AN INTEGRATED LAND-USE TRANSPORT MODEL APPLICATION: SIMULATING THE IMPACT OF NETWORK DISRUPTIONS ON ACTIVITY-TRAVEL ENGAGEMENT PATTERNS

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Introduction

Network disruptions refer to a class of events that disrupt the regular flow of traffic on one or more roadway facilities. Network disruptions lead to a drop in capacity on the roadway element where the event occurs and cause delays, build up queues and lead to spillbacks on to surrounding links on the network. Network disruptions may include planned events such as full roadway or lane closures to accommodate work zones along a freeway segment or bridge section, or unplanned events such as traffic crashes or roadway/bridge failures. The modeling of the impacts of network disruptions on travel demand and traffic flow has important implications. First, in the context of unplanned network disruptions, understanding the impact of such events and associated delays allows for the planning of emergency response services. Emergency response services can be optimized so that crisis teams can respond to incidents as quickly as possible and alleviate the impact of disruptions. Second, modeling the impact of network disruptions allows for estimating the changes in activity-travel demand along both the space and time dimensions that may result due to such events. Such an understanding would allow professionals to devise traveler information systems and routing strategies that would minimize adverse impacts on people's activity-travel schedules.

The effects of network disruptions may be simulated using a variety traffic models. However, there are some key considerations which determine the accuracy in representation of the disruption and its associated impacts. First, the model should be sensitive to information provision and reflect the influence of information provided on routing decisions for people entering the network after the onset of the disruption. For example, there are a number of outlets that provide information about network disruptions including radio traffic reports, Google maps about current traffic conditions, and advanced traveler information systems (such as 511 systems) about roadway closures among others. The traffic model should be able to represent the alternate routing decisions that individuals employ in response to this information and resultant network conditions. Second, any model of the network disruption should account for the short-term re-routing decisions that people already on the network employ in order to minimize the impact of disruption. For example, when a crash occurs on a freeway, drivers upstream of the crash may get off at the next exit (if possible) and choose to take alternate routes to get to their destination instead of staying on the freeway waiting for the accident to clear. Third, the network disruption model should be able to capture the impact of disruptions on activity-travel engagement patterns and the demand that is generated. An extra hour spent on the network due to travel delays is an hour that is no longer available for subsequent activity-travel engagement. This may lead to individuals adjusting, or modifying their activity-travel engagement patterns. The last consideration is of particular relevance in the context of planned network disruptions which may affect a sub-population in a region for extended periods of time (e.g. "Carmageddon", Reuters 2011).

There is a rich body of literature on the modeling of unplanned network disruptions (Chang and Nojima 2001, Kamga et al. 2011) and planned network disruptions (Clegg 2007). However, the literature on modeling network disruptions and understanding its impact on activity-travel engagement patterns is limited. Zhu et al. (2010) present a study looking at the impact of the I-35W bridge collapse over the Mississippi River in Minneapolis on traffic flows in the surrounding region and on the travel behavior patterns from observed data. However, the research does not consider the impact on activity-travel patterns per se. Sundaram (2002) presents a framework for modeling network disruptions and captures its impact on activity-travel behavior. However, the model implementation employs a hybrid model of travel demand and not a full-scale microsimulation model that allows for a more accurate representation of underlying behaviors and the various interactions and constraints that individuals experience.

In this paper we present a framework for modeling network disruptions which allows for an accurate representation of activity-travel engagement, network dynamics, and the interplay between the two enterprises. The framework combines a travel demand model system (generating the activity-travel engagement decisions) with a traffic simulation model which simulates the routing decisions and movement of vehicles on the network. A prototype system has been developed using microsimulation-based models of travel demand (OpenAMOS – an open-source activity-based travel demand model system) and traffic microsimulation (MALTA - Multi-Resolution Assignment and Loading of Traffic Activities) to accurately capture the interactions and constraints that people experience as they pursue their activity-travel agendas. The prototype is used to model an unplanned network disruption such as a crash on a major freeway corridor. A comprehensive analysis is conducted to assess the impact of the network disruption, and characterize the network congestion dissipation dynamics under a variety of information provision scenarios. In the next section, the framework is presented followed by a description of the study area. In the final section, key contributions of the framework are highlighted.

