THE DESIGN OF AN INTEGRATED MODEL OF THE URBAN CONTINUUM – LOCATION CHOICES, ACTIVITY-TRAVEL BEHAVIOR, AND DYNAMIC TRAFFIC PATTERNS

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ABSTRACT

Over the past several decades, there has been a clear shift towards microsimulation approaches in modeling urban systems. This shift has generally taken place along three lines of inquiry. First, in the land use modeling arena, attempts are being made to model market dynamics in the land use markets. Second, in the activity-travel demand modeling arena, emerging models simulate the activity-travel patterns of individuals along the continuous time axis while explicitly accounting for time-space prism constraints and interactions, household interactions and task allocation, and modal availability. Third, in the network modeling arena, dynamic traffic assignment models are seeing increasing interest from the planning community. These three streams of research have largely proceeded along parallel lines with only few attempts to integrate the model streams into a unifying framework. The authors are developing a unifying model design and paradigm which integrates land use microsimulation models, activity-based microsimulation models of travel demand, and dynamic traffic assignment models. The integrated model system, dubbed SimTRAVEL (Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land), is intended to serve as a platform that would allow the integrated modeling of urban systems in a seamless fashion. In this paper, the authors present a comprehensive overview of the design of SimTRAVEL. The paper includes design considerations that went into the specification of SimTRAVEL, the behavioral paradigms that define the SimTRAVEL approach, and the analytical formulations underlying SimTRAVEL model components. There is a detailed description of the model design and algorithm with explicit representation of the feedback loops and equilibrium conditions embedded in the model.

Keywords: Integrated Modeling, Microsimulation, Activity-Based Demand Model, Land-use

INTRODUCTION

The advent of microsimulation approaches to the analysis of urban land use and transport systems has ushered in a new era in urban systems modeling (Waddell, 2002). Microsimulation approaches allow one to represent the complex behaviors of individual agents in a system while recognizing the interactions, constraints, and decision mechanisms that drive their actions and choices (Kitamura et al, 2000). The implementation of microsimulation approaches has been made possible by advances along multiple dimensions. Advances in econometric and statistical modeling methods, numerical optimization techniques, computational hardware and software technology, and data collection and management systems have all contributed to making the implementation of microsimulation model systems a reality (Goulias and Kitamura, 1992).

The primary motivation underlying this research is the desire to integrate advances in microsimulation model development that have largely occurred in three (somewhat) independent streams of research. In the first stream, land use researchers have developed microsimulation models of land use development (Waddell, 2000). These models are intended to represent the behaviors of households and businesses as they make location choices (Waddell et al, 2007). Households make choices regarding residential location, individuals in households make choices regarding workplace location and school location (perhaps in consultation with other members of the household, resulting in interactions), and businesses make decisions about where to locate their enterprises and offices. Developers make decisions regarding the parcels of land that will be developed either for residential or commercial use. These location choices, coupled with demographic and socio-economic evolutionary processes, land regulations, and zoning policies, drive the development patterns in urban areas. More importantly, these location choices are often driven by transport accessibility considerations, thus calling for the feedback of transport level of service measures from transport models to submodels within the land use microsimulation model system. The land use microsimulation model system includes a series of submodels that mimic market clearing processes as different agents buy and sell building stock, relocate home and work sites, and participate in real estate transactions and development decisions.

The second stream of model development has seen travel modelers usher in a new generation of activity-based travel demand model systems (Miller, 2002). At the heart of the activity-based model paradigm is the microsimulation of daily activity-travel patterns of households and individuals within households (Kitamura and Fujii, 1998). These models consider household activity agendas, individual activity schedules that are formed through interactions among household members (as activities get allocated among household members or are undertaken jointly by a set of household members), activity linkages and trip chaining, and destination and mode choices at the level of the trip chain to explicitly account for interactions among trips in a chain. These models are intended to capture time-space interactions by considering time-space prism constraints, time allocation behavior represented by activity and travel durations, and history dependency in activity-travel behavior (Kitamura et al, 2000; Kasturirangan et al, 2002). At the end of the process, one would conceivably obtain a complete activity-travel pattern, with activities and trips simulated along a continuous time axis, for each individual in a synthetically generated population of the urban area. Different activity-based model systems incorporate the capabilities described in this paragraph to varying degrees (for example, tour-based nested logit model systems do not explicitly consider activity durations and treat time in discrete chunks), but the point remains that microsimulation models of activities and travel are seeing increasing acceptance in the modeling community. The activity-based model system has two major linkages that are of interest in the context of this project. On the one hand, the model system needs land use information from the land use microsimulation model. On the other hand, the model system generates the travel plans of individuals that need to be assigned to networks and, in turn, utilizes network level-of-service measures to model activity-travel choices including activity time allocation, destination and mode choices, and travel durations.

The third stream of research that has had a major impact on the profession is that of dynamic traffic assignment (DTA). Dynamic traffic assignment models constitute a class of mesoscopic models wherein the route choices of individual trips/vehicles are modeled in order to simulate traffic flows along links in the network. In contrast to using microscopic car-following and cellular automata type paradigms to simulate vehicular movements and infer traffic flow parameters, the dynamic traffic assignment models use well-established macroscopic theories of traffic flow characteristics to compute capacities, travel times, and speeds on links in the network. Thus, individual vehicular movements (microscopic) are modeled and simulated using macroscopic traffic flow relationships, leading to the concept of mesoscopic dynamic traffic assignment models. These models route origin-destination (O-D) flows and update paths on a second-by-second basis depending on prevailing conditions on the network. Wardrop's principle of user equilibrium holds at any point in time as travelers (individual vehicles) are routed along the shortest path prevailing when the trip is initiated. More advanced dynamic traffic assignment models are capable of simulating enroute path choice processes where individual travelers may modify their route plan along the way in response to congestion on one or more links. The dynamic traffic assignment models are related to activity-based travel demand models and land use microsimulation models in important ways. The dynamic traffic assignment model depends on the activity-travel model for time-dependent O-D flows. In turn, the dynamic traffic assignment model delivers time-dependent network conditions (level of service and accessibility measures) that influence activity-travel choices (mode and destination choices, for example) and longer term location choices in the land use model (residential and workplace location choices, for example).

