Evaluation of the Mobility Impacts of Advanced Information Systems

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ABSTRACT

Advanced technologies under the aegis of advanced traveler information systems (ATIS) and advanced traffic management systems (ATMS) are being employed to address the debilitating traffic congestion problem. Broadly identified under the label intelligent transportation systems (ITS), they focus on enhancing the efficiency of the existing roadway utilization. Though ITS has transitioned from the conceptual framework stage to the operational test phase that analyzes real-world feasibility, studies that systematically quantify the multi-dimensional real-world impacts of these technologies in terms of mobility, safety, and air quality, are lacking. This paper proposes a simulation-based framework to address the mobility impacts of these technologies through the provision of information to travelers. The information provision technologies are labeled as Advanced Information Systems (AIS), and include pre-trip information, en-route information, variable message signs (VMS), and combinations thereof. The primary focus of the paper is to evaluate alternative AIS technologies using the heavily traveled Borman expressway corridor in northwestern Indiana as a case study. Simulation results provide insights into the mobility impacts of AIS technologies, and contrast the effectiveness of alternative information provision sources and strategies.

Key Words: intelligent transportation systems, evaluation, simulation, information technology.
INTRODUCTION

Over the past decade, severe traffic congestion on urban highways has resulted in a significant deterioration in the quality of travel experience, especially in terms of travel delays, air quality, and safety. In recent years, a broad spectrum of technologies known as Intelligent Transportation Systems (ITS) are being proposed to alleviate these concerns. In the context of highway travel, ITS focuses on the enhancement of the efficiency of existing roadway utilization. Two major ITS technologies are: (i) Advanced Traveler Information Systems (ATIS); which provide route advisory/guidance information to travelers, and (ii) Advanced Traffic Management Systems (ATMS); which seek to manage traffic through the surveillance of current network conditions. Over the past decade, the ITS arena has transitioned from the conceptual framework stage to the operational test phase that analyzes real-world feasibility. Though ITS has matured over the years, studies and procedures that systematically evaluate and quantify the multi-dimensional real-world impacts of these technologies in terms of mobility, safety, and air quality, are lacking. While operational tests attempt to evaluate these impacts in controlled small-scale real-world experiments, they are expensive and labor intensive, and often generate limited or situation specific data, precluding generic conclusions and insights on the relationships between key variables. Because of their logistic needs and operational constraints, they cannot normally afford sensitivity analyses that address “what if” scenarios.

Simulation models are gaining popularity as a viable alternative to model and analyze ITS impacts. Simulation models provide cheap, flexible, and broad-based tools to analyze the alternative ITS technologies and their effects. A key advantage is their ability to analyze advanced technologies which currently lack real world implementation or which represent
enhancements to existing technologies at a specific site. Several traffic simulation models exist for conventional traffic networks (Gartner et al. 1998). Most of them lack capabilities to adequately address the functional requirements of ITS technologies such as ATIS/ATMS. The primary deficiencies of these models are their lack of: (a) capabilities to model path-based traffic dynamics, (b) an explicit modeling and representation of user response decisions, (c) capabilities to model multiple user classes (Peeta & Mahmassani 1995) encountered under Advanced Information Systems (AIS) technologies, and (d) applicability to general networks (such as integrated freeway and surface streets). The absence of basic data structures necessary to support network path processing (e.g., searching for paths that satisfy certain criteria, solving for the k-shortest paths, updating path trip times) is a critical shortcoming for developing a capability to determine user behavior in response to supplied real-time information and to implement route guidance instructions provided by an AIS technology. Another shortcoming in the AIS context is that none of these models is sufficiently developed with regard to the objects or data structures necessary to support simulation and analysis of different control actions.

The most commonly used assignment-simulation models, so called because of their ability to assign paths in addition to the traffic simulation capability, for ITS applications are DYNASMART (Jayakrishnan et al. 1995; Mahmassani et al. 1998) and INTEGRATION (Van Aerde 1990). The Federal Highway Administration’s effort in this regard, called CORSIM (Halati et al. 1997), is currently under development. A limitation of some simulation-assignment models is that the only path processing capability provided is that of the shortest path computation. This is inadequate in the AIS context where a representation of user behavior/decisions requires a richer array of information on alternative route choices. Hence, a desirable feature for simulation models in this context is the ability to solve for and dynamically
update traffic conditions on several paths simultaneously between a given origin-destination (O-D) pair.

