A Network-Sensitive Transport Modeling Framework for Evaluating Impacts of Network Disruptions on Traveler Choices under Varying Levels of User Information Provision

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ABSTRACT
There is considerable interest in the application of active traffic demand management (ATDM) and traveler information systems strategies to mitigate the adverse impacts of congestion and network disruptions. Such strategies and user information provision systems not only impact network performance through the modification of traveler route choices, but also through changes in the entire range of activity-travel choices such as activity generation, destination choice, mode choice, and time of day choice. The simulation of the impacts of alternative strategies on network performance therefore calls for the development and application of integrated modeling frameworks capable of reflecting the entire slate of activity-travel pattern adjustments that may occur in response to changes in network conditions and user information provision. This paper describes an integrated modeling framework wherein an activity-based travel demand model and a dynamic traffic assignment model are tightly coupled together with continuous information exchange between the models along the continuous time axis. The framework is enhanced to accommodate the possible impacts of alternative user information provision strategies on traveler choices and applied to a subregion in the Greater Phoenix metropolitan area to demonstrate the sensitivity of the model to network disruptions under alternative information provision scenarios. Model results are consistent with expectations and show that impacts of network disruption are substantially mitigated in the presence of traveler information systems. Further, the model results show that workers – who have more rigid work schedules and locations – are more greatly impacted by network disruptions than non-workers who do not have such constraints. Integrated modeling tools such as that described in this paper offer promise for evaluating emerging operational and policy strategies aimed at influencing traveler choices.

Keywords: Network disruption, traveler information systems, traveler choice simulation, travel demand and network supply interaction, integrated travel models

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INTRODUCTION

Network disruptions refer to a class of events that alter 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 result in spillbacks on to surrounding links in 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 ability to model the impacts of network disruptions on travel demand and traffic flow is important for a number of reasons. 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 routed and delivered so that crisis teams tend 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 minimize adverse impacts on people's activity-travel schedules.

The effects of network disruptions may be simulated using a variety of transport modeling tools. However, the following key considerations play a key role in the development of appropriate modeling frameworks capable of simulating the dynamics associated with network disruptions:

- The model system should be able to account for the effects of information provision while accurately representing the spatial and temporal scales of the information that the different sources seek to provide. For example, there are a number of outlets that provide information about real-time network conditions such as Google maps that provide information about traffic conditions only along major freeway and arterial corridors, radio traffic reports that provide more spatially aggregate information about incidents, variable message signs on selected freeway corridors, and commercial services that provide real-traffic information for a fee. These are but a few of the Advanced Traveler Information Systems (ATIS) technologies capable of providing system-wide information based on prevailing network conditions. However, each of these technologies differs in the spatial and temporal extents of coverage, and these spatio-temporal dimensions need to be effectively captured in a model used to simulate traveler response to user information systems under network disruptions.
- There are different decision paradigms that characterize how individuals' process information during a network disruption. When provided with information prior to embarking on a trip (pre-trip), individuals may alter their destination or mode, or completely forego the activity based on network conditions. On the other hand, individuals that are en-route to an activity destination may change their route, destination, or skip the activity altogether. The system modeling tool should be able to capture both pre-trip and en-route decision processes with respect to how the activity-travel events are planned and executed.
- Finally, trips should not be considered in isolation when evaluating impacts of network disruptions. Trips result from an individual's desire to engage in activities, subject to his/her knowledge about the network. Prevailing network conditions and the choices made in response to information provision (or lack thereof) affect subsequent activity-travel engagement decisions in the latter part of the day. For example, if an individual is oblivious to an incident along a planned route, then he or she may experience congestion and arrive late at a destination. This delay may have cascading effects resulting in a modification of subsequent activity-travel engagement patterns. Upon arriving late at the activity destination, the individual may adjust the duration of the activity, or keep the duration of the activity constant, but alter subsequent activity-travel episodes. The same individual, when provided with information about network conditions, may skip the planned activity or choose a different destination to pursue the same activity; both of these decisions could impact subsequent

activity-travel engagement decisions. It is necessary for models to provide a holistic accounting of individuals, their behaviors and interactions, and the daily activities and trips they wish to pursue. This last consideration also has implications for drawing inferences regarding quality of life impacts. If trips are considered in isolation, then computed quality of life indices may not be representative of the entire daily activity-travel patterns of individuals, and could lead to inaccurate policy inferences.

In this paper, a framework for modeling network disruptions which allows for an accurate representation of activity-travel engagement, network dynamics, and the interplay between these two components is presented. The framework, called SimTRAVEL (Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land) combines a land use - travel demand model system generating activity-travel engagement decisions with a traffic simulation model which routes and simulates the movement of vehicles on the network. A prototype of SimTRAVEL has been developed by integrating microsimulation-based models of land use (UrbanSim; Waddell et al. 2008), travel demand (OpenAMOS – an open-source activity-based travel demand model system), and network dynamics (MALTA - Multi-Resolution Assignment and Loading of Traffic Activities; Chiu and Villalobos, 2008). The prototype is designed with a view to accurately capture the interactions and constraints that people experience as they pursue their activity-travel agendas. The prototype, described previously in Pendyala, et al (2011), is used to model the impacts of an unplanned network disruption on a major freeway corridor. A comprehensive analysis is conducted to assess the impact of the network disruption on activity-travel engagement patterns under a variety of traveler information provision scenarios.

