derived from the fundamental diagram.

The applicability of the default model parameters supplied with each DTA package will be tested empirically against field measurements to ascertain if the models need further calibration before a comparison can be effective. The use of field data provides an objective baseline that is exogenous to the models themselves.

The development of mesoscopic simulation has largely been motivated by the perceived inability of microscopic simulation to yield reasonably fast results when executed iteratively (as in a DTA) on medium and large networks. As more computing power becomes affordable and available on desktops, it will be useful to re-evaluate this motivation to ascertain if the more realistic microscopic processes can be retained for DTA. As part of this study, a comparison between the microscopic, mesoscopic and anisotropic network loading models will be performed. Both the accuracy of the model outputs and the computational effort required by each of these approaches will be evaluated to draw conclusions about the need to compromise modeling fidelity in order to gain running time savings.

Conclusion

This paper briefly summarizes the demand and supply modeling aspects of three simulation-based DTA tools: DYNASMART-P, DynusT and TransModeler. The primary focus of this study is to understand the basic theoretical differences in these tools, empirically study their generated outputs, and explore their ability to replicate the real world. Rigorous numerical testing is currently underway to compare the different approaches in terms of their ability to reliably capture dynamic traffic conditions and equilibrium. A common network and demand data are being used so that the comparisons are performed with an objective baseline. The numerical results are expected to be available within two months.

References

1. Balakrishna, R., D. Morgan, H. Slavin and Q. Yang (2009) “Large-Scale Traffic Simulation Tools for Planning and Operations Management.” 12th IFAC Symposium on Control in Transportation Systems, Redondo Beach, California.
2. Ben-Akiva, M., M. Bierlaire, H. N. Koutsopoulos and R. Mishalani (2002) “Real-Time Simulation of Traffic Demand-Supply Interactions within DynaMIT.” In Gendreau, M. and P. Marcotte (eds) Transportation and Network Analysis: Miscellenea in honor of Michael Florian, Kluwer, pp. 19-36.
3. Bottom, J. (2000) “Consistent Anticipatory Route Guidance.” Ph.D. dissertation, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology.
4. Caliper (2009a) “TransCAD Transportation Planning Software: Travel Demand Modeling with TransCAD – User’s Guide.”
5. Caliper (2009b) “TransModeler Traffic Simulation Software – Version 2.5 User’s Guide.”
6. Mahmassani, H. S. (2002) “Dynamic Network Traffic Assignment and Simulation Methodology for Advanced System Management Applications.” 81st annual meeting of the Transportation Research Board.
7. Mahmassani, H. S. and H. Sbayti (2006) “DYNASMART-P Version 1.2 User’s Guide”.
   Peeta, S. and A. Ziliaskopoulos (2001) “Foundations of Dynamic Traffic Assignment: The Past, the Present and the Future.” Networks and Spatial Economics, Vol. 1, No. 3/4, pp. 233-266.
8. Simon, H. (1957) “Models of Man.” Wiley, New York.
9. Tian, X., M. Mahut, M. Jha and M. A. Florian (2007) “Dynameq Application to Evaluating the Impact of Freeway Reconstruction.” 86th annual meeting of the Transportation Research Board.
10. UA (2009) “DynusT ONLINE USER’S MANUAL (version 2.0.0.1 Beta)”. Accessed on 28th October, 2009.