This paper discusses a general framework to analyze the mobility impacts of information provision under AIS technologies. It is used to evaluate alternative AIS technologies using the Borman expressway in northwestern Indiana as a case study. The framework uses DYNASMART to simulate the mobility impacts and a day-to-day Bayesian updating model (Jha et al. 1998) to update travelers’ route travel time perceptions in light of prior experience and information provided by an ATIS/ATMS system.

FRAMEWORK

The overall framework for analyzing the impacts of advanced information systems (AIS) technologies consists of a traffic simulator, a day-to-day driver route choice behavior model that accounts for past travel experience, the AIS strategies, and input data. As illustrated in Figure 1, these components are integrated into a framework that estimates time-dependent network performance measures used to determine the mobility, air quality, and safety impacts of these technologies. While procedures for estimating air quality and safety impacts have also been addressed as part of the general framework (Sinha et al. 1998), this paper focuses only on the mobility impacts using the Borman Expressway network in northwestern Indiana as a case study.

The framework is based on the principle of before-and-after scenarios, in which the steady-state (stable) traffic flow pattern on the network is estimated before the installation of AIS technologies using the day-to-day Bayesian travel choice dynamics model and compared with the estimated traffic flow pattern after a particular AIS strategy is employed for the duration of interest (typically the peak period). For both scenarios, a traffic flow simulator, DYNASMART
(Jayakrishnan et al. 1995), is used to determine the associated traffic flow patterns. While the overall framework in Figure 1 is general in nature, the experiments in this paper do not use the day-to-day perception updating model to determine a stable pattern after the installation of an AIS technology. Instead, they determine the system performance immediately after the installation of the AIS technology. This is primarily due to the lack of adequate computational resources. The modified framework used to analyze the mobility impacts here is shown in Figure 2.

The framework first estimates the steady-state (stable) traffic flow pattern for the network prior to information provision through AIS. The day-to-day route choice model predicts the route of each network user on a given day based on past experience using the route choice logic and the simulator. Its inputs include the network structure, signal data, control data, demand data, and incident data. In addition, the parameters for the utility functions in the model reflect the individual driver behavior characteristics. The procedure is repeated for n days (25, for our experiments), where n represents the day on which a steady-state (stable) traffic pattern is ensured, reflecting realistic driver routes that are based on sufficient travel experience. This set of paths represents the network traffic flow pattern prior to the application of an AIS strategy, and forms the initial path set for DYNASMART. The specific AIS strategy is simulated using DYNASMART to determine the system-wide performance measures that indicate mobility impacts.

Several AIS technologies are considered to analyze the mobility impacts including pre-trip information, en-route information, variable message signs, incident management systems, and multiple information sources (MIS). The specific AIS technology employed is reflected through a set of information system parameters in the simulator. After setting these parameters in
DYNASMART and using the time-dependent initial path set, the AIS strategy is simulated using DYNASMART in the descriptive mode. The resulting traffic flow pattern indicates the influence of the AIS strategy.