Framework for Modeling Network Disruptions

As noted earlier, one of the key components that need to be included in the context of network disruption models is the activity-travel scheduling and rescheduling behavior exhibited by individuals in response to network delays caused by disruptions. This calls for an integration of an activity-based travel demand model with a dynamic traffic simulation model. The integration approach should be able to accommodate constant feedback between the travel demand model and the traffic simulation model along the continuous time axis to account for the interaction between the two systems and capture the impact of network conditions on subsequent activity-travel engagement decisions.

An approach often proposed to integrate the activity-travel demand model and the network supply model is to run the models sequentially. Each of the model systems is run independently and coupled together through input-output data flows. However, such an approach cannot be used to model the impacts of network disruptions because there is no feedback between the model systems along the time axis as activity-travel patterns evolve over the course of the day in response to network conditions. Pendyala et al. (2011) present an event-based approach for integrating the two model systems that can support continuous feedback between the model systems. Figure 1 presents an overview of the integration approach. Within each minute of the day, the demand model simulates activity-travel engagement decisions of all individuals. Trip information, including, origin, destination, mode, and vehicle information, is passed to the dynamic traffic assignment model for routing trips on the network. The traffic assignment model in turn routes the trips and simulates vehicular movements on the network. Once the trips arrive at their destination, the traffic assignment model passes back the arrival information to the demand model to simulate subsequent activity-travel engagement decisions. The activity-travel demand model simulates adjustments to activity schedules based on actual arrival times experienced by travelers. At the end of the simulation for a day, network skims by time of day are updated for use in a subsequent iteration of the model system.

The framework presented in Figure 1 lends itself to modeling network disruptions. In the context of modeling the impacts of network disruptions on activity-travel engagement decisions, there are two key considerations. First, the actual arrival times need to be fed back to the travel demand model to simulate activity-travel engagement decisions in the subsequent time interval. Second, network conditions after the onset of an incident also need to be passed back to the travel demand model so that the simulated activity-travel engagement patterns are a reflection of the network conditions that prevail at the time. The prevailing network conditions should be used in routing decisions. The framework presented in Figure 1 can accurately capture the first consideration, i.e., adjusting activity-travel scheduling behavior in response to arrival information. However, the framework cannot simulate information provision, i.e., the framework does not accommodate feedback of the existing (prevailing) network conditions in simulating activity-travel and routing decisions in the subsequent period(s) of the day.

Figure 2 presents a revised framework for integrating demand and supply model systems so that the effects of network disruptions can be simulated in a behaviorally consistent way. The model systems proceeds in a manner consistent with the framework proposed by Pendyala et al. (2011) in Figure 1, where converged base year link travel times (L_{base}) are used from start of day until the onset of the disruption ($t = a$) and again from the time that the disruption is cleared ($t = b$) until the end of day. However, for the time period between onset and clearing of the disruption ($a \leq t \leq b$), the linkage between the travel demand model and the traffic simulation model is modified as follows:

