SIMULATION-BASED EVALUATION OF DYNAMIT'S ROUTE GUIDANCE AND ITS IMPACT ON NETWORK TRAVEL TIMES

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Abstract
Traveler information has the potential to reduce travel times and improve their reliability. Past studies have identified critical issues and parameters that influence the quality of route guidance and its impact on travel time savings. A key concern with the dissemination of driver information is the phenomenon of overreaction. Prediction-based route guidance based on short-term forecasts of network state is expected to be more effective in minimizing overreaction than naive strategies based on historical or current traffic patterns. DynaMIT (Dynamic network assignment for the Management of Information to Travelers) is a simulation-based decision support system designed to generate prediction-based route guidance. This paper outlines a simulation framework to examine the effectiveness of DynaMIT's guidance in an objective laboratory environment, and presents results from controlled simulation experiments to quantify the effect of various guidance generation parameters on the quality of DynaMIT's guidance.

Keywords: Travel delay; Traffic simulation; Estimation; Demand prediction; Overreaction
Topic area: C6 Network Design, Optimal Routing and Scheduling

1. Introduction
Drivers using information from an Advanced Traveler Information System (ATIS) could potentially make better travel decisions, thereby benefiting both guided drivers as well as those without access to traffic information. Traveler information can be *pre-trip* or *en-route*, based on when the information is accessed by the traveler. En-route information, while still allowing the driver to switch to alternative routes, precludes a change in the departure time or mode (in some cases, however, the driver might have the option to park away from the final destination and switch modes for the remainder of the trip). *Descriptive* information provides the driver with descriptions of current or future traffic conditions, and leaves the actual choice of route to the driver. Alternatively, *prescriptive* information recommends a particular route, with some fraction of drivers complying with the system's recommendation.

A real concern while disseminating traveler information is the phenomenon of *overreaction*. A high percentage of drivers reacting to real-time information can merely shift congestion spatially and/or temporally, thereby rendering the disseminated guidance inconsistent with experienced trip conditions. Such a scenario can seriously undermine the reliability of, and public confidence in the ATIS. *Consistency* implies that driver response to information is already captured when guidance is generated, thereby preventing

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overreaction. Anticipatory route guidance, seen as the key to achieving consistency, is based on the prediction of future traffic states, thus allowing the system to effectively guide equipped drivers.

Limited theoretical and simulation-based analyses on small networks have generally confirmed the need for prediction-based guidance (see, for example, Ben-Akiva et al., 1991, Kaysi, 1992 and Ben-Akiva et al., 1996). Recent work (Bottom et al., 1999) provides a rigorous mathematical formulation of the guidance generation process as a fixed-point problem, and explores its solution from an algorithmic perspective. Simulation-based results demonstrating the effect of various guidance generation parameters on network performance are presented, but do not include the effects of information penetration rate and demand prediction accuracy on system performance.

The objective of this paper is to evaluate the effect of three design parameters on network performance:

- Frequency of information update
- Penetration rate of information sources (i.e. the fraction of guided drivers)
- Demand prediction error

A simulation-based evaluation laboratory MITSIMLab (Yang, 1997, Yang, Koutsopoulos, 1996) is employed to analyze the sensitivity of network performance as a function of the above parameters. DynaMIT, a simulation-based Dynamic Traffic Assignment system, is used. DynaMIT has been designed to generate consistent, anticipatory route guidance through detailed modeling of complex demand-supply interactions (Ben-Akiva et al., 1997, Ben-Akiva et al., 2002).

The remainder of this paper is organized as follows. Section 2 provides an overview of DynaMIT. A description of the evaluation methodology and MITSIMLab are presented in Section 3. The results of a detailed case study are outlined in Section 4, with the final section summarizing the numerical results and findings.