Given the interdependency among these three model entities, there has been much interest in the profession to link these model systems together (Timmermans, 2003; Miller, 2006). Several researchers have developed conceptual designs of integrated model systems and others have attempted to operationalize joint model systems by coupling models through data exchange processes and feedback loops (Salvini and Miller, 2005). However, there is much to be done in the integrated land use – transport modeling arena. Virtually all attempts at integrated land use – transport modeling have generally focused on two of the three model systems noted in the previous paragraphs. There are models that attempt to link land use microsimulation model systems with activity-travel model systems (Waddell et al, 2008; Salvini and Miller, 2005) and there are other attempts to link activity-travel models with dynamic traffic assignment models and network simulators (e.g., Lin et al, 2008; TRANSIMS; Kitamura et al, 2008; Kitamura et al, 2005; Boyce and Bar-Gera, 2004). Rarely, if ever, has there been even a complete conceptual design that truly integrates all three modeling enterprises that together represent the urban continuum – from longer-term location choices to medium term vehicle ownership and activity lifestyle choices to short-term route choices.

The fact that much remains to be done in the integrated modeling arena has been articulated by several well-known researchers in the field. The above discussion serves as primary motivation for this research which constitutes a major effort at developing a truly integrated model system of the urban continuum. Building on the work that has been done in the field to date, the goal is to develop a set of procedures, methods, tools, and concepts that can significantly move the cause of integrated modeling forward. This paper is a part of the work in progress to develop the integrated model paradigm dubbed SimTRAVEL (Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land). The next section discusses in detail the design considerations that went into the integrated modelling framework. In the third section, the overall framework and design of the integrated model is presented. Finally, some concluding thoughts about the model limitations and future plans for implementation are provided.

MODEL DESIGN: BEHAVIORAL PARADIGMS AND OPERATIONAL CONSIDERATIONS

The development and application of dynamic microsimulation approaches to land use and travel analysis has been largely spurred by the valuable insights into travel behavior and location choice behavior that have been acquired over the past few decades of behavioral research. During this period, aggregate demand models gave way to more disaggregate models that are largely estimated at the level of the individual household or traveler, but applied to larger spatial blocks such as traffic analysis zones. Due to the increasing need for fine-grained application of models to address policy issues and questions of relevance to planning contexts of today and tomorrow, the profession has gradually but surely moved into the domain of microsimulation modeling where movements and choices of individual travelers and vehicles are simulated in time and space with varying degrees of granularity. In developing such a model system, what are the key behavioral paradigms that define the model structure, relationships among choice dimensions that need to be explicitly incorporated into the model system, and operational design elements that guide the model implementation strategy? This section highlights such considerations that went to the development of the integrated model design.

It was aimed to represent behavior along continuous time. It is possible to represent time as discrete periods or chunks of time, and determine the scheduling of activities and trips using discrete choice models that place trips (or tours) into time of day blocks or periods. While this is computationally convenient, particularly when available networks are not necessarily time-varying, such a coarse treatment of time leaves much to be desired. Time is a continuous entity, activity durations and travel times are continuous variables, and the fine-grained treatment of time offers the ability to handle fine-tune adjustments and changes to activity schedules and trip departure and arrival times. The ability to model activity-travel patterns along the continuous time axis, particularly in response to policies that aim to shift travel along the time axis, motivates the treatment of time as a continuous entity in the model system proposed here. Such a treatment of time is also necessary and consistent with the paradigms and approaches embedded in dynamic traffic assignment models; in other words, the discrete period treatment of time is really possible only when it is limited to the demand model component and one is going to use static assignment procedures with aggregated origin-destination matrices.

There are myriad constraints and interactions that influence activity-travel patterns and land use location choices. There are interactions among choice processes, such as those between residential location choice and work/school location choices. There are interactions among individuals, both within households and across households (particularly among co-workers, for example). There are dependencies that must be accommodated such as that involving children, whose travel needs can only be met through certain travel arrangements (e.g., public transport, bicycle or walk, chauffeuring by an adult) – thus imposing constraints. Similarly, there are interactions and dependencies across activities and trips, particularly those that belong to the same trip chain or tour. There are time-space prism constraints that, under most circumstances, cannot be violated as people are limited to a certain action space, the size of which is usually determined by the speed of travel, network characteristics, and mandatory activity requirements in the daily schedule. There are modal constraints such as those associated with the availability (or lack thereof) of a personal vehicles and the more rigid nature of transit schedules, routes, and hours of operation.

When one is considering the design of an integrated land use – transport model system, the need to recognize the presence of feedback processes is further amplified by the fact that feedback loops may exist both within and across model components. The incorporation of feedback processes tends to add complexity to the modeling process, and it is sometimes difficult to interpret the behavioral phenomenon that is represented by the presence of a feedback loop. However, feedback loops play a vital role in representing the learning process that travelers use to modify and adjust their schedules, particularly over time based on past experience. Feedback loops also play a critical role in bringing a model to an equilibrium point or state, for example, to a state where travel times obtained from the network model no longer change from one iteration to the next. In designing SimTRAVEL, it was attempted to adopt fewer feedback loops, only those that are critically required to represent behavioral processes and bring about a stable state. In this context, the convergence criteria typically used in model components and the extent to which such convergence criteria can be easily transferred to an integrated model development context are being examined.

One of the major challenges associated with the development and implementation of an integrated model system is that of computational burden and efficiency. Microsimulation model systems essentially purport to simulate the behaviors of individual agents and decision-making units in a fine-grained time-space representation. These model systems include numerous components, must run through a series of computations for the entire population of a region, and do this a number of times through feedback loops until convergence is achieved. Moreover, simulation models must often be run dozens of times as each simulation run is merely one stochastic realization of the behavioral process depicted by the model system. Databases used in large-scale fine-grained integrated model systems are inevitably extremely large and the handling of these databases imposes significant computational burden.