The remainder of this paper is organized as follows. In the next section, a discussion on modeling network disruptions under user information provision is furnished. Then, the integrated modeling framework and the SimTRAVEL prototype that has been developed are described. In the fourth section, the case study and the different scenarios that are evaluated are described. In the fifth section, results from the application of the prototype to model different network disruption scenarios are presented. Finally, the paper offers a discussion of the implications of the results along with some concluding thoughts.

MODELING NETWORK DISRUPTIONS UNDER USER INFORMATION

There is a rich body of literature in the transportation domain focusing on better understanding the impact of network disruptions. The literature may be broadly classified into two themes, namely, measuring activity-travel behavior changes in response to network perturbation and user information provision, and the development of system modeling tools for simulating network disruptions and evaluating different policies and solutions to alleviate the impacts of network disruptions. Along the first theme of understanding the activity-travel behavior dynamics associated with network disruptions, Zhu et al. (2010) use measurements from the field to quantify the impacts of the collapse of the I-35W bridge, which spans the Mississippi River in Minneapolis, on traffic flows in the region and travel behavior patterns. Yun et al. (2011) explore travel behavior changes exhibited by individuals in response to a planned network disruption – a nine-week reconstruction project of Interstate 5 (I-5) in Sacramento, California. They conduct surveys of commuters to measure changes in traveler behavior brought about by the planned highway closure. The study presents results from the first two surveys and highlights the types of behavioral changes exhibited by individuals. Other studies include those by Chang and Nojima (2001), Zhu et al. (2010), and Kamga et al. (2011) who examine impacts of unplanned network disruptions, and that by Clegg (2007) which focuses on the impacts of planned network disruptions. While these studies are dedicated to understanding the impacts of network disruptions on traveler behavior, they are rather limited in scope – examining specific dimensions of activity-travel engagement behavior, or focusing exclusively on specific demographic segments. There are very limited studies that examine impacts on the entire range of activity-travel choices in response to network disruptions, as well as network dynamics arising from the deployment of one or more disruption mitigation strategies. Several studies highlight the data collection issues and other challenges faced by researchers in understanding the behavioral changes exhibited by individuals in response to network disruptions.

Within this domain, there have been several studies aimed at understanding how traveler information provision may impact travel behavior in the event of a network disruption. Levinson (2003) explores the benefits gained by individuals due to in-vehicle navigation systems that provide real-time traveler information about both recurring and non-recurring congestion. Kraan et al. (2000) present results from a stated preference survey conducted to understand traveler responses to advanced traveler information systems. The study was limited to shopping trips and survey respondents were afforded the flexibility to altering their destinations and desired arrival time. However, the study did not consider a number of other possible activity-travel adjustments that individuals may make, such as skipping activities, re-scheduling activities, and altering route. Liu and Mahmassani (1998) present results from an advanced dynamic interactive traveler simulator experiment exploring the different types of behaviors exhibited by individuals in response to advanced traveler information systems. These studies identify the need for additional research on the types of behaviors exhibited by individuals when presented with user information, and the role of socio-economic and demographic variables on the behaviors exhibited.

In the modeling tool development domain, previous research has largely focused on modeling dynamics in network operations under a variety of mitigation strategies while assuming that the travel demand itself is exogenous. He and Liu (2011) present an approach for modeling network day-to-day network conditions after the onset of an unexpected network disruption. They present calibration and validation results using data collected after the I-35W bridge collapse. As mentioned earlier, these research efforts do not model the entire range of activity-travel decisions that may be altered in response to network disruptions. Sundaram (2002) presents a framework for modeling network disruptions with a view to capturing their impacts on activity-travel behavior. However, the model system constitutes a hybrid model with a traditional four-step model travel demand as opposed to a full-scale microsimulation model of activity-travel behavior that provides for a more accurate representation of underlying behaviors, interactions, and constraints characterizing travel. Jenelius et al. (2011) present a model of departure time choice in response to network conditions in the context of trip chains formed by individuals. The study is however limited to trip chains with three activities i.e. two trips, and associated departure time choices. The model presented in their study does not accommodate changes in other activity-travel choices such as activity type choice (activity generation), destination choice, and number of stops.

With respect to modeling the impacts of traveler information systems technologies on network performance under various network perturbation scenarios, Al-Deek et al. (1998) consider three different types of travelers. The three types of travelers are those that do not have ATIS, those that have delayed ATIS in the form of radio or other technologies, and those that have real-time ATIS. They aimed to study the impact of different technology configurations and analyze the traveler and system benefits derived from varying levels of technology penetration. Paz and Peeta (2008) present a framework for generating traffic routing strategies by accounting for driver's likely behavior in response to path recommendations provided by a user information system. While the model systems presented in prior research provide platforms to evaluate the impact of technology on network path choices and performance, the models do not consider activity-travel engagement decisions (scheduling and re-scheduling and other dynamics) that individuals may alter from the use (or lack thereof) of traveler information technologies.

A NETWORK-SENSITIVE ACTIVITY-TRAVEL SIMULATION FRAMEWORK

A key consideration in modeling the impacts of network disruptions is that the travel modeling and simulation framework should be able to capture the activity-travel scheduling and rescheduling behavior exhibited by individuals in response to network delays. This calls for the integration of an activity-based travel demand model with a dynamic traffic assignment model within a unified framework that maintains consistency in activity-travel choice processes as patterns evolve over the course of a day. Considering the dynamics associated with network disruptions, the framework should allow the activity-based travel demand and traffic assignment model systems to communicate with each other along the continuous time axis. Only a framework where the demand and supply model systems constantly exchange information is capable of truly capturing activity-travel demand and network supply dynamics in the presence of network disruptions and various configurations of traveler information provision.