2. Overview of DynaMIT

DynaMIT (Dynamic Network Assignment for the Management of Information to Travelers) is a system for the generation of consistent, anticipatory route guidance. DynaMIT combines a flexible microscopic demand simulator and a detailed mesoscopic supply simulator to effectively capture complex demand and supply processes and their interactions. Accurate modeling of origin-destination flows, pre-trip and en-route driver decisions, traffic dynamics, queueing and spillback allow the system to estimate and predict network state in a realistic manner. DynaMIT is designed to prevent overreaction by ensuring that the generated guidance is consistent with the conditions that drivers are expected to experience. This is achieved through explicit modeling of drivers' reaction to information. The flexible simulation system can adapt to diverse ATIS requirements, and is designed to handle a wide range of scenarios including incidents, special events, weather conditions, highway construction activities and fluctuations in demand. We present here a brief overview of the system's framework (a detailed review of DynaMIT's model components can be found in Massachusetts Institute of Technology, 2000).

Figure 1 outlines DynaMIT's framework. DynaMIT integrates various sources of off-line and real-time traffic data, such as the network, historical traffic conditions and real-time traffic surveillance, to generate accurate estimates and predictions of network state. Designed to operate with limited historical data, DynaMIT has the capability to build up the database on a day-to-day basis. The real-time information is provided by the surveillance and control systems on the network. DynaMIT is designed to interface with a wide range of surveillance and control systems. The minimum real-time information required by DynaMIT is time-dependent link flows, incident characteristics (location, starting time, duration, severity), and traffic control strategies. DynaMIT operates in a rolling horizon framework.

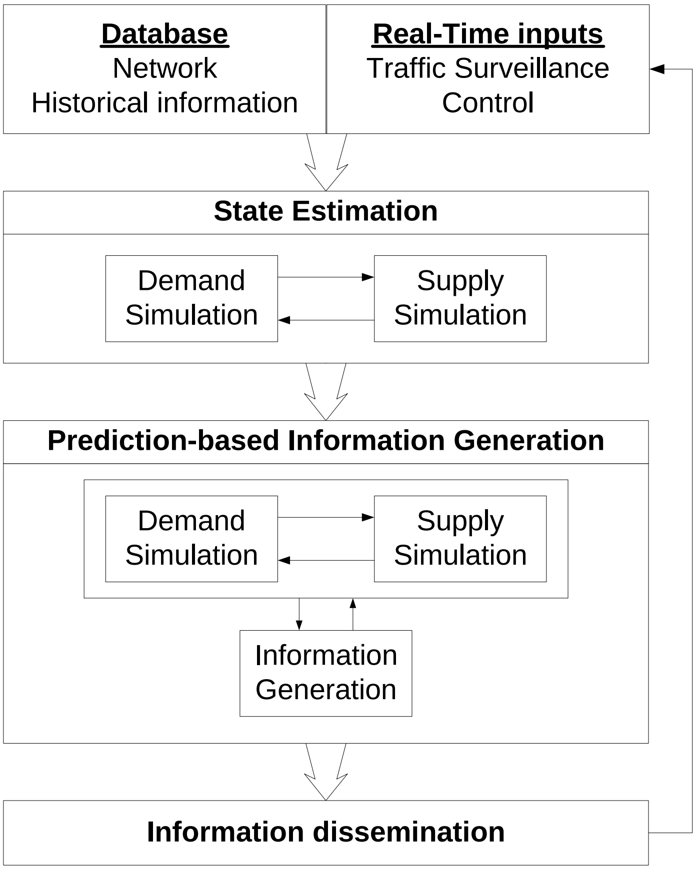

Figure 1. DynaMIT Framework

Most existing surveillance systems are limited to vehicle detectors located at critical points in the network. The information provided by these traffic sensors must therefore be used to infer network-wide traffic conditions. The state estimation module performs the task of providing estimates of current network state in terms of OD flows, link flows, queues, speeds and densities. A detailed network representation coupled with state-of-the-art traveler behavior models allows DynaMIT to generate demand and network state estimates that are congruent, while utilizing the most recent information available from the surveillance system.