While great strides have been made in the microsimulation of people's travel in automobile modes, there has been relatively less progress in the microsimulation of multimodal travel involving transit modes. Although the demand component of the model system may incorporate transit modes in the mode choice component, the dynamic traffic assignment is often limited to routing private automobile trips only. The transit assignment process often defaults back to a static assignment process with aggregated transit origin-destination tables serving as input to the transit assignment step. In simulating transit travel, it is necessary to ensure that several key constraints and aspects are adequately captured.
These include:

1. The representation of transit access and egress legs of a trip

2. The limits placed on a destination choice set to include only those destinations that can be reached by transit

3. Consideration of constraints associated with transit schedules and hours of operation

4. Inter-relationships between transit networks and highway networks (buses run mostly on roadway networks; when a roadway network gets congested, speeds reduce for both auto and bus modes)

Finally, a key consideration in the model design was the desire to develop a truly integrated model system, one in which activity-travel-location choice behavior is captured in a coherent behavioral framework that seamlessly brings model components together. Integrated model system development often reduces to a loose stitching of multiple model systems such as a land use model, travel demand model, and network assignment model. Data and outputs flows from one model to the next in a sequential fashion, and although feedback loops across model systems are present, the overall framework constitutes a loose coupling of model components. Such a loose stitching of disparate model components limits the ability to represent behavioral phenomena that cut across multiple model systems, bring about efficiencies in data handling and access, and may induce behavioral inconsistencies that cannot be effectively reconciled. The goal was to develop a truly integrated model system, one that would appear to represent behavior in its entirety across the time-space continuum.

OVERALL MODEL FRAMEWORK AND DESIGN

This section presents a detailed description of the proposed integrated model design, with heavy emphasis on the linkage between the activity-travel demand model and the dynamic traffic assignment model. For illustration and implementation purposes, specific individual model systems have been chosen, but the procedures and techniques presented in this paper are intended to be broadly applicable to a wide range of modelling platforms. The authors themselves have been involved in the development of these model systems. The land use microsimulation model system to be used in this project is UrbanSim (Waddell et al, 2003), an open source software system for simulating land use markets on the residential and non-residential front. UrbanSim includes a suite of residential location choice, workplace location choice, and employer location choice models (among several other model components) to mimic land use dynamics over time. The activity-based travel model system in SimTRAVEL is dubbed OpenAMOS and is a comprehensive microsimulator of human activity-travel patterns. OpenAMOS is largely based on previous work that resulted in the development of AMOS (Activity-Mobility Simulator) and its Florida implementation called FAMOS, PCATS (Prism-Constrained Activity Travel Simulator), and STPG (Synthetic Travel Pattern Generator) (Pendyala et al, 1998; Pendyala et al, 2005). The dynamic traffic assignment model component of SimTRAVEL is called MALTA (Chiu et al, 2008; Villalabos et al, 2008). MALTA is capable of reading origin-destination trip tables, trip chains, or individual travel records and routes trips along time-dependent shortest paths to estimate volumes on network links. MALTA also incorporates a simulation module that tracks the movements of individual vehicles through the network with speeds constantly updated using established macroscopic speed-flow relationships. The overall design framework of the integrated model is shown in Figure 1.

The land use microsimulation model (UrbanSim), although integral to the overall model system, is not linked to the extent that the demand and network supply models are integrated. This is because the land use model deals primarily with longer term location choices, and employment and residential land use phenomena that serve as inputs to the travel model system. The activity-travel demand model (OpenAMOS) and the dynamic traffic assignment model (MALTA), on the other hand, deal with short term travel choices that are inextricably linked together.

Two basic approaches were considered to undertake the model integration. One approach, which is essentially a sequential process, involves a loose coupling of model systems. Each model system is run virtually independently without any cross-linkage across the model systems. In this configuration, the activity-travel demand model would be run through its series of steps and feedback loops with a certain set of network level of service attributes until complete activity-travel patterns are simulated for all individuals in the population. These activity-travel patterns would then be fed to the dynamic traffic assignment model that would then proceed through its series of steps and feedback loops until a stable set of travel times is obtained. This stable set of travel times would then be fed back up to the activity-travel model; the activity-travel model would be run using this new set of network level of service attributes, and a new set of activity-travel patterns will emerge. This new set of activity-travel patterns would be fed into the dynamic assignment model, which would (in turn) produce yet another new set of travel times for the activity-based travel demand model. This sequential process of running each individual model system independent of the other with simple input-output data flows connecting the two entities constitutes a sequential process in which model systems are loosely stitched or coupled together. This design was not along the goal of this effort.

An alternative integrated model system in which the demand model and the network supply model constantly communicate with another was then designed. In this design, activities and trips generated along the continuous time axis are routed and simulated on the network as they happen. In other words, this design adopts more of an event-based paradigm in which every activity, trip departure, trip arrival, and choice instance is an “event” that is simulated along the time axis. The dynamic interaction framework is shown in Figure 2.

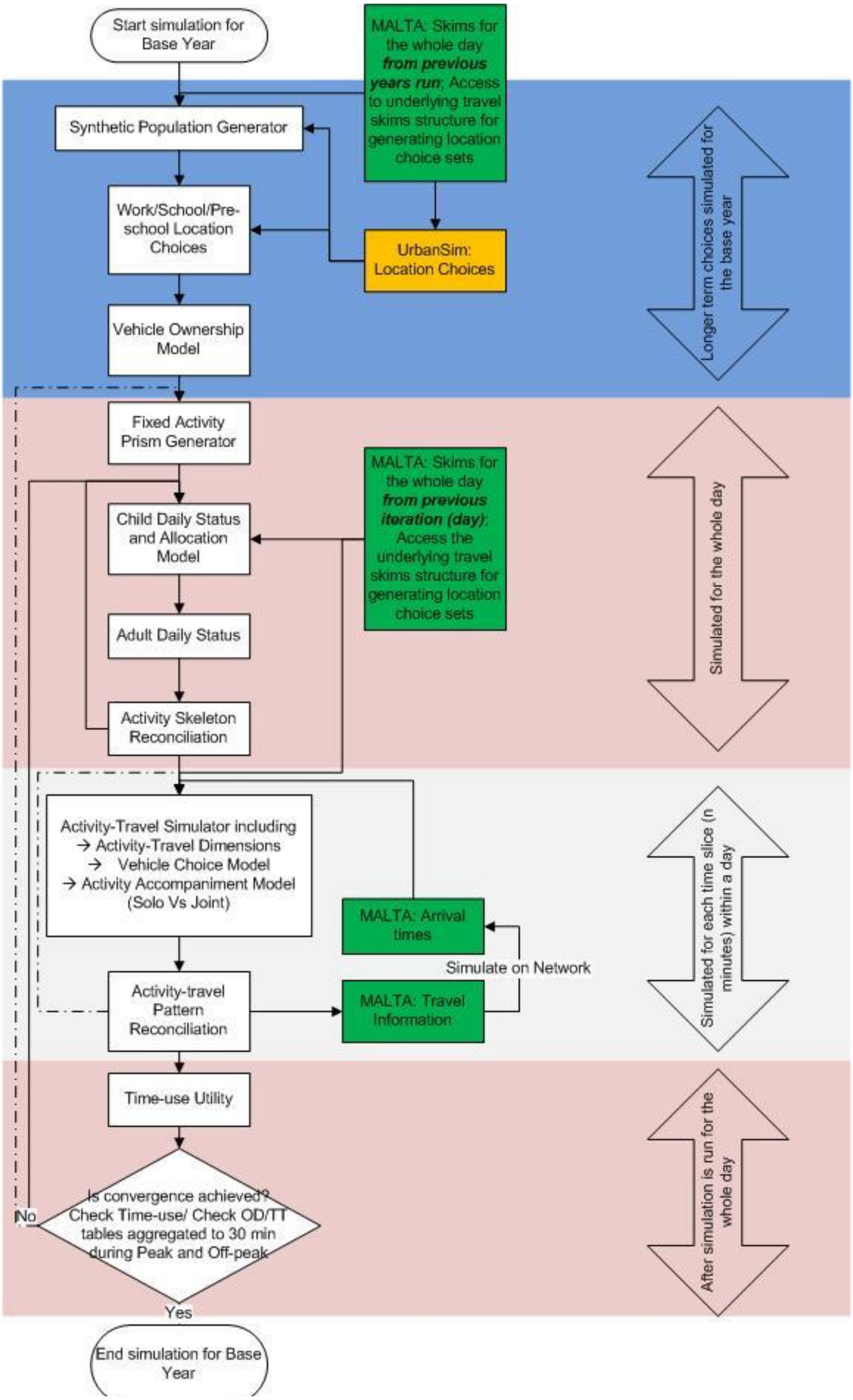

Figure 1 – The SimTRAVEL design framework

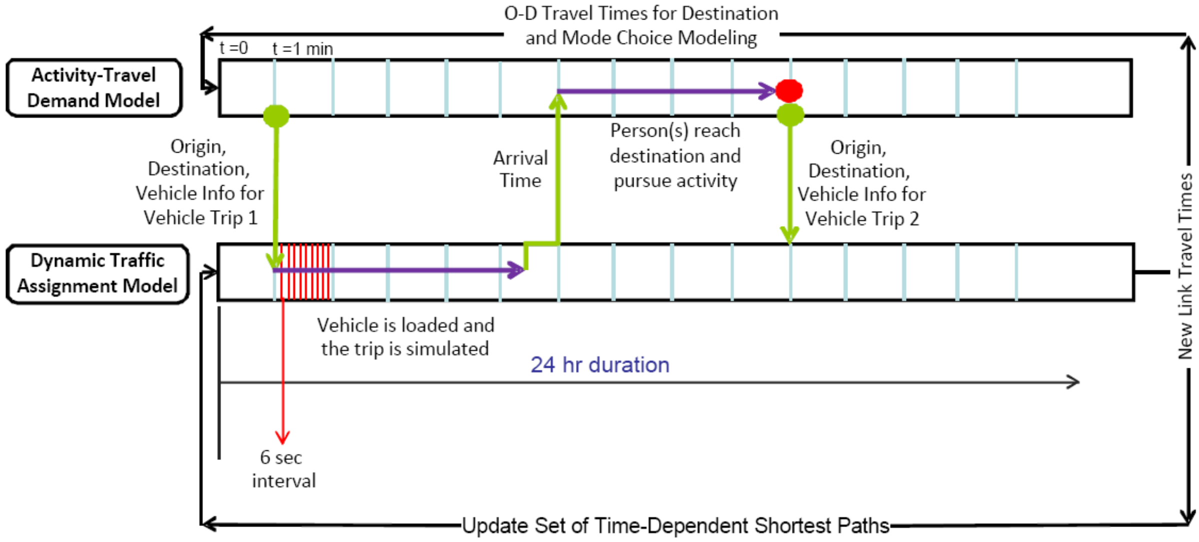

Figure 2 – Operational paradigm underlying integrated demand-supply model

In the activity-based model system, mode and destination choices for various activities are determined using joint mode/destination choice modeling approach. The mode choice set includes only those alternatives that are feasible at any given point in time while the destination choice set includes only those alternatives that can indeed be reached by the fastest mode possible in the mode choice set, while adhering to time-space prism constraints. The joint mode-destination choice model component uses network level of service attributes (primarily travel times) to simulate these choices. Therefore, the activity-travel demand model needs an initial set of network travel times to get started. These initial travel times could be derived from the existing validated four-step travel demand model. However, as these travel times are likely to be very different from those obtained from a dynamic traffic assignment based algorithm, it was decided to employ an initial boot-strapping procedure to obtain a more consistent initial set of travel times – i.e., more consistent with travel times that are likely to be obtained from a dynamic traffic assignment modeling methodology. This initial bootstrapping procedure will be described in detail later in this section.