An approach that has been proposed to integrate activity-travel demand and network supply models is to run the models sequentially (Lin et al. 2008; Kitamura et al. 2005). In such a configuration, each of the model systems is run separately and linked together sequentially through input-output data flows and feedback loops. However, the sequential approach cannot be used to model the impacts of network perturbations because the framework does not provide for constant communication between the model systems along the continuous time axis. The modeling of network disruptions calls for an event-based approach to integrating the activity-based travel demand and dynamic traffic assignment model systems.

An event-based model integration framework with tight coupling across the model systems was presented by Kitamura et al. (2008) and more recently operationalized by Pendyala et al. (2011). Figure 1 presents the integrated model framework that has been operationalized within SimTRAVEL. In each minute of the day, the demand model simulates activity-travel engagement decisions of all individuals. Information from the demand model, including, origin, destination, mode, and vehicle attributes for all trips that need to be executed on the network, is then passed to the dynamic traffic assignment model for identifying the route and simulating the movement of vehicles on the network. Once the trips arrive at their destination, the traffic assignment model passes back the arrival (time) information to the demand model to simulate activity-travel engagement decisions in subsequent time steps. The activity-travel demand model simulates activity schedules in subsequent time steps based on actual arrival times experienced by travelers. Thus, if a traveler is delayed in arriving at a destination due to congestion on the network, then subsequent activity engagement decisions will be affected. These types of impacts are effectively captured in the event-based paradigm implemented within SimTRAVEL. This process proceeds for all 1440 minutes within a day and activity-travel schedules for an entire day are generated. Network conditions obtained at the end of the daily simulation are then fed back to re-simulate activity-travel schedules and the process is repeated until convergence in the network conditions is achieved, i.e., the network inputs that are used to simulate activity-travel patterns and the network conditions resulting from the activity-travel patterns are the same. It should be noted that, within the basic design of the framework, network skims from a previous iteration are being used by the demand model to simulate activity-travel choices (destination choice, mode choice, activity type choice) but actual network conditions prevailing within the current iteration at the appropriate time step are used to determine traveler arrival times at destinations.

The event-based framework presented in Figure 1 lends itself to modeling network disruptions and can be used for understanding impacts of network disruptions on activity-travel engagement decisions. In the context of modeling network disruptions, however, there are two key features that an integration framework needs to support. 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. This is already accommodated in the basic framework described earlier. Second, the model system should be able to use travel skims (travel times) of the current iteration (as opposed to the previous iteration) in simulating activity-travel choices. The basic framework described earlier needs to be modified to accommodate this capability so that the modeling of information provision impacts can be accomplished. In order to evaluate the impacts of real-time traveler information systems, the model framework should be able to pass network conditions prevailing after the onset of an incident 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 (as opposed to "expected" travel times derived from a previous iteration). The prevailing network conditions should also be used in identifying time-dependent shortest paths for travelers who may be seeking to avoid the congested (disrupted) portion of the network. Essentially, 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 allow the utilization of prevailing network travel times for simulating activity-travel choices and routing decisions in the subsequent time period(s) of the day after the onset of the disruption. Therefore, the event-based framework presented in Figure 1 is further enhanced for this study so that it can be used to evaluate the impacts of various information provision scenarios, which is very important application area for such a dynamic integrated modeling tool.

Figure 2 presents a revised event-based framework for integrating the activity-based travel demand and dynamic traffic assignment models that supports modeling information provision under network disruption. The model system proceeds in the same minute-by-minute fashion presented in Figure 1, where converged base year link travel times (L_{base}) from the previous iteration are used from the 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 assignment and 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}) from the previous iteration with the existing travel times (L_t) on the network for the current and 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), i.e., time varying skim files, for use in the travel demand model.
3. The dynamic traffic assignment 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 trips that need to be loaded on the network, which travelers have chosen to undertake based on information about 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/mandatory 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 assignment model, routes are identified using prevailing conditions (L_t) as the expectation of the network for all subsequent time intervals. The traffic assignment model then loads and routes/simulates the trips through the network.
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 process described above is represented in the flowchart depicted in Figure 2. The flowchart presented in Figure 2 offers a robust framework for modeling traveler choices under alternative information provision scenarios in the event of a network disruption. As mentioned earlier, the timesensitive activity-travel simulation framework presented in this section has been operationalized as part of a larger research effort by Pendyala et al. (2011). The prototype model system, dubbed SimTRAVEL (Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land), integrates microsimulation-based model systems of land use, activity-based travel demand, and dynamic traffic assignment consistent with the framework presented in Figure 1. The land use model system employed in the prototype is UrbanSim, the travel demand model system employed is OpenAMOS (Open-source Activity Mobility Simulator) and the dynamic traffic assignment model implementation is MALTA (Multi-Resolution Assignment and Loading of Traffic Activities) (Pendyala et al. 2011). For purposes of this study, the SimTRAVEL prototype was enhanced to incorporate additional feedback between the travel demand and dynamic traffic assignment model systems as necessitated by the framework presented in Figure 2 so that network perturbations can be modeled accurately under information provision scenarios.

CASE STUDY APPLICATION

The primary objective of this effort was to demonstrate the applicability of the enhanced SimTRAVEL prototype to evaluate a network disruption scenario under alternative information provision strategies. The applicability and the different features of the prototype are demonstrated by modeling three disruption scenarios with varying levels of information provision and subsequently analyzing the activity-travel dynamics under these scenarios. The three scenarios evaluated in this study are described below:

- *No disruption*: In this scenario, no incident occurs and base line conditions prevail. The scenario serves as a baseline against which the other two scenarios are compared and analyzed.
- *No information provision*: In this scenario, a planned network disruption is introduced; however people are assumed to be oblivious to the disruption and go about planning and executing their activity-travel patterns based on their previous experience (expectations) of network conditions. Individuals are assumed to be using an expectation of the network conditions in making decisions about activity-travel engagement and route choices. The assumption of no information provision and complete ignorance of the network conditions may be unreasonable given the ubiquity of different types of information media and communication technologies (e.g., 511 systems, radio, and real-time traffic data like Google Maps) which afford individuals the ability to learn about real time traffic conditions. In this scenario, individuals are assumed to have no information during the trip planning stage, i.e., prior to actually embarking on a trip. Once the individuals are on the network, they experience delays due to the disruption, actual arrival times reflect the impact of the disruption, and travelers make adjustments to their activity-travel engagement choices in subsequent time periods in response to delays experienced due to the disruption. However, every activity-travel (demand) engagement decision (pre-trip) itself is made based on expectations of travel times (i.e., converged travel times from the base model run with no disruption). Changes and adjustments in activity-travel patterns emerge in subsequent time periods because people arrive at destinations considerably delayed, and face subsequent time constraints that result in activity travel patterns different from those that would have emerged had there been no disruption on the network.
- *Full information provision*: In this scenario, travelers that are already on the network follow their planned routes even after the onset of the network disruption (i.e., there is no enroute switching). However, individuals that are about to embark on a trip (pre-trip stage) are assumed to be aware of the incident and the prevailing network conditions. The activity-travel engagement and routing decisions of these individuals are based on the prevailing network conditions and not based on expected conditions of the network that they generally experience. Thus, while travelers already on the network at the onset of the disruption will inevitably be considerably delayed and need to adjust their subsequent activity-travel schedules in response to delayed arrival times, those that embark on

trips after the onset of the disruption will be able to plan their trips with full knowledge of network conditions. They can presumably choose alternative destinations (for non-mandatory activities), activity types, and routes to best plan around and avoid adverse impacts of the network disruption. Every traveler, including those that were already on the network at the onset of the disruption, is assumed to have full knowledge of prevailing network conditions at the pre-trip planning stage. Thus, a traveler who was on the network at the onset of the disruption and arrived late at his or her destination is now fully aware of the network conditions when planning the next trip.

The no information provision and full information provision scenarios comprise network disruptions under two rather extreme levels of information provision, with some simplifications on the representation of activity-traveler choices. In reality, traveler awareness of network conditions is likely to fall between these two extremes modeled in this study. Moreover, in the real-world, travelers are likely to change paths or destinations en-route; however, the current modeling framework in SimTRAVEL does not accommodate en-route adjustments to routes and destinations. People who are already on the network at the onset of the disruption must proceed to the planned destination on the planned route (based on expected travel times). Nevertheless, modeling and analyzing the two information provision scenarios described earlier demonstrates the abilities of a dynamic integrated model system in simulating the impacts of network disruptions under alternative information provision strategies while also providing some indication of the range of impacts on activity-travel engagement behavior that may result from a network disruption. The study sheds light on the impact of information provision during network disruption on traditional measures of network conditions (total trips, and delays) and also on activity-travel engagement behavior (trip lengths, trip durations, trip rates, and daily time allocation).

The case study area consists of three cities (Chandler, Gilbert, and Queen Creek) in the southeast region of Maricopa County (Greater Phoenix) in Arizona (Figure 3). There are about half a million people residing in about 150,000 households in the three city area. The demand for the three city region is generated using the full-scale microsimulation model in SimTRAVEL while the demand for the rest of the Maricopa region was captured by creating trip lists from origin-destination tables produced by the existing four-step travel model. This enabled modeling the impact of network conditions while accounting for congestion on the roadway network in the model region. Essentially, about two million trips were simulated by the activity model within SimTRAVEL for the residents of the three-city region, while the remaining 13 million trips in the region were derived from the origin-destination tables of the calibrated Maricopa Association of Governments (MAG) four-step travel demand model. A planned network disruption was introduced by dropping the lane capacity of a section of the freeway that runs through the middle of the three city region and connects it to the rest of the Maricopa (Greater Phoenix) region. The simulation considers an incident situation wherein only one lane in each direction of the freeway segment is operational (as opposed to the usual three general purpose lanes in each direction) and other lanes are closed to clear the incident. The incident was assumed to start at 7:00 AM and end at 10:00 AM. Within the simulation, it is assumed that the onset of the disruption and the clearing of the disruption are both instantaneous; in other words, the simulation does not reflect the more gradual onset of delays and congestion, and dissipation of queues, that are observed in reality. This simplification was done for operational convenience and future development efforts will focus on more realistically capturing such phenomena.

The time period was chosen to reflect peak travel demand generated by individuals residing in the three city region. In Figure 3, the stretch of freeway that is disrupted is on the Santan Loop 202 that is a vital freeway corridor for the southeast region of Maricopa County. Residents of the three cities of Chandler, Gilbert, and Queen Creek rely heavily on this freeway corridor to commute and access other shopping and social-recreation destinations. Due to data limitations, the land use simulation model (UrbanSim) had to limit work and school locations of residents in the three city area to fall within the boundaries of the three city area. In reality, many residents of the three city area have work locations outside the three-city area (say, in Tempe, Mesa, Phoenix, Scottsdale); by limiting work locations to fall within the localized region, it is likely that the simulation is not fully replicating travel patterns undertaken by workers in the region on a weekday. However, no such limitation exists for non-work trips; non-work trip destinations may fall outside the boundaries of the three-city area. As the limitation only impacts a subsample of workers (whose work locations are in reality beyond the boundaries of the three-city area) in the context of their work trips and associated trip chains, and with 13 million trips derived from the 2009 validated four-step travel model for the region, it is not surprising that the SimTRAVEL model system was found to validate very well against observed activity-travel patterns in the 2009 National Household Travel Survey (Pendyala et al. 2011).

MODEL APPLICATION RESULTS

Before running the three scenarios, the SimTRAVEL prototype was run iteratively to obtain a set of stable and converged base year time-dependent origin-destination skim matrices. This set of network travel times from the base year simulation run was then used to launch the three scenarios. A variety of demand characteristics were examined to assess the impacts of network disruptions under alternative user information provision strategies. The number of trips generated in the baseline no disruption case is 14,320,888 trips. In the full information scenario, 14,321,746 trips were generated, whereas in the no information scenario a total of 14,317,790 trips are produced. The number of trips generated in the no information scenario is the smallest and this is consistent with expectations. In the no information scenario, people are presumably planning trips and selecting routes without any knowledge about the incident. As a result, they experience higher delays and spend more time on the network, which will in turn affect their time constraints for subsequent activity-travel engagement decisions. Available time to pursue activities will shrink leaving individuals with less time to engage in any non-fixed activities (relative to the baseline no disruption case). It is interesting to note that the number of trips generated in the full information scenario is higher than the no disruption baseline scenario by about 858 trips. It is possible that there are shadow effects at play here. While travelers who are already en-route are stuck in congestion, links downstream of the bottleneck and neighboring roadways may be experiencing free flow conditions relative to the baseline no disruption case due to shadow effects. As a result, individuals (with full information) planning their trips will alter destinations and routes and take advantage of the higher level of service on other links (in the shadow of the disruption). These individuals arrive earlier than expected, and have more time to subsequently engage in activities and travel. This phenomenon may be contributing to the slight increase in activity and travel engagement in the full information provision case. The total vehicle miles traveled (VMT) in the full information scenario is also about 10125 miles higher than the base scenario. The higher VMT may result from two phenomena. First, as mentioned earlier, there is a slight increase in the number of trips pursued in the full information case. Second, individuals are likely selecting alternative routes (e.g., using surface streets) to avoid the section of the freeway affected by the incident to get to their activity locations, because they have complete knowledge about the incident and the network conditions; these alternative routes may be longer in distance (but shorter in time because of the network disruption on the freeway section) resulting in the higher VMT.

Within the scope of this paper, it is not possible to provide an exhaustive set of results. Therefore, two illustrative sets of results are presented in this paper. Figure 3 shows the shift in trip duration (length) distributions for workers under the two information provision scenarios (relative to the baseline case). The differences between the two scenarios are quite readily apparent. In the no information provision case, the number of trips of shorter length drop dramatically with the level of reduction decreasing with increasing trip duration. For example, the largest drop is seen in trips of 10-20 minutes duration and the smallest drop is seen in trips of 50-70 minutes duration. Conversely, there is an increase in the number of trips of long duration. In the absence of information, workers are stuck in congestion, considerably delayed, and the trip length distribution shifts considerably towards longer trip lengths (durations). When there is full information provision, on the other hand, the impacts are far less dramatic. There is a decrease, albeit smaller, in the number of very short trips, which suggests that travelers cannot fully escape the impacts of the network disruption even when provided full information. Some travelers who are already en-route when the disruption occurs will be delayed (experiencing longer trip lengths) and those who begin trips during the disruption period may not be able to fully avoid the critical freeway section in its entirety even though they are aware of the disruption. There is an increase in the number of trips of medium duration, and a series of slight increases in the long duration trip lengths (but far less dramatic than in the no information provision case). These results are consistent with expectations and demonstrate the ability of the model system to mimic shifts in travel patterns under alternative disruption and information provision scenarios. Similar trends are seen for non-workers (figure not shown), except that the shifts are less pronounced presumably because non-workers have greater flexibility and discretion in planning and executing trips (with respect to timing, destination, and participation) in contrast to workers who have less degrees of freedom due to rigid work schedules and locations.

Table 1 shows the daily time allocation to trips and activities across all individuals in the simulation (i.e., the half-million people whose trips and activities were simulated within SimTRAVEL) under the various scenarios (in units of person days). The trends are once again readily apparent. The time spent on activities (i.e., at activity locations) drops quite dramatically in the no information provision scenario relative to the full information provision scenario. For workers, the largest reductions in activity time occur at home and at work, presumably because of the impact of the freeway disruption on commute travel. There are reductions in maintenance and discretionary activity duration as well. In the case of full information provision, there is a drop in work activity duration (presumably because workers cannot fully escape the disruption in the context of commuting to a fixed work location), but the drop is considerably less than in the case of no information provision. There is a large decrease in maintenance activity duration, perhaps because workers decide to forego these activities, or shorten these activities in duration, in the presence of full information about network conditions. As a result, workers actually gain a little more time at home, and the overall reduction in out-of-home activity duration is substantially smaller than in the no information provision case. Similar trends are seen for non-workers except that the impacts on non-workers are substantially smaller. Non-workers presumably have greater degrees of freedom and spend less time out of home to begin with – thus dampening the impact of the disruption.

With respect to travel durations, similar impacts are observed. Workers experience the greatest increase in travel time expenditure when there is no information provision. In particular, travel to and from work increases considerably, presumably because of the need to use the freeway section for commuting. In the presence of full information, there is some impact on travel time expenditure (particularly for commute), but the impact is far less than in the case with no information provision. In the case of non-workers, once again the impacts are dampened relative to workers with increases in travel time considerably higher when there is no information provision compared to the scenario of full information provision. In the case of full information provision, the travel time expenditure change is quite modest – with slight decreases in travel time for maintenance and other trips. It is possible that non-workers are choosing destinations and routes completely beyond the influence area of the disruption for these activities, and save travel time expenditure (by choosing closer destinations and/or benefiting from shadow effects). It is worth noting that, in all cases, consistency is maintained as the aggregate reduction in activity duration is virtually identical to the aggregate increase in travel time expenditure.

Overall, it can be seen that the model system is capable of reflecting the impacts of network disruptions on activity-travel patterns and network dynamics under alternative information provision strategies.

Given the small magnitude of changes noted in the metrics, one could argue that the changes are just an artifact of the stochasticity associated with the microsimulation-based demand model. While the stochasticity in the demand model does contribute to predicted differences across model runs, there should not be any trends in the results if the differences are purely stochastic in nature. While some of the changes observed may be attributed to stochasticity, the clear trends observed in the results suggest that the differences are indeed caused by the altered input conditions (i.e., the level of information provision).

CONCLUSIONS

This paper describes a research effort aimed at implementing a microsimulation-based integrated modeling framework capable of simulating the impacts of network disruptions under alternative user information provision strategies. The model system, called SimTRAVEL (Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land), employs a paradigm wherein there is constant information exchange 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 undertaken in this study provides key insights into the impacts of network disruptions on time use and travel behavior under different levels of information provision. The study demonstrates the feasibility of applying an integrated dynamic model system to capture the complex behavioral decisions and adjustments that travelers make in response to network conditions in the presence and absence of information.

As part of this research effort, the original SimTRAVEL framework is modified to reflect knowledge of prevailing network conditions on the part of travelers in the presence of user information systems. The framework, when applied to three different scenarios, is found to offer plausible results consistent with expectations. The model system is applied to a baseline case (no network disruption), a no information provision scenario (with network disruption), and a full information provision scenario (with network disruption). An examination of model outputs shows that impacts on activity-travel patterns are more dramatic in the no information provision scenario (as expected) with a drop in number of activities/trips and activity durations, and a corresponding increase in trip durations and daily travel time expenditures. The differences are larger for workers, presumably because they have rigid work schedules and locations that preclude them from being able to fully escape the effects of the disruption even in the presence of full information. In all cases (for both workers and non-workers), impacts are substantially less dramatic in the presence of full information.

This study offers promising results demonstrating the ability of the dynamic integrated model system to simulate the impacts of operational active traffic demand management (ATDM) and traveler information systems strategies under alternative network conditions. Future work should focus on enhancing the effort along a number of lines. First, there is a need to more accurately quantify the extent to which results are affected by stochasticity in the simulation model runs. By isolating the stochasticity effects, it would be possible to more accurately predict the actual impacts of network perturbations and information provision strategies on activity-travel patterns. Second, the model system needs to be enhanced to avoid the instantaneous onset and clearing of the network disruption. In the real world, there will be a more gradual build-up of congestion and queues at the onset of the disruption and a gradual dissipation of queues upon reopening all lanes to traffic. By integrating queuing models of traffic flow that simulate formation and dissipation of shockwaves at bottlenecks, the model system can be made more reflective of real-world conditions experienced by travelers. Finally, the model system needs to be applied on a full regional scale as opposed to a smaller subregion as was done in this study. This would allow a more complete validation of the predictions offered by the model system.

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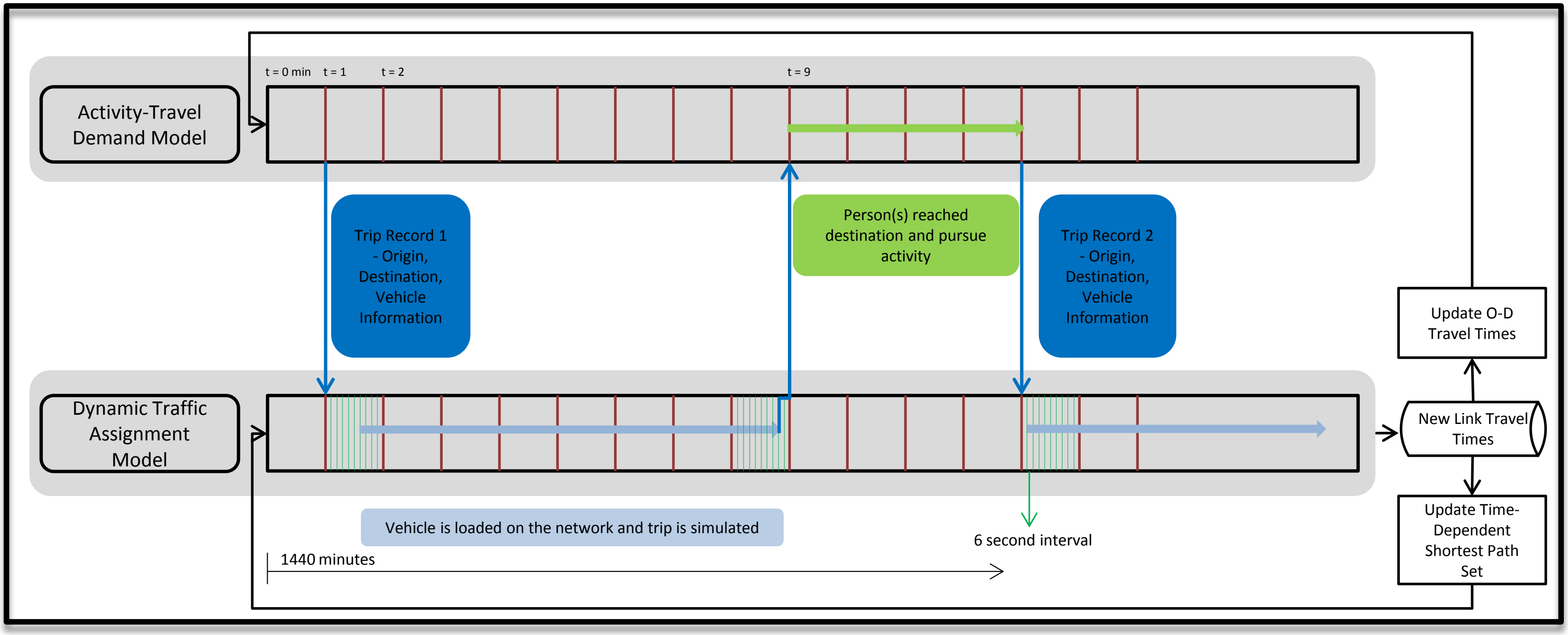

FIGURE 1. Network-Sensitive Activity-Travel Simulation Framework Incorporating an Event-Based Paradigm

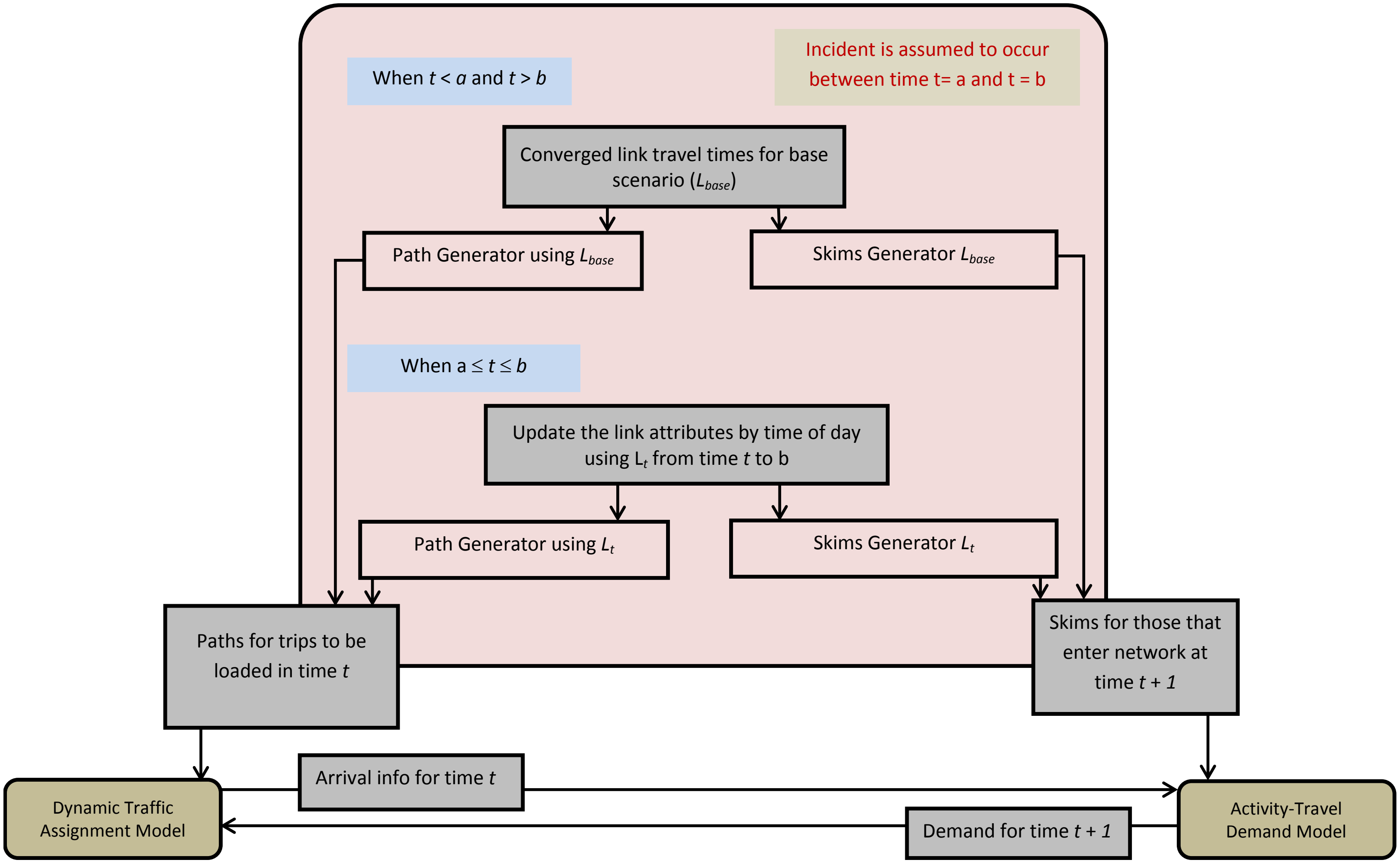

FIGURE 2. Modified SimTRAVEL Framework to Simulate Information Provision Strategies Under Network Disruptions