DynaMIT's demand estimation is sensitive to the guidance generated and information provided to the users, through an explicit simulation of pre-trip departure time, mode and route choice decisions. The pre-trip demand simulator updates historical OD matrices by modeling the reaction of each individual to guidance information, and aggregating individual trips to obtain updated OD matrices. These flows are further adjusted to reflect the current travel demand on the network, since actual OD flows could diverge from historical patterns due to capacity changes (such as road or lane closures and special events) and other day-to-day fluctuations. The OD estimation model uses updated historical OD flows, real-time surveillance measurements of actual link flows, and estimates of assignment fractions (the mapping from OD flows to link flows based on route choice fractions and perceived travel times) to estimate OD flows for the current estimation interval in real-time.

The network state estimator utilizes a traffic simulation model that simulates the actual traffic conditions in the network during the current estimation interval. Inputs include demand estimated by demand simulator, updated capacities and traffic dynamics parameters, the control strategies implemented and the traffic information and guidance disseminated. The driver behavior model captures the responses to ATIS in the form of en route driver path choices.

A key input to the OD estimation model is the assignment matrix obtained from the traffic simulator. The demand simulator and network state estimator may have to go through several iterations before converging to a consistent estimate of current network state. The output of this process is an estimate of the actual traffic conditions on the network, including origins and destinations of vehicles, link flows, queues, velocities and densities.

The OD prediction model operates on the aggregated historical demand adjusted by the pre-trip demand simulator to provide the required estimates of future OD flows. The network state prediction module predicts future traffic conditions for a given control and guidance strategy, using current estimates of network state and predicted OD flows as inputs. It uses a traffic simulation model and driver en route behavior model to predict the performance of the network for the prediction horizon. The traffic information and guidance generation function uses the predicted traffic conditions to generate information and guidance according to the various ATIS in place.

The DynaMIT guidance generation algorithm results in unbiased and consistent information. While unbiasedness guarantees that the information provided to travelers is based on the best available knowledge of current and anticipated network conditions, the consistency prevents overreaction by ensuring that DynaMIT's predictions of expected network conditions match what drivers would eventually experience on the network. Such a guidance strategy means that there is no better path a driver could have taken under the provided information (for a detailed treatment of the consistency problem, see Bottom et al., 1998). An iterative process is employed in order to obtain guidance that satisfies these requirements. An iteration consists of a trial strategy, the state prediction under the trial strategy, and the evaluation of the predicted state (for consistency). Since, in general, the updated historical OD flows depend on future guidance and information, the update of the historical OD flows (using the departure time and mode choice models) and the OD prediction models are included in the iteration. This approach is quite general, and is applicable to cases with both pre-trip and en-route information availability.

DynaMIT explicitly models driver response to information. Pre-trip departure time and path choice, as well as en-route path choice, are captured through discrete choice models (Antoniou et al., 1997). Further, path choice decisions are based on the Path-Size Logit model (Ben-Akiva, Bierlaire, 2003, Ramming, 2002) to account for driver perceptions of overlapping paths.

3. Evaluation methodology

Figure 2 illustrates the proposed evaluation framework. A detailed microscopic traffic simulation laboratory will be used to simulate the movement of individual drivers between various O-D pairs on the “real” traffic network, and also replicate the operation of the surveillance (sensor) system. The simulated traffic counts from the surveillance component will feed into the prediction-based information generation module (DynaMIT). The information generated by DynaMIT will be communicated to the traffic simulator. Simulated drivers with access to information might make route and departure time choices that affect traffic flows. The result of these choices is intercepted by the surveillance system, and will impact the predictions (and hence the generated guidance) during future time intervals.

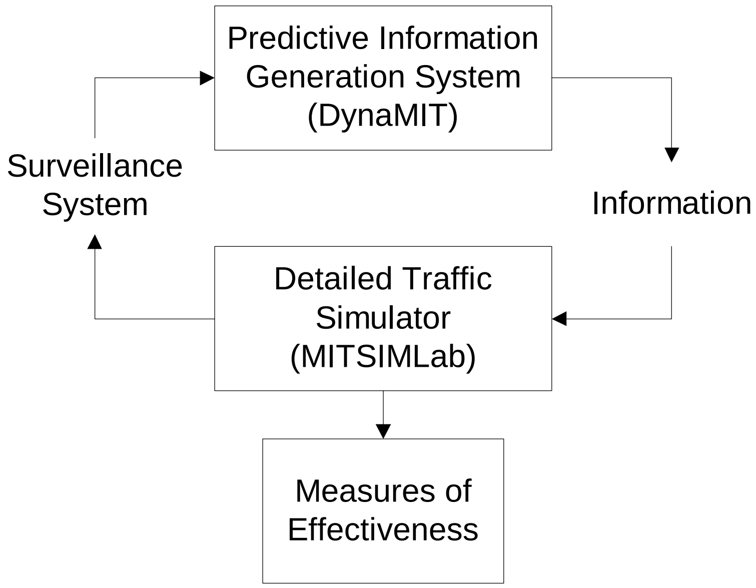

Figure 2. Evaluation Framework

The evaluation of DynaMIT requires a simulator that can accurately mimic driving and travel behavior, while simulating the operation of a variety of control and routing strategies. In this research, we use MITSIMLab, a detailed microscopic traffic simulation laboratory, to represent the real world and to simulate driver reaction to the guidance generated by DynaMIT. A flexible design provides a set of parameters to control the interactions between MITSIMLab and DynaMIT.

MITSIMLab consists of a microscopic traffic simulator (MITSIM) and a traffic management simulator (TMS). While MITSIM models detailed driver behavior, TMS mimics the traffic control and traveler information systems. The traffic control and route guidance strategies generated by DynaMIT feed back into MITSIM through the TMS, and affect the subsequent behavior of guided drivers. The corresponding changes in traffic patterns are recorded by the surveillance system, and communicated to DynaMIT in order to generate fresh control strategies and guidance. A wide range of measures of effectiveness can be obtained from MITSIMLab in order to evaluate network-wide travel times and delays.

MITSIM uses a microscopic simulation approach, in which movements of individual vehicles and operations of traffic control and surveillance devices are represented in detail. This representation is necessary for evaluating dynamic traffic management systems at the operational level, since it allows for capturing the stochastic nature of traffic flow, drivers' response to real-time traffic information, and operations of surveillance sensors.

Figure 3 illustrates the interactions between MITSIMLab and DynaMIT. DynaMIT integrates historical information with the latest surveillance data from MITSIM to perform state estimation. This step yields the best estimate of the current network state, which forms the starting point for traffic prediction and guidance generation. The network state prediction module forecasts future traffic conditions based on the current network state, the proposed control and routing strategies, and predicted OD flows. The generation of control and routing strategies involves iterations between a proposed strategy and the predicted network performance under that strategy. One of two actions are taken based on the evaluation:

- If a satisfactory strategy has been identified, the strategy is implemented; or,

- If additional strategies need to be tested, another generation-prediction iteration is conducted.

The generated strategies are communicated to the control and routing devices simulated in MITSIM, through the ATIS module. Drivers' reactions to the disseminated information and changes in the control system are reflected in subsequent traffic flows, which are intercepted by the simulated surveillance system for the next state estimation step.