1. At the end of every simulation interval (t), the dynamic traffic assignment model replaces the expected link travel times (L_{base}) with the existing travel times (L_t) for all subsequent intervals because that is the best estimate of prevailing and future network conditions after the onset of an incident.
2. The new link travel times (L_t) by time of day are used to generate origin-destination travel time matrices (OD_t) for use in the travel demand model.
3. The traffic simulation model passes the travel time matrix (OD_t) reflecting prevailing conditions, along with all trips that have arrived at their destination, to the demand model so that activity-travel engagement decisions for the subsequent time interval may be simulated.
4. The travel demand model in turn passes back trips that need to be loaded on the network based on the prevailing network conditions (OD_t). In response to the prevailing (delayed) conditions, people may choose alternate destinations, or may just choose to proceed early to their next fixed activity (e.g., work) because they know it will take longer to get to the fixed activity.
5. Once the trips are received by the dynamic traffic network simulation model, routes are identified using prevailing conditions (L_t) as the expectation of the network for all subsequent time intervals. The traffic simulation model then loads and routes/simulates the trips.
6. The simulation time step is incremented ($t = t$+1) and the process (Steps 1 - 5) is repeated until the incident is cleared.
7. Once the incident has cleared, the base year converged network conditions by time of day are used once again to simulate activity-travel engagement and routing decisions.

The flowchart presented in figure 2 offers a robust framework for modeling incidents. The same framework may also be used to represent network disruption dissipation phenomena after the incident is cleared. This can be achieved by feeding back prevailing network conditions even after the incident is cleared, until the system matches base year network conditions.

Application Case Study and Expected Results

The framework presented in the previous section for modeling network disruptions is implemented using SimTRAVEL – Simulator of Travel, Routes, Activities, Vehicles, Emissions, and Land. SimTRAVEL constitutes an integrated model system based on the framework presented in Figure 1. The prototype has been enhanced to incorporate additional feedback between the model systems, and update the travel time matrices used in the simulation process, as necessitated by the framework presented in Figure 2. The land-use model in SimTRAVEL is UrbanSim – an open-source land use microsimulation model system (Waddell et al 2008). The travel demand model employed is OpenAMOS – an open-source activity-based travel demand model system (Pendyala et al 2011). The traffic microsimulation model system used in SimTRAVEL is MALTA -Multi-Resolution Assignment and Loading of Traffic Activties (Chiu and Villalabos 2008). The study region comprises three cities (Chandler, Gilbert, and Queen Creek) in the southeast region of Maricopa County, Arizona. There are about half a million people residing in about 150,000 households in the three city area. In order to simulate congestion, origin-destination tables from the four-step model of the region are used to simulate background traffic by converting them to trip lists disaggregated by time of day.

Three different simulation runs are being conducted as part of this research effort. These runs, depicting three different levels of information provision, are as follows:

1. **No information provision**: In this scenario, people are assumed to have no knowledge of prevailing conditions on the network and so individuals are making decisions about activity-travel patterns in OpenAMOS and routing decisions in MALTA without any regard for the presence of an incident. The assumption of no information provision is unreasonable because individuals that are on the network are aware of the prevalent conditions and those that are about to embark on a trip probably know about network conditions through some form of traveler information system such as local radio and 511 systems. Nevertheless, it is considered an interesting exercise to apply the model under this rather unrealistic assumption.
2. **Diversion with no en-route route switching:** In this scenario, travelers that are already on the network follow their planned routes even after the onset of the network disruption. Only individuals that are about to embark on a trip are aware of the prevalent network conditions. The activity-travel engagement and routing decisions of these individuals are based on the prevailing network conditions.
3. **Diversion with en-route route switching:** This scenario is similar to the previous case, except that. the assumption of travelers on the network not switching their routes is relaxed. Travelers on the network are allowed to switch to alternate routes in response to the network conditions they perceive. While it is theoretically possible to use the framework presented in Figure 2 to model this scenario, its implementation is computationally prohibitive because every traveler on the network needs to make a decision whether to continue on the planned path or switch paths to improve travel times. Therefore, instead of a single decision instance for path selection in the scenario where no en-route switching is allowed for a trip, there are multiple decision instances for path selection in this scenario.

The simulation runs account for different levels of information provision and route switching, and should provide important insights into how integrated demand-supply models may be used to simulate the impacts of network disruptions and operations strategies on activity-travel engagement.

Implications for Modeling Practice

The research effort described in this paper comprises one of the very few operational implementations of a microsimulation-based integrated model for simulating network disruptions. This effort constitutes a unique application of a tightly integrated model that involves constant feedback between the activity-travel demand model and the dynamic traffic simulation model so that activity-travel patterns evolve in response to actual network conditions experienced by travelers. The scenario analysis envisioned in this project would provide important insights into the impacts of network disruptions on time use and travel behavior under different levels of information provision. This effort offers planning agencies tools that may be used for modeling the impacts of network events and operational strategies on activity-travel patterns.

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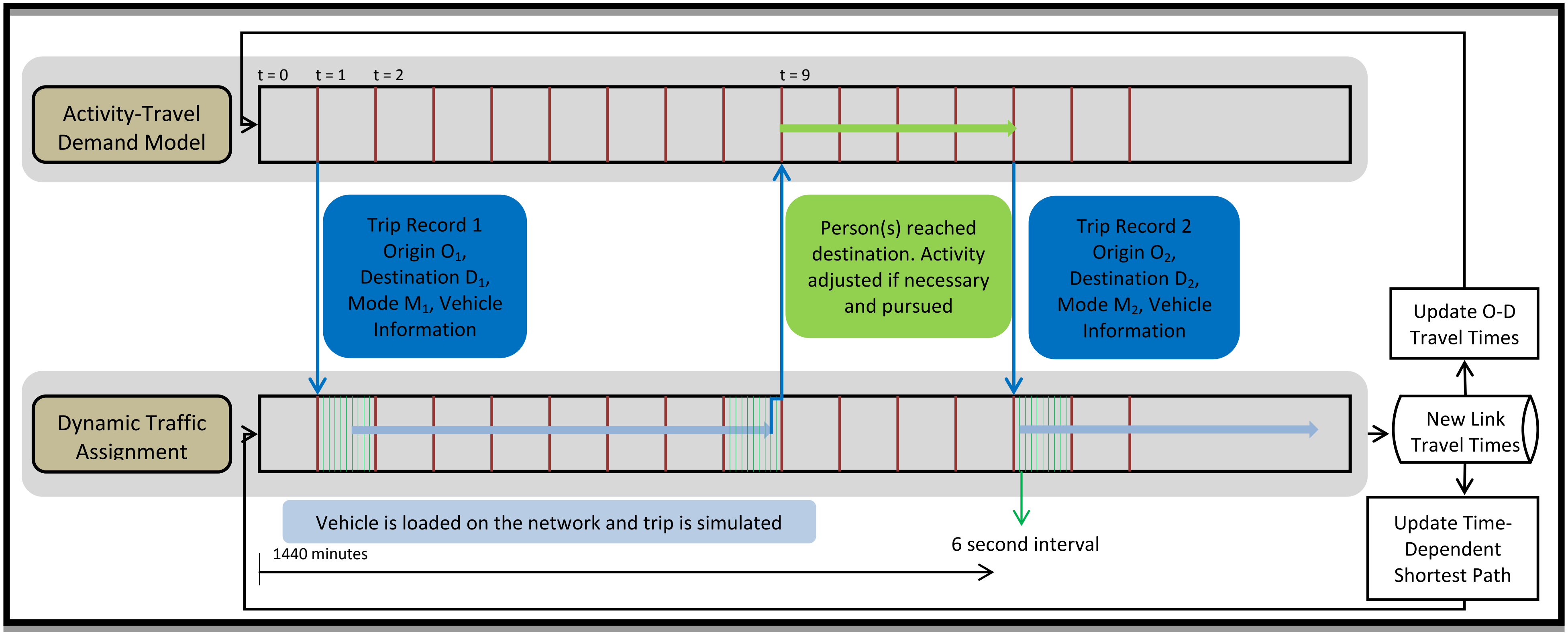

Figure 1: Framework for integrating travel demand and traffic simulation for dynamically generating activity-travel patterns

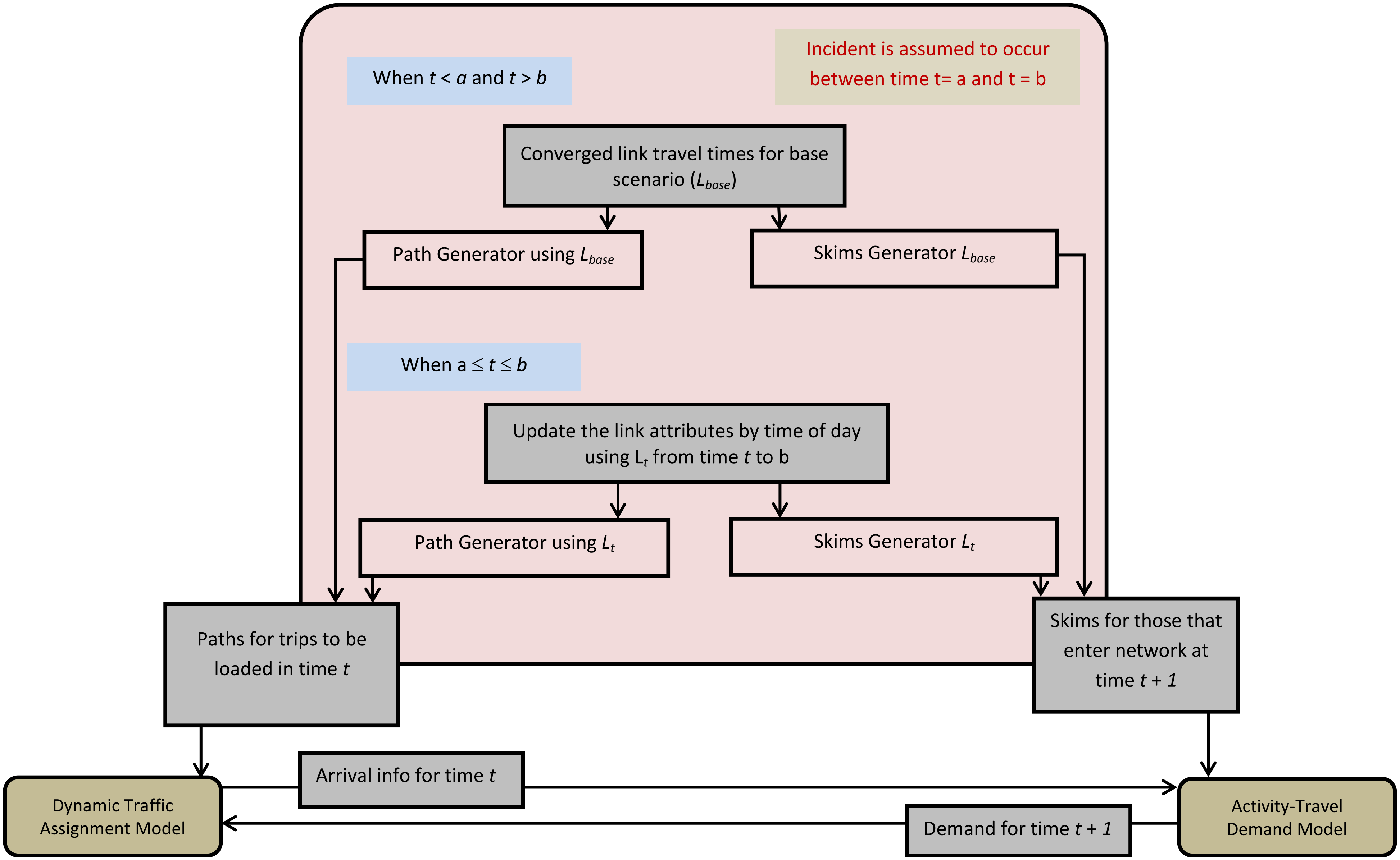

Figure 2: Modified framework for integrating travel demand and traffic simulation models to model network disruption