COMPARISON OF SIMULATION-BASED DYNAMIC TRAFFIC ASSIGNMENT APPROACHES FOR PLANNING AND OPERATIONS MANAGEMENT

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Abstract

Transportation practice is increasingly recognizing the need for dynamic models for realistic scenario analyses and policy decision-making. Dynamic Traffic Assignment (DTA) theory and tools are now thought to be sufficiently advanced to meet this need. However, DTA has historically been associated with mesoscopic models, motivated by the perceived computational intractability of high-fidelity microscopic models in an equilibrium context. In this paper, we use a real-world project to demonstrate that current hardware and efficient software allow for large-scale DTA under the more desirable microscopic traffic simulation framework. Such a tool is a more natural fit for most dynamic analyses, including evacuation and emissions modeling. A calibrated peak-period microscopic model for 500 square miles of the Greater Phoenix region of Arizona is presented to illustrate that DTA no longer need compromise modeling accuracy purely on running time considerations. We also qualitatively discuss the potential loss in accuracy arising from accepting the more common assumptions inherent in mesoscopic approaches.

Introduction

Metropolitan planning organizations (MPOs) and Traffic Management Centers (TMCs) are increasingly seeing the need for high-fidelity 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 (e.g. work zone scheduling or evacuation planning) and operations management (e.g. incident response). Static approaches are tailored towards long-term processes involving significant changes in land use, residential location choices and auto ownership decisions, and are not equipped to handle within-day dynamics at a level necessary for day-to-day operations. 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. Peeta and Ziliaskopoulos (2001) provide a conceptual review of various DTA approaches.

As in static planning models, travel demand for dynamic models is specified through origin-destination (OD) trip matrices. However, each matrix contains the trips that depart within a very short time interval, usually between 5 and 15 minutes. DTA packages are built on the premise that a dynamic equilibrium exists in the real world. The definition of this equilibrium is an 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)*. A model thus calibrated may then be used to analyze a variety of scenarios involving perturbations such as incidents and work zones.

We focus here on DTA based on traffic simulation network loading, in which the demand input is disaggregated into trips that are loaded onto the network through route selection logic based on historical or congested travel times. One possible next step is to aggregate the resulting simulated travel times and update drivers' route choices in the next iteration. Bottom (2000) provides a detailed algorithmic treatment of such problems in the transportation context.

DTA implementations can vary widely in their modeling assumptions, features and capabilities. These differences are largely in the network loading approach, which can be microscopic, mesoscopic or macroscopic depending on how they each represent network supply and vehicle movements. A microscopic loading employs detailed models of vehicular interactions such as car following and lane changing maneuvers. 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, and congestion is captured through models of queuing and spillbacks. It should be noted that the three loading mechanisms outlined above comprise a broad classification. Variants or combinations of the same may appear in practice. One such example is the hybrid network loading, which provides the flexibility to define links of different fidelity yet execute a simultaneous loading across the entire network.

The primary synthesis of the above discussion, in the context of this paper, is that the DTA equilibrium framework is independent of the network loading. This critical aspect is often not clearly articulated in the literature. In reality, DTA can be implemented with any reasonable network loading approach, **including traffic micro-simulation**. Comparisons of 'DTA against micro-simulation', for example, are misleading and have resulted in an ad hoc assumption that all DTA tools must use mesoscopic loading. The aim of this paper is to present relevant practical evidence that microscopic DTA (a) is computationally feasible on affordable hardware, (b) preserves the realism that drives the development of microscopic models, and (c) is more useful in many real-world situations where mesoscopic models must necessarily make simplifying assumptions and post-facto inferences.

Methodology

The overall project methodology is conceptually simple, yet complex and challenging in its execution. It involved the development of a detailed and geographically accurate multi-modal microscopic traffic simulation model for the Maricopa Association of Governments, its scope covering nearly 500 square miles served by dense urban streets and highways. The model was calibrated to match time-dependent traffic count and speed data observed in the field. Time-varying OD trip matrices and congested dynamic network travel times were primarily estimated, while numerous other simulation inputs and parameters controlling vehicle mix, driving behavior, etc. were fine-tuned as needed. Keeping with the focus of this paper, we restrict our discussion to the DTA application that generated congested travel time skims for a given set of demand and supply parameters. Details of the rest of the calibration process are available elsewhere.

The microscopic MAG network was developed in TransModeler (Caliper, 2010) to mirror the road network at the lane level. This task included the definition of nodes, links, curvature and grade, along with a faithful replication of lane configurations, turn bays and lane groups (dictated by turn markings available in aerial photographs). More than 1,800 signalized intersections were coded and available timing plans imported from various sources. The resulting representation is show in Figure 1, and includes about 17,000 nodes and 23,000 links. A zoomed-in view indicates the level of detail and geographic accuracy.

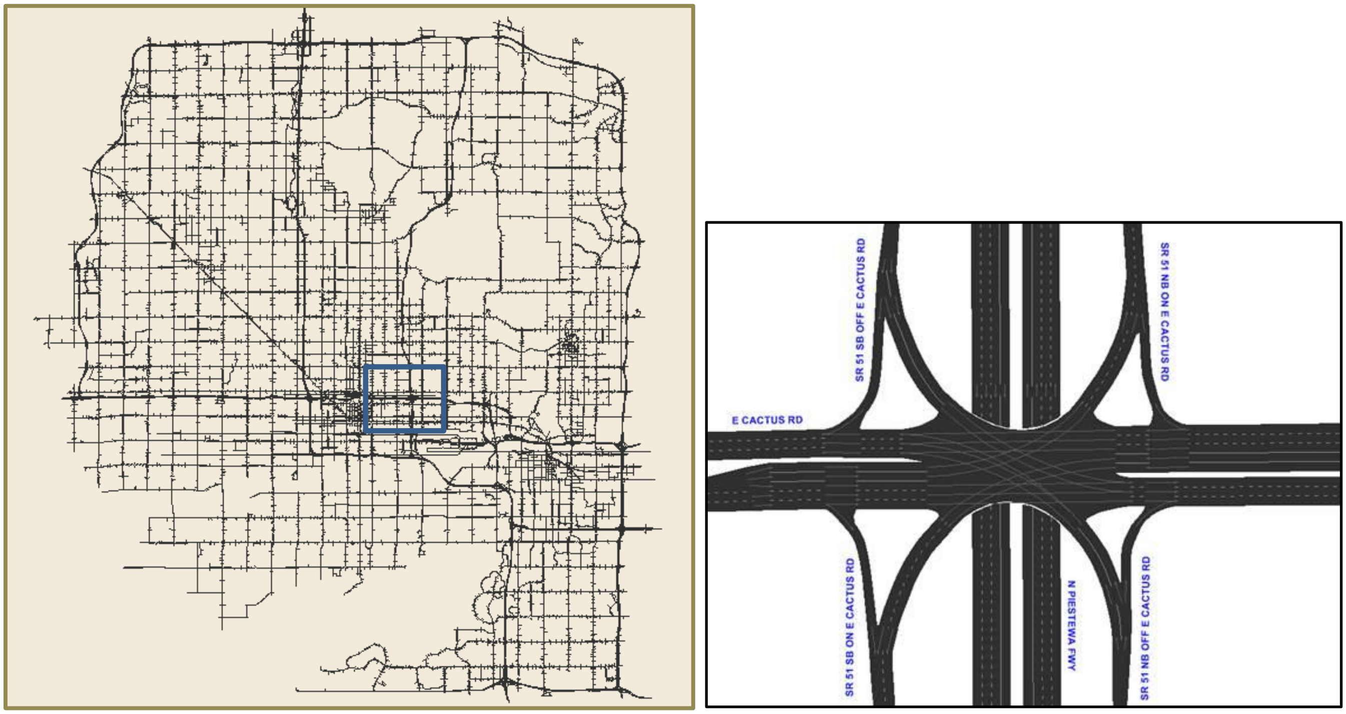

Figure 1. The Microscopic MAG Network Representation in TransModeler

TransModeler's microscopic loading uses car following and lane changing logic, and the operation of traffic control infrastructure is simulated in great detail. TransModeler can also perform DTA at mesoscopic and macroscopic fidelities, as well 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. Speed calculations in mesoscopic fidelity are captured through speed-density relationships by facility type. A vehicle's speed in 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.

TransModeler employs iterative algorithms to attempt a dynamic equilibrium solution. The outputs from one iteration feed back into the next after an update of either route flows or network travel times. Considering the travel time updating mechanism as an illustration, 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 updating function is then applied before re-evaluating drivers' route choices:

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

Where x_i and x_{i+1} are the input and output travel times, respectively, at iteration *i*. 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). The updated path flows are simulated in iteration *i+1* until pre-specified convergence criteria are met.

Dynamic Traffic Assignment Results

Figure 2 illustrates the convergence of TransModeler's microscopic DTA for the AM peak period, as well as the overall fit to observed counts. About 800,000 trips are simulated within this 3-hour period. Based on the relative gap measure, the model moves consistently towards equilibrium. These results were obtained on a desktop with dual 6-core processors (3.33 GHz) hyper-threaded to 24 cores with 48 GB of physical memory, a hardware specification that is an affordable desktop option today.

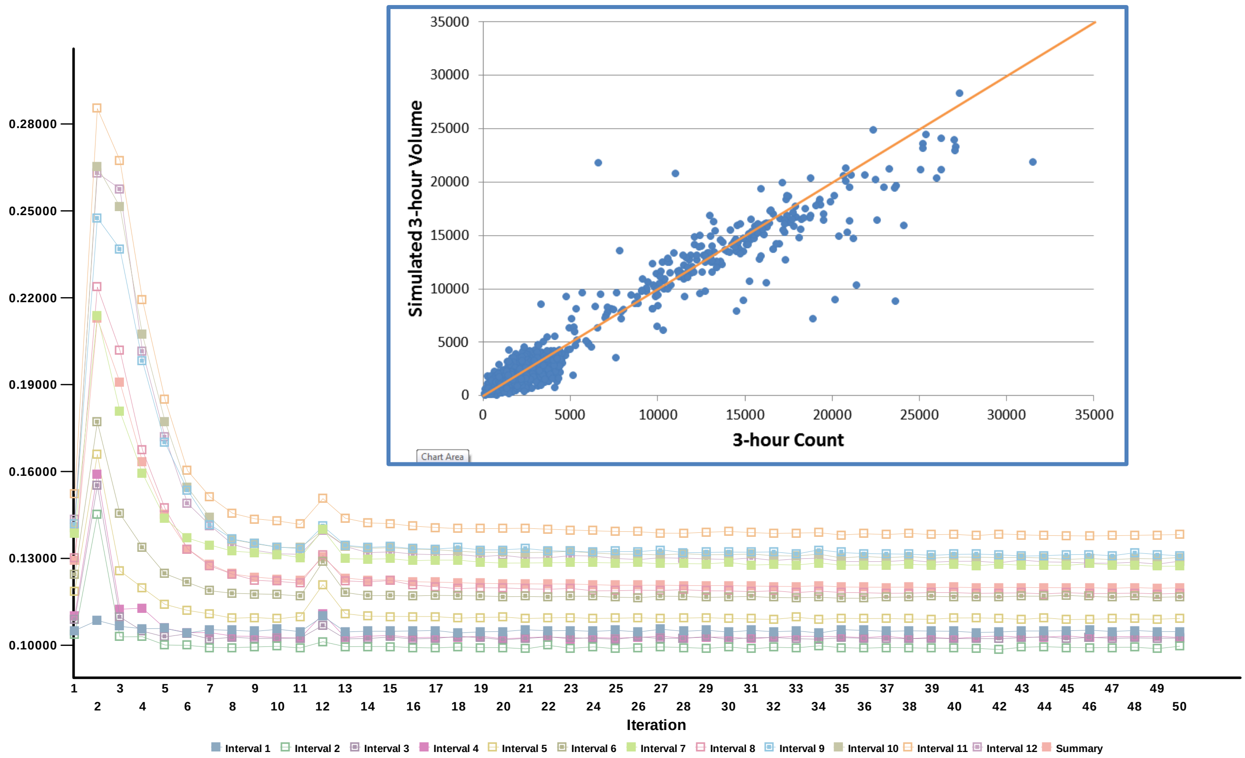

Figure 2. Relative Gap Convergence for Microscopic DTA in MAG

Microscopic network loadings ran in about 28 minutes each for the 3-hour simulation window. Mesoscopic loadings in TransModeler took about 11 minutes, while hybrid loadings (with the freeways and ramps modeled as mesoscopic) took about 21 minutes. In addition, each iteration included a path update step taking about 16 minutes. It should be noted that the above microscopic model has been significantly optimized as part of the MAG project. A similar effort on the meso and hybrid models should reduce the corresponding running times.

A Note on Mesoscopic Network Loading

Mesoscopic models (generally with lower modeling fidelity than typical microscopic models) have traditionally been motivated by running time considerations. Any loss in modeling accuracy has been presented as a trade-off that is necessary for obtaining timely results in practice. While it may have been a valid consideration several years ago, there appear to be no systematic studies quantifying this trade-off: how much do we lose in fidelity, how might this potential loss affect policy decisions, and is it worth the running time savings? Emission models, for example, require detailed vehicle trajectories along with second-by-second acceleration and deceleration records. This is an automatic output of micro-simulation, but is not directly available from mesoscopic models with their coarser temporal resolution and lack of lane-level trajectory and driver's lane choice modeling. While efforts are underway to infer these data as well as possible from meso models, a microscopic DTA would provide the required data without any additional effort. Meso models today are also limited in their handling of (and sensitivity to) multiple modes, value of time by user class, vehicle types, etc. Further, urban networks today operate complex signal control systems involving coordination, offsets, etc. It is also unclear if meso models are significantly easier to calibrate and validate: a model more faithful to real-world processes could be easier to match to real-world data with potentially fewer variables to estimate.

Such fundamental questions are difficult to answer when the DTA tools themselves differ broadly in their assumptions, network representations, model fidelity and vehicle loading approach. Further, the literature shows that few tools have been tested on the same dataset to facilitate comparison. TransDNA, a recent addition to Caliper's suite of state-of-the-art dynamic models, provides a testbed for such objective analyses. It uses a mesoscopic simulation approach in which vehicles make route choices and are subsequently propagated towards their destinations according to queuing models and speed-density functions. Critically, it shares software architecture, network representation and database formats with TransModeler, so that theoretical approaches and algorithms may be evaluated with minimal confounding from software implementation and transportation network data. Such comparisons are currently underway for the Phoenix model.

Conclusion

The development of mesoscopic simulation has largely been motivated by the perceived inability of microscopic simulation to yield reasonably fast results when executed as a DTA on medium and large networks. With more computing power becoming affordable and available on desktops, it is useful to re-evaluate this motivation to ascertain if the more realistic and behaviorally rich microscopic process can be retained for DTA. At issue is the extent of accuracy loss when moving from microscopic to mesoscopic models, and the inherent value of the accompanying running time savings. This assumes greater significance in certain applications such as emission modeling, which require trajectory and vehicle dynamics outputs that are part of micro-simulation but are lacking in meso approaches. In this paper, we conclude that microscopic DTA is feasible. The practical implications of our study are significant. To the best of our knowledge, the MAG project using TransModeler represents the largest microscopic traffic model yet, preserving high levels of network and demand/behavioral detail. On-going research with TransDNA, a new mesoscopic tool sharing TransModeler's software architecture, will attempt to quantify the meso model's loss of accuracy when compared to the corresponding micro model, and any project implications this might entail.

References

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