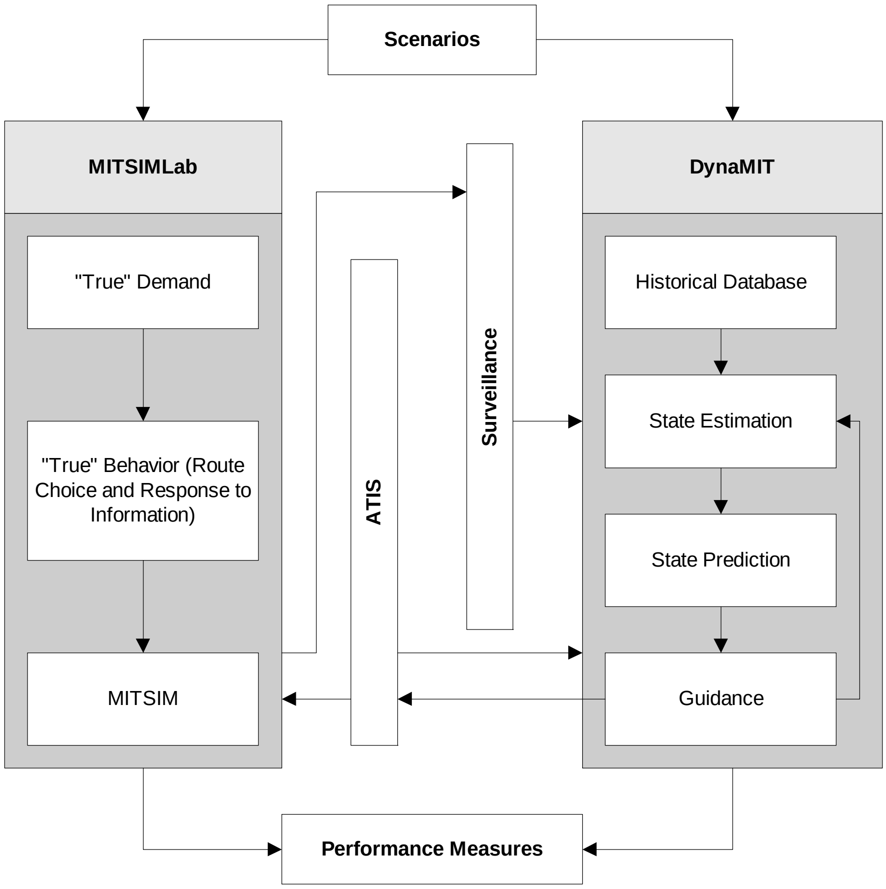

Figure 3. MITSIM-DynaMIT Interactions

4. Case study: sensitivity of results to design parameters

Network description: The Central Artery/Tunnel network from Boston spans 7.5 miles of highway, totaling 161 lane-miles, half of which will be in tunnels. The network has four major highway interchanges connecting new roads to existing highway systems. The multiple interchanges and the circular geometry with many on and off ramps provide more than one choice of route between almost all OD pairs in the network. The proposed deployment of the latest ITS technologies and elaborate surveillance and control devices on this network makes it a useful choice for studying and evaluating the impact of ATIS.

The network (Figure 4) consists of 182 nodes and 211 links. The links are further divided into 639 segments based on link geometry. The Third Harbor/Ted Williams tunnel segment is a two-way, four-lane, controlled access toll highway approximately four miles long. The scenarios in this paper study the effectiveness of guidance in minimizing the negative impacts of an incident in the tunnel.

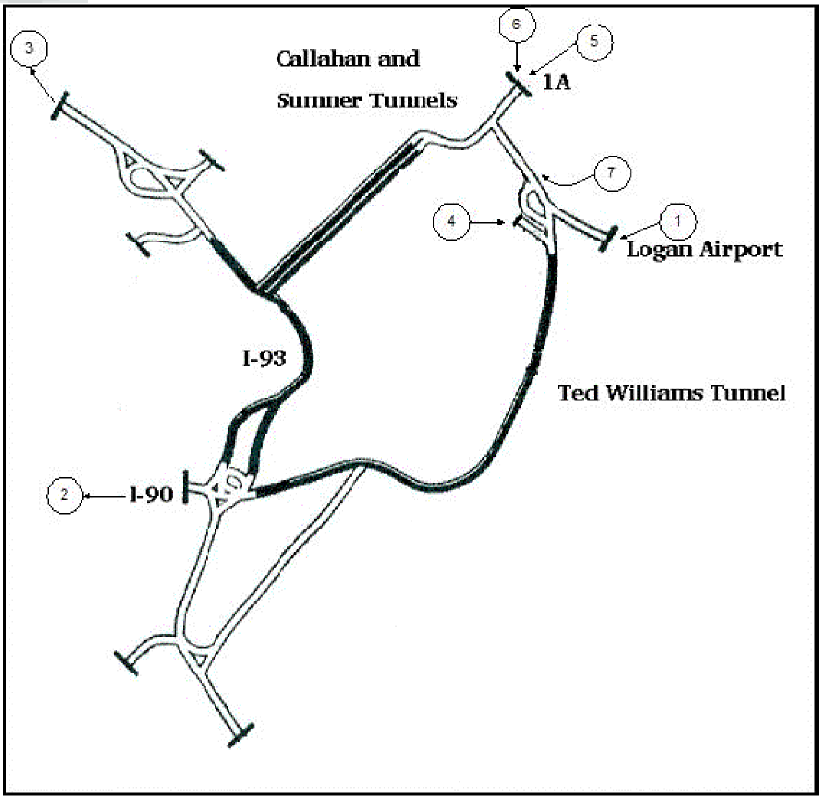

Figure 4. The Study Network

Demand patterns and ATIS: Table 1 depicts the OD demand profile used in this case study. The values in the table represent vehicle departures per hour, from the respective origins. The demand is further classified by departure intervals of duration 15 minutes, in order to better capture traffic dynamics. The simulated ATIS models information penetration through the percentage of guided vehicles for each OD pair (A value of 30% was used for all scenarios except when studying the effect of guidance penetration). Guided drivers were assumed to have in-vehicle access to descriptive network-wide information generated by DynaMIT. Un-guided drivers continued on habitual paths chosen based on historical estimates of perceived travel times. The estimation and prediction lengths were fixed at 10 and 20 minutes respectively.

Table 1. Demand Profile by OD Pair and Departure Time Interval

Time Interval	**OD Pair**									
	1-2	**1-3**	**4-2**	**4-3**	**5-2**	**5-3**	**6-2**	**6-3**	**7-2**	**7-3**
7:00-7:15	2080	320	120	600	144	624	128	608	16	16
7:15-7:30	2600	400	150	750	180	780	160	760	20	20
7:30-7:45	2600	400	150	750	180	780	160	760	20	20
7:45-8:00	2340	360	135	675	162	702	144	684	18	18
8:00-8:15	1300	200	75	375	90	390	80	380	10	10
8:15-8:30	520	80	30	150	36	156	32	152	4	4
8:30-8:45	0	0	0	0	0	0	0	0	0	0

Performance measures and base case: Detailed records of each completed trip were obtained from MITSIMLab. An average travel time was computed for each simulation run, and the results from multiple realizations were further averaged to control for the stochasticity inherent in MITSIMLab. The time horizon in this study was the AM peak period between 7:00 AM and 8:00 AM. The OD demand in Table 1 was simulated in MITSIM (with no guidance), to obtain a base reference point for comparing the subsequent scenarios. The average travel time under incident-free conditions was found to be 369 seconds, or 6.15 minutes. The scenarios consisted of an incident in the Ted Williams tunnel (refer Figure 1). Beginning at 7:10 AM, the incident reduced the capacity of the 2-lane tunnel to 720 vehicles per hour (representing a 65% reduction from its original value). It was further assumed that the incident cleared in 20 minutes, ending at 7:30 AM. The average travel time on the network (with no guidance information) was found to be 690 seconds, or 11.5 minutes. The records of all completed trips affected by the incident were used in computing this travel time estimate. The simulation was run until 8:45 AM, well past the end of the incident, to ensure that traffic conditions were returned to base case levels after the end of the incident.

The following sections describe the results of various sensitivity analyses performed in order to better understand the effect of information dissemination on travel time.

Update Frequency: The update frequency plays an important role in the quality of the generated guidance. It is expected that a higher frequency of updates would result in drivers reacting to the information in a timely manner, and helps maintain the drivers' knowledge of current network conditions. The predictions generated by DynaMIT would also be based on more accurate estimates of current network state.

Figure 5 validates this hypothesis, and leads to an interesting observation: The added savings of using an update interval greater than 15 minutes is not very significant. Similarly, the marginal benefit of using a very high update frequency (say every 2 minutes, as compared to every 5 minutes) is perhaps not worth the computational effort that is required in order to support it. The actual choice of update frequency might depend on other factors such as the computational power available, or the desired level of network performance.

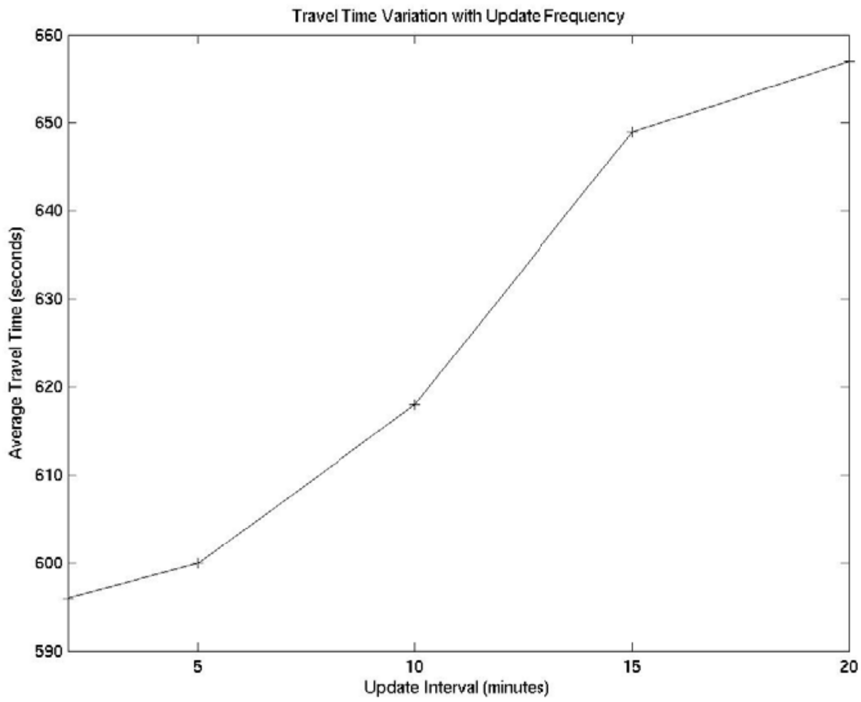

Figure 5. Effect of Information Update Frequency

Guidance Penetration Rate: A guided driver is assumed to have access to descriptive information in his/her vehicle. The percentage of drivers with access to such in-vehicle information was varied so as to study the phenomenon of overreaction. Various values of guided fractions (0%, 20%, 30%, 50%, 70% and 100%) were tested. The results are summarized in Figure 6. The results indicate a general trend of decreasing average travel times as the percentage of guided drivers increases. However, some overreaction was also observed, as indicated by the slight increase in travel times as the guided fraction increased beyond 70%.

Figure 6 indicates that an increase in the update frequency (generating guidance every 5 minutes instead of every 10 minutes) reduces the effect of over-reaction significantly (as seen from the lower slope of the plot between the last two data points). The shorter update interval allows the system to quickly adjust to changing network conditions, thereby providing more frequent and up-to-date information to equipped drivers. This indicates the need for better, more accurate anticipatory traveler information that accounts for future demands and driver behavior.

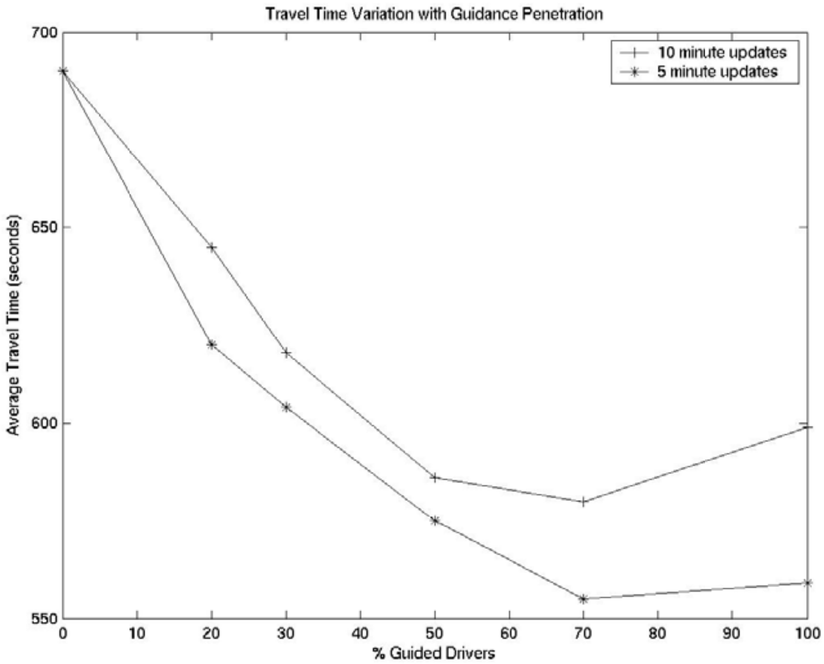

Figure 6. Effect of Guidance Penetration Rate

Demand Prediction Errors: Systematic demand prediction errors were simulated by adjusting the OD flows used by the guidance generation algorithm. The effect of both under- and over-predicting demand were studied. Figure 7 summarizes the results. As expected, any error in demand prediction has an adverse effect on the prediction accuracy. The results also indicate that the impact of over-predicting demand is less severe than when demand is under-predicted. An explanation for this observation is that the prediction module will yield more conservative travel time estimates with over-predicted demand than with a demand level lower than the actual values.

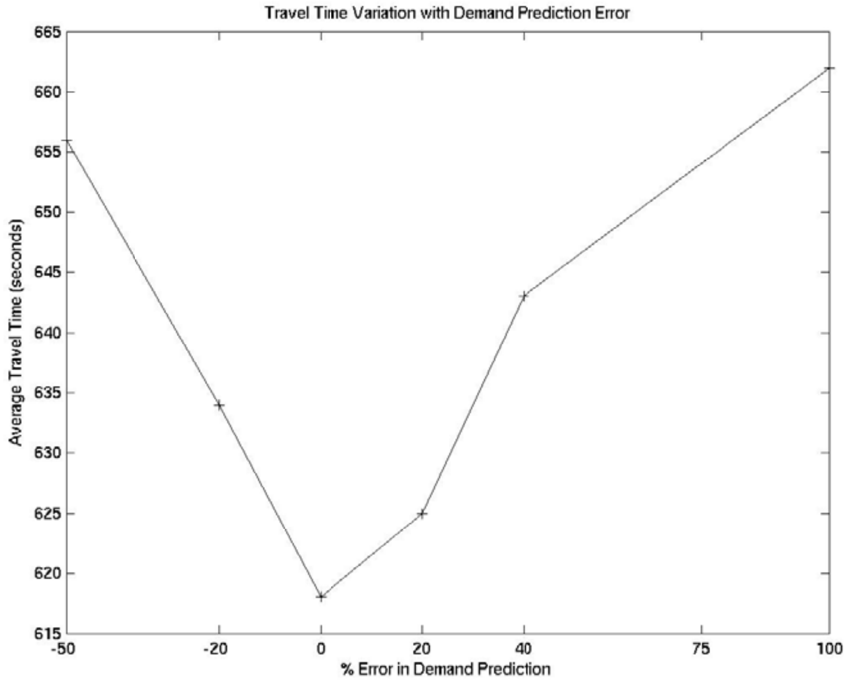

Figure 7. Effect of Systematic Demand Prediction Error

5. Conclusion

This paper describes a simulation-based analysis of traveler information quality, and its impact on network performance. The results provide a useful step towards quantifying the sensitivity of travel times with reference to guidance penetration, demand prediction error and update frequency. Experiments with DynaMIT indicate that overreaction can be controlled through more frequent information updates. Further, saturation in network travel times at both very high and very low update frequencies suggests a trade-off effect between desired performance and available computational resources.

The results in this paper confirm some existing findings on overreaction, while providing valuable insights into the role played by critical parameters that control simulation-based guidance generation systems. A logical extension to this work is to study the effect of network state estimation on experienced travel times. The role of (pre-trip) mode and departure time switching in response to guidance can add a challenging dimension to the evaluation of ATIS. More work is required on large urban networks, to gain a deeper understanding of the guidance generation process.

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