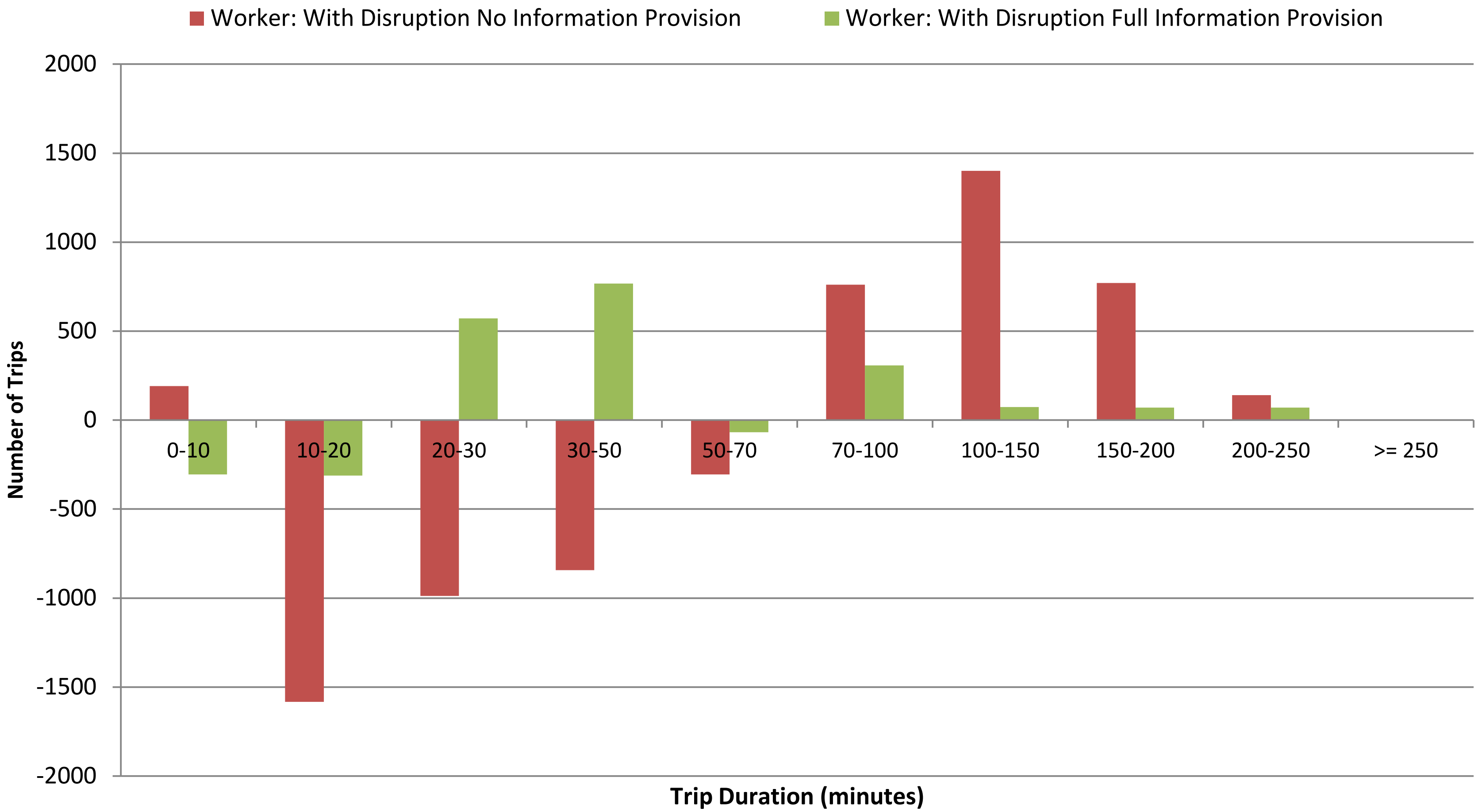

FIGURE 3. Difference in Trip Duration Distributions for Workers

TABLE 1. Difference in Daily Time Allocation for Trips and Activities Across All Individuals in Person-Days

	Worker		Non-worker	
	No Information Provision	Full Information Provision	No Information Provision	Full Information Provision
Number of people	150435	150435	187757	187757
Time Spent on Activities				
Home	-72	8	-71	-31
Work	-111	-28	0	0
School	4	4	-1	1
Maintenance	-21	-50	-62	-7
Discretionary	-15	-4	-8	13
Pick Up	1	1	2	2
Drop Off	1	1	8	2
OH-Other	-3	-3	9	5
Total activity duration	*-217*	*-71*	*-123*	*-15*
Time Spent on Trips				
Home	46	31	33	9
Work	110	23	0	0
School	2	0	2	0
Maintenance	21	7	22	-9
Discretionary	8	4	12	10
Pick Up	6	0	15	1
Drop Off	24	3	34	7
OH-Other	4	0	7	-3
Total travel duration	*221*	*69*	*124*	*16*