For now, assume that an initial set of node-to-node travel times and origin-destination shortest paths (a shortest path set obtained through the bootstrapping procedure) is available. Then, Figure 2 shows how the activity-travel demand model and the dynamic traffic assignment model will be linked together in a truly integrated framework. The time-resolution in the activity-travel demand model is one minute. Essentially, activities can begin and end, and trips can begin and end, on the minute. A 24-hour day may be broken up into 1440 one-minute periods because there are 1440 minutes in a day. At each minute, a number of trips, with associated origin-destination-mode-vehicle information, occur. These trips come from the activity-travel demand model which populates each trip with these essential four ingredients of information. In addition, the activity-travel demand model also provides information on number of occupants, relationship among occupants in a vehicle, vehicle type and identifier, and trip purpose. Armed with the origin-destination-mode-vehicle information for all trips that occur at a minute, the activity-travel demand model passes all of this information to the dynamic traffic assignment model. The set of trips passed from the activity-travel demand model to the dynamic traffic assignment model in each one minute time-slice is routed. Wardrop's principle of user equilibrium holds in that the trips are allocated to different routes in the shortest path set (between an origin-destination pair) such that travel times across all used paths are equal.

The dynamic traffic assignment model (MALTA) is capable of simulating the movements of individual vehicles in intervals of 6 seconds. Every six seconds, the position of a vehicle (on its path to the destionation) is updated. Each minute has 10 six-second intervals, thus allowing one to monitor the position of each vehicle on the network every six seconds. In order to avoid lumpy loading of vehicles onto the network at each minute, vehicles will be loaded onto the network every six seconds. Thus, there will be 10 instances of vehicle loadings in each minute within the dynamic traffic assignment model. All trips passed from the activity model to the dynamic traffic assignment model at each minute will be uniformly distributed across the six-second time slices.

After the vehicles are loaded, the trips are actually simulated on the network in terms of their movements. As mentioned earlier, positions of vehicles can be monitored every six seconds. While it is theoretically possible to update node-to-node travel times at the same resolution of six seconds, this is probably unwarranted and computationally very burdensome. Therefore, the project team felt that a resolution consistent with that of the activity-travel demand model can be used for updating link travel times. Thus, the dynamic traffic assignment model updates node-to-node or link travel times every one minute based on network conditions. Using well-established macroscopic speed-flow relationships, the speeds and travel times on every link are updated on a minute-by-minute basis. Vehicle trips are now executed on the network using these travel time updates until vehicles reach the assigned destination. The arrival time is obtained from the dynamic traffic assignment. The dynamic traffic assignment model feeds back to the activity-based travel demand, in every one minute time slice, the set of trips (with all necessary identifiers and attributes) that have reached their destination. The activity-based model then allows these individuals to pursue their activities. The time allocation to an activity is computed using a duration model, while ensuring that time-space prism constraints are not violated. When an activity is completed, an individual reaches the next decision point on undertaking an activity. The mode-destination-vehicle combination for the next activity is determined in the activity-based travel model and the set of trips generated in each one minute time slice is fed to the dynamic traffic assignment model.

In each one minute time-slice, there will be a set of trips that are fed from the activity-based travel model to the dynamic traffic assignment model, and a set of trips that are fed from the dynamic traffic assignment model to the activity-based travel demand model. The time-dependent shortest paths are obtained at the end of one 24-hour simulation or iteration. At the end of a 24-hour simulation, one obtains a set of link travel times or node-to-node travel times for every minute of the day. For example, if there are 20000 links in a network, then one will have 20000 x 1440 link travel times. Using these link travel times, the *k* time-dependent shortest paths between all origin-destination pairs can be computed for every minute of the day. Just for simplicity, if one assumed the value of *k* to be constant across all origin-destination pairs, then the number of time-dependent shortest paths defined for each one-minute time slice would be $n \times n \times k$ where *n* is the number of origins or destinations. Considering that there are 1440 minutes in a day, the total number of time-dependent shortest paths that are generated and carried from one iteration to the next is $n \times n \times k \times 1440$.

Thus, the integrated model system developed incorporates some very appealing features. It actually accounts for the fact that arrival times are determined by conditions on the network, not based on some preconceived and predetermined travel times. Thus, arrival times are simulated and determined literally in "real-time" along the continuous time axis based on the simulations of vehicle movements and updated vehicle speeds (every minute) within an iteration. On the other hand, the *k* time-dependent shortest paths are defined in such a way that day-to-day learning processes are mimicked. The overall feedback loop may be considered representative of a day-to-day learning process whereby the set of shortest paths gets updated "from one day to the next" based on traveler experiences. This updating process is captured by the larger feedback loop shown in the figure.

Consistent with the notion of dynamic traffic assignment, shortest paths computed in this algorithm are time-dependent shortest paths. Time-dependent shortest paths recognize the fact that time elapses when one moves from one link to the next along a route/path. Say, a route between an origin-destination pair is composed of five links. The travel time for the route is not equal to the sum of the link travel times at an instantaneous moment in time. Instead, the travel time for a route is computed by aggregating travel times across links in a time-dependent manner. For example, suppose it takes 5 minutes to traverse the first link. Then, the travel time on the second link that is added to the first link travel time is that which is experienced five minutes later (i.e., five minutes after the start of travel at the beginning of the first link). This process continues until the travel time for a route is computed. The *k* time-dependent shortest paths are identified in this way for each origin-destination pair. The value of *k* will be determined as part of the model development and testing phase, although it is expected that the value of *k* will be at least two and no more than five. The algorithm will accommodate varying values of *k* across origin-destination pairs.

The question regarding how one gets the process started still remains. As can be seen from the figure, it is necessary to have a set of *k* time-dependent shortest paths to get the integrated model system started. One way to do this is to use the link travel times from an existing validated four-step travel demand model. The link travel times from the model can be used to compute origin-destination route travel times and identify the shortest paths. However, there is a problem with this approach. Because the travel times provided by the four-step travel demand model are obtained based on coarse aggregations of time periods (several hours at a time with just 4-5 time periods in a day) and obtained using origin-destination matrices derived from trip-based estimates of demand, these travel times are not likely to offer a robust means of computing *k* time-dependent shortest paths. In order to obtain a more robust set of travel times and time-dependent shortest path set at the beginning, it is planned to implement a boot-strapping procedure that is depicted in Figure 3.

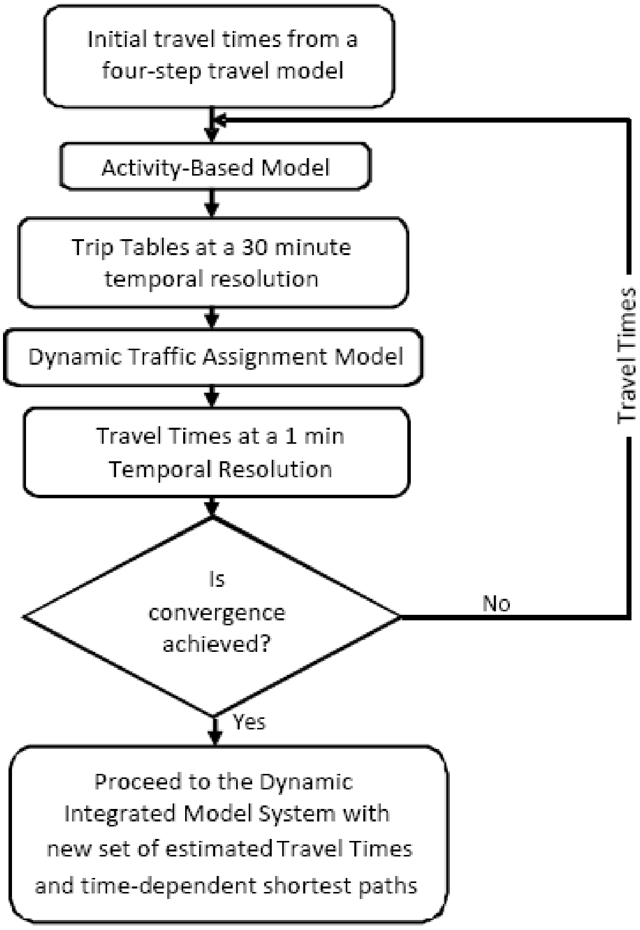

Figure 3 – Initial bootstrapping procedure for estimating travel times

In this boot-strapping procedure, the travel times from the validated four-step travel demand model are used to do a complete run of the activity-based travel demand model. Arrival times are determined based on the travel times provided by the four-step travel model. After a complete 24-hour simulation of activity-travel demand is completed, the trips are aggregated into 30-minute origin-destination matrices. These 30-min origin-destination matrices are fed into the dynamic traffic assignment model. Dynamic traffic assignment models are fully capable of reading in origin-destination matrices and uniformly distribute the traffic demand of a 30-minute period across the time span to facilitate route assignment and vehicle simulation. The dynamic traffic assignment model will run through a complete 24-hour simulation and output node-to-node or link travel times at one-minute resolution.

Essentially, the bootstrapping procedure mimics the more traditional sequential process. Origin-destination travel times are used in the activity-based travel model to generate complete activity-travel schedules for all individuals in the population. These schedules are then aggregated into a set of origin-destination matrices and assigned using dynamic traffic assignment models. In the first run, the dynamic traffic assignment model will also use the travel times from the four-step travel model and identify a set of shortest paths for each time period based on these travel times. However, these paths are not likely to be time-dependent shortest paths because of the aggregate treatment of time in most, if not all, four-step travel models. The trips are assigned and vehicular movements simulated with the result that link travel times can be derived on a minute-by-minute basis (because vehicular positions can be tracked at a six second resolution). The link travel times are then used to compute a new set of origin-destination travel times and identify a new set of time-dependent shortest paths. A new iteration of the bootstrapping procedure then commences. This process is continued until the origin-destination travel times do not change appreciably from one iteration to the next. The set of time-dependent shortest paths and link travel times obtained at the end of the bootstrapping procedure are used to initiate the dynamic integrated model system presented in Figure 2.

The two procedures described thus far constitute the integration of the demand and supply models for modeling travel along the continuous time axis. The connection and integration with the land use model completes the SimTRAVEL framework (eventually, the goal is to integrate these model components with MOVES for emissions modeling, but such an integration effort is beyond the scope of the current effort). The land use microsimulation model system aims to simulate the residential and work location choices of residents in a region, business and employment location choices, and other longer term processes that capture household and business evolution.

The location choice models embedded in the land use microsimulation model system are sensitive to network level of service attributes and accessibility measures. These measures generally constitute travel times, although cost components may also be included in accessibility computations. Accessibility measures generally take the form of a weighted travel time measure that captures the quantity of opportunities of a certain activity type within different travel time ranges of a location. Alternatively, accessibility measures can take the form of a travel time-weighted quantification of the number of destination opportunities that can be visited from a certain location to pursue a certain activity type with the exponent on the travel time variable serving to discount those destinations that are farther away. The land use microsimulation model system employs a range of such travel time and activity intensity based accessibility measures to reflect the impacts of such measures on land use choices exercised by residents and businesses.

Recognizing that land use choices tend to be longer term choices, while activity-travel choices embedded in the frameworks depicted in Figures 1 and 2 are shorter-term travel choices, there is no instantaneous feedback process between the travel model components and the land use model component. Instead, the relationship between land use location choices and activity-travel choices is assumed to have a time lag associated with it. The accessibility indicators that people experience in one year affect their longer term location choice decisions in the subsequent year. The time resolution of SimTRAVEL is one year when it comes to land use location choice modeling. The travel times obtained at the end of the process (in Figure 2) for year *t* are used to compute a series of accessibility measures. These year *t* accessibility measures are then fed into the land use microsimulation model system to simulate location choices and land use patterns in year *t+1*. The year *t+1* land use configuration then serves as input to the integrated demand and supply model system (depicted in Figure 2) for year *t+1*. At the end of the process, travel times for year *t+1* are obtained and these are used to calculate accessibility measures for year *t+1*. These accessibility measures are fed into the land use microsimulation model to obtain land use configuration and location choices for year *t+2*, and the process continues in an evolutionary process until the horizon forecast year is reached.

There is potential to simulate the activity-travel patterns of only those individuals who actually experience a change in household/person characteristics from one year to the next. For those households that experience no change (other than a simple aging of one year) in location choices or household/person demographics, perhaps the activity-travel patterns remain largely unchanged. By limiting the simulation to those households and persons that actually experience a transition of some kind, the computational burden associated with annual simulation of activity-travel demand and location choices can be substantially reduced. While this concept remains certainly appealing, the intention is not to proceed with the implementation of this approach at the outset. The implementation of such an approach requires considerable thought and the development of a methodology that can keep track of activity-travel patterns of households and individuals that undergo a change versus those that do not undergo a change. It is also difficult to set criteria for what constitutes a “change” in circumstance in a household or person situation. For example, would a 10 percent increase in income (with absolutely no other changes in the household/person characteristics) constitute a “change” worthy of modeling activity-travel patterns in a simulation year, or would this constitute a non-event that does not bring about any changes to activity-travel patterns. Given the complexity of household activity-travel patterns, route choice behavior, and location choices, it may be prudent to initially proceed with modeling behavior for the entire population in a traditional sense. If considered feasible, this approach may be considered on a trial basis after the complete model system is in place and fully tested.

The final piece of this puzzle is to determine stopping criteria for the integrated demand – supply model depicted in Figure 2 (and the bootstrapping procedure depicted in Figure 3). As these are iterative processes with feedback loops, appropriate convergence or stopping criteria must be defined. It is envisaged that the exact quantitative criteria for stopping the process will be established as part of the model development and testing process. The setting of convergence criteria must carefully weigh considerations of computational burden against those of accuracy and precision in the model estimates.

For the bootstrapping procedure, it is proposed that the process be run through to convergence. There are essentially two measures that will be used to determine convergence in the bootstrapping procedure. They are 30-min aggregate origin-destination tables and origin-destination travel times. It has been reported in the literature that the use of averaging helps bring iterative processes to convergence in a computationally feasible and efficient manner (as opposed to more naïve methods wherein such averaging techniques are not employed). Appropriate averaging techniques including those that weight outputs from more recent iterations more heavily than those from previous iterations will be implemented. These methods of weighted successive averaging should help bring the process to closure efficiently. Criteria will be established in terms of the maximum allowable difference (absolute difference) between results of one iteration and the immediately preceding iteration for each origin-destination pair, as well as the overall average absolute difference across all origin-destination pairs. Once all criteria are met (i.e., all differences between two successive iterations are below the convergence criteria threshold values), the process is stopped and the resultant travel times are used to start the dynamic integrated model system process (shown in Figure 2).

Very similar logic will be applied to bring the process depicted in Figure 2 to a stop as well. The origin-destination travel times will be averaged over successive iterations and compared between two successive iterations. When no origin-destination travel time difference (between two iterations) exceeds a certain threshold value, and the overall average absolute difference is within a set criterion, the process may be stopped. In addition to using travel times, 30-minute origin-destination trip tables during each iteration will be computed and the results across iterations will be compared. Averaging techniques will be applied to bring the process to closure in a computationally efficient manner and prevent random oscillations of large magnitude. While it is potentially feasible to compare link volumes or path volumes from one iteration to the next, it appears that might be prohibitive from a computational standpoint and the non-uniqueness of the flow solution may present a potential problem for using volume comparisons as convergence criteria. As such, it was considered more practically feasible to compute 30-minute origin-destination trip tables from the dynamic integrated model system and compare differences across iterations to determine if convergence criteria are met.

Thus, the plan is to use origin-destination travel times and origin-destination flows (aggregated into 30-min blocks), suitably averaged over successive iterations, to bring the process to convergence. This may be extremely difficult considering that there are literally 1440 origin-destination travel times and millions of cells in the origin-destination matrices. How is it possible to compare these millions of values and ensure that all of them are within a certain threshold value between two successive iterations? It may be prudent to allow a certain small percentage of values to deviate beyond the established threshold criterion. The exact convergence criteria, allowable exceptions, and other exact stopping parameters will be determined as part of the model development and testing process.

Finally, with respect to stopping criteria and convergence, it is being considered that perhaps convergence (in terms of two successive iterations being virtually identical to one another) does not necessarily have to be achieved. Given that the transportation system is constantly in a state of flux, day to day variations in travel and volumes abound, and activity-travel behavior is characterized by high degrees of randomness, perhaps the network and demand never reach a stable equilibrium point. Under this paradigm, it may be sufficient to simply set a maximum number of iterations that the process will be run and then accept a weighted average of the results at the end of the set number of iterations. If the maximum number of iterations is set to a value that is large enough, then the differences between the last two successive iterations should not be large anyway. So, a balanced approach between setting convergence criteria and controlling the process through the deployment of a maximum number of iterations so that the process does not continue for eternity in case convergence criteria are not met rapidly is being considered. This balanced approach would provide for near-convergence, while providing computational efficiency and accommodation of the notion that true equilibrium is never truly achieved in the real world.

CONCLUSIONS

In summary, SimTRAVEL is a comprehensive integrated model system capable of modeling the urban continuum, from longer term land use location choices to instantaneous activity-travel-route choices. SimTRAVEL is envisioned to be a comprehensive integrated land use – transport model system capable of offering policy sensitive forecasts to a wide range of modal and socio-economic scenarios in a variety of geographic contexts. It is envisioned to be multimodal with the ability to accommodate highway and transit modes in the accounting of personal travel. Thus, the overarching goal of this multi-year project is to develop a comprehensive multimodal model system of personal activity, travel, and location choices. There are inevitably going to be aspects of travel that are not modeled, particularly in the initial prototypes of the model system, including – for example – bicycle and walk travel, freight travel, visitor and tourist travel, long-distance travel, and travel of goods and services.

In the context of SimTRAVEL, there are no additional validation criteria or sensitivity analysis that would apply. SimTRAVEL would be expected to meet all of the same validation criteria and standards that were expected of individual model components comprising SimTRAVEL. Once the model systems are integrated to form SimTRAVEL, the integrated model will be subject to all of the same sensitivity tests that have been described in the context of the individual model components. Population and employment will be changed, modal system conditions will be modified, capacities and speeds will be perturbed, and policy interventions will be imposed. The way in which SimTRAVEL responds to these perturbations will be examined and evaluated in detail to determine if the model is forecasting land use patterns and activity-travel choices in a behaviorally intuitive manner. The same benchmarks will largely be used in the context of considering SimTRAVEL acceptable in terms of performance and forecasting accuracy. The goal is to have an integrated model prototype by the end of Summer 2010 and a more fully functional system available by the end of the calendar year in 2010. Much of the assessment of the integrated model will be undertaken in early 2011 as part of the year 3 effort in which the entire model system will be thoroughly documented together with an evaluation of the model performance from a forecasting and application perspective, as well as a computational burden perspective.

REFERENCES

Boyce, D. and H. Bar-Gera (2004). Multiclass Combined Models for Urban Travel Forecasting. Networks and Spatial Economics 4, 115-124.

Chiu, Y-C., H. Zheng, J. A. Villalobos, W. Peacock and R. Henk (2008). Evaluating Regional Contra-Flow and Phased Evacuation Strategies for Central Texas Using a Large-Scale Dynamic Traffic Simulation and Assignment Approach. J. Homeland Security and Emergency Management, 5(1), Article 34.

Goulias, K. G. and R. Kitamura (1992). Travel Forecasting with Dynamic Microsimulation. Transportation Research Record, 1357, 8-17.

Kasturirangan, K., R.M. Pendyala and F.S. Koppelman (2002). Role of History in Modeling Daily Activity Frequency and Duration for Commuters. Transportation Research Record, 1807, 129-136.

Kitamura, R. and S. Fujii (1998). Two Computational Process Models of Activity-travel Behavior. In: Theoretical Foundations of Travel Choice Modelling (T. Gärling, T. Laitila and K. Westin, ed.), pp. 251-279, Pergamon Press, Oxford.

Kitamura, R., A. Kikuchi and R.M. Pendyala (2008). Integrated, Dynamic Activity-Network Simulator: Current State and Future Directions of PCATS-DEBNetS. 2nd TRB Conference on Innovations in Travel Modeling, Portland, OR.

Kitamura, R., A. Kikuchi, S. Fujii and T. Yamamoto (2005). An overview of PCATS/DEBNetS micro-simulation system: Its development, extension, and application to demand forecasting. In: Simulation Approaches in Transportation Analysis: Recent Advances and Challenges (R. Kitamura and M. Kuwahara, ed.), pp. 371-399, Springer, New York.

Kitamura, R., C. Chen, R. M. Pendyala and R. Narayanan (2000). Micro-simulation of Daily Activity-Travel Patterns for Travel Demand Forecasting. Transportation, 27, 25-51.

Lin, D-Y., N. Eluru, S.T. Waller and C.R. Bhat (2008). Integration of Activity-Based Modeling and Dynamic Traffic Assignment. Transportation Research Record (in press).

Miller, E.J. (2002). Propositions for Modelling Household Decision-Making. International Colloquium on the Behavioral Foundations of Integrated Land Use and Transportation Models: Assumptions and New Conceptual Frameworks, Quebec City, Canada.

Miller, E.J. (2006). Integrated Urban Models: Theoretical Prospects. 11th International Conference on Travel Behaviour Research, International Association for Travel Behaviour Research, Kyoto University, Japan.

Pendyala, R.M., R. Kitamura and D.V.G.P. Reddy (1998). Application of an Activity-based Travel-demand Model Incorporating a Rule-based Algorithm. Environment and Planning B, 25, 753-772.

Pendyala, R.M., R. Kitamura, A. Kikuchi, T. Yamamoto and S. Fujii (2005). The Florida Activity Mobility Simulator (FAMOS): An overview and preliminary validation results. Transportation Research Record, 1921, 123-130.

Salvini, P. and E.J. Miller (2005). ILUTE: An Operational Prototype of a Comprehensive Urban Microsimulation Model of Urban Systems. Networks and Spatial Economics 5, 217-234.

Timmermans, H.J.P. (2003). The Saga of Integrated Land Use – Transport Modeling: How Many More Dreams Before We Wake Up? 10th International Conference on Travel Behaviour Research, Lucerne, Switzerland.

Villalobos, J. A., Y.-C. Chiu and P. B. Mirchandani (2008). MALTA – The Spatially and Temporally Scalable Dynamic Traffic Simulation and Assignment System. INFORMS Computing Society newsletter.

Waddell, P. (2000). A Behavioral Simulation Model for Metropolitan Policy Analysis and Planning: Residential Location and Housing Market Components of UrbanSim. Environment and Planning B, 27, 247-263.

Waddell, P. (2002). UrbanSim: Modeling Urban Development for Land Use, Transportation and Environmental Planning. J. Am. Planning Assoc., 68, 297-314.

Waddell, P., A. Borning, M. Noth, N. Freier, M. Becke and G. Ulfarsson (2003). UrbanSim: A Simulation System for Land Use and Transportation. Networks and Spatial Economics 3, 43-67.

Waddell, P., C.R. Bhat, N. Eluru, L. Wang and R.M. Pendyala (2007). Modeling the Interdependence in Household Residence and Workplace Choices. Transportation Research Record, 2003, 84-92.

Waddell, P., X. Liu and L. Wang (2008). UrbanSim: An Evolving Planning Support System for Evolving Communities. In: Planning Support Systems for Cities and Regions (R.K. Brail, ed.), Chapter 6, pp. 103-138, Lincoln Institute of Land Policy, Cambridge, MA.