**The DYNASMART simulation-assignment model**

DYNASMART (DYnamic Network Assignment Simulation Model for Advanced Road Telematics) is a deterministic mesoscopic assignment-simulation model for ITS applications. A comprehensive description of DYNASMART can be found in Jayakrishnan et al. (1995), and its latest capabilities are discussed in Mahmassani et al. (1998). It models traffic flow patterns, and evaluates overall network performance under real-time information systems for a given network configuration, traffic control system, and time-dependent origin-destination demand pattern. The modeling approach integrates a traffic flow simulator, a network path processing component, user behavior rules and information supply strategies. In addition to the user behavior rules explicitly modeled (such as user optimal, boundedly rational, myopic, etc.), it provides the logic and data structures to incorporate other realistic behavioral rules for the response of drivers to information/guidance. It moves vehicles using macroscopic relationships between speed and concentration on a road section, but tracks vehicles individually in terms of their behavioral tendencies. Thereby, the response of each user to supplied AIS information is modeled individually. Such an approach is often labeled as “mesoscopic”, and is a paradigm for ITS simulation models because its ability to keep track of individual vehicles offers a significant capability to model the effects of in-vehicle information systems without the computational cost associated with microscopic simulation.
DYNASMART is used in two ways in our framework. First, it is used to determine stable initial travel patterns based on the paths externally specified as part of the day-to-day perception updating model. Second, it is used to estimate the traffic flow pattern under an AIS technology, thereby generating the performance measures for determining the various impacts. Here, it is used as a simulation-assignment model that incorporates pre-trip and/or en-route path selection (or switching) decisions of users in determining the traffic flow pattern.

**The day-to-day Bayesian perception updating model**

This model addresses the day-to-day dynamics in user behavior based on past experience and user perceptions of ATIS supplied information. It can be used to determine a stable initial traffic flow pattern before the deployment of an AIS strategy, and a stable flow pattern after the deployment. A detailed discussion of the model is provided in Jha et al. (1998). A two stage Bayesian updating is used to capture perception updating by users. It consists of the post-trip updating of user path perceptions based on the current day’s travel experience and pre-trip updating of path perceptions based on ATIS traffic information on the current day. The travel time perceptions of users and the travel time information provided by ATIS are described through probability distribution functions. The variance of a distribution function indicates a user's level of confidence in that source of information. It is assumed that on any given day a user has a certain level of knowledge about travel times in the network and updates his/her knowledge in light of the ATIS traffic information. The updated perception of travel time is obtained through Bayesian updating, where the perception before receiving information corresponds to the prior and the updated perception corresponds to the posterior. Users use their posterior perception to select a combination of route and departure time on that day. After
making the trip, users update their posterior perception in light of the experienced travel time and obtain the prior perception for the next day. However, as stated earlier, this model is used in our experiments only to determine the initial stable flow pattern prior to the deployment of AIS technologies based on past experience.

CASE STUDY: THE BORMAN EXPRESSWAY NETWORK

To analyze the mobility impacts of AIS, a case study is performed on the Borman expressway network. The Borman expressway is a 26 kilometer section of I-80/94 located in northwestern Indiana. It is one of the most heavily traveled expressways in the nation, averaging 140,000 vehicles per day. Indiana Department of Transportation (INDOT) is currently installing an ATMS on the Borman expressway for incident and congestion management (HTMS 1996). As part of the ATMS, INDOT aims to disseminate information to travelers through variable message signs (VMS) and highway advisory radio (HAR).

The Hoosier Helpers is a highway service patrol operated by INDOT which provides assistance to disabled vehicles on the Borman expressway (HTMS 1996). Under the new ATMS setup, INDOT plans to use the Hoosier Helpers for incident management, initially through faster response and clearance of the incident, and in future as part of information dissemination through VMS and system-wide coordination of emergency services.

SIMULATION EXPERIMENTS

This section discusses the Borman network structure, associated traffic characteristics, and the AIS technologies being analyzed. Simulation experiments are conducted for the following scenarios: (i) regular afternoon peak period traffic, (ii) lane closure on the west bound
(WB) Borman, and (iii) link closure on the WB Borman. Scenarios (ii) and (iii) represent frequent incident situations on the Borman expressway. Hence, the impact of AIS technologies under incidents is especially important for the Borman case study.

**Network Structure and Traffic Characteristics**

The study network is illustrated in Figure 3, and consists of the Borman expressway (shaded in the figure), I-90 Indiana toll road, interstate freeway I-65, and the surrounding street network. The overall network in the figure is called the Borman expressway network (or simply “Network” or “Borman Network”). It has 197 nodes and 458 links. The link characteristics (length, number of lanes, capacity, free flow speed) were collected from relevant state and local transportation agencies. The network has 78 nodes with actuated signal control and the rest have no signal control. Potential detour routes from the Borman include I-90, US 20, US 30, Ridge road, and 73rd avenue, depending on the final destination.

The time-dependent O-D trip demands on the Borman Network are obtained from a previous study in the region and updated using INDOT-projected growth rates to reflect the 1997 O-D demand pattern. The afternoon peak hour is relatively worse than the morning peak and is hence considered in this study. Vehicles are generated over a 60 minute period which includes a 5 minute startup generation time for the network to be sufficiently loaded. Statistics are accumulated for vehicles generated between minutes 5 and 60, thereby circumventing start-up and end effects.

**AIS Technologies**
Six AIS technologies are considered to evaluate mobility impacts on the Borman Network. A detailed description of these technologies, the assumptions made in the simulation experiments, and the experimental factors used, are presented in this section.

The Base Case

The impacts of the various AIS technologies are analyzed by comparing the system performance under each technology with the situation before their installation. This situation, called the “base case” in all our experiments, represents the time-dependent traffic flow pattern under the steady-state (stable) O-D demand pattern prior to the implementation of these technologies, and provides the yardstick by which the effectiveness of various technologies is measured. The steady-state O-D demand and route choice pattern are obtained by simulating the travel choice decisions of travelers on the network over 25 days based only on past experience using the day-to-day travel choice model.

Pre-Trip Information

Under pre-trip information, users are assumed to receive information on the current best path to their respective destinations. The information is obtained at the beginning of the trip possibly through radio, television, kiosks, internet, telephone call to an automated service in the traffic control center, etc. The set of assumptions made for the pre-trip information technologies in the simulation experiments are: (1) the initial paths of users are their steady-state base case paths, (2) users do not switch en-route, (3) only a certain percentage of users have access to pre-trip information, and (4) 100% compliance is assumed for users with access to pre-trip
information. Six values are considered for the percentage of users with pre-trip information: 0, 20, 40, 60, 80, and 100.

**En-route Information**

Under an en-route information capability, users are assumed to obtain en-route updates on the best path to their respective destinations at every decision point. The following assumptions are made while analyzing the effectiveness of the en-route information technologies through simulation experiments: (i) the initial paths of the users are their steady-state paths corresponding to the base case, (ii) a certain percentage of users have access to en-route information: 0, 20, 40, 60, 80, and 100 are considered, and (iii) users switch en-route according to a boundedly-rational rule under which a user switches from his/her current route only if the travel time savings on an alternative route based on current network conditions exceeds a threshold, within which the results are satisfying and sufficing. The threshold savings for the boundedly-rational (BR) rule is assumed to be twenty percent, and the absolute minimum trip time savings for a switch is assumed to be one minute. Akin to the pre-trip information case, users who do not have access to en-route information stay on their initial steady-state paths and do not switch en-route.

**Incident Management Systems (IMS)**

Due to the high volume of traffic on the Borman expressway, incidents are critical events vis-à-vis system performance. The Hoosier Helpers reach the incident site aiding rapid detection, verification and characterization of the incident. The effectiveness of the Hoosier Helpers as an incident management system is analyzed indirectly by assuming that the IMS reduces the
incident duration. Assumptions (i) and (ii) for the pre-trip information technologies also hold here. Three values for incident duration reduction are considered, 10, 20, and 30 minutes. A 30 minute reduction represents a more effective IMS compared to the other two.

**Variable Message Signs (VMS)**

It is assumed in our experiments that incidents on the Borman expressway trigger information provision through VMS. Users who comply with the VMS message are assumed to switch to the current best path to their destination, if it is different from the current route involving the Borman expressway. Such a model implies that: (i) users who comply with the message are reasonably familiar with the Borman network and can estimate good alternative routes to their destinations, or (ii) users are provided a specific detour route (for a short distance around the affected area before rejoining the Borman mainline) around the bottleneck area, and those who comply are unfamiliar drivers or familiar drivers who concur with the suggestion (this depends on their perceptions and confidence in information). Given the various possibilities and because of the absence of actual behavior data, a simple compliance rate is assumed to analyze the impacts of VMS information provision on system performance. Such sensitivity analysis is useful for providing insights into the relationship between system performance and compliance rate. The compliance rate in actual situations would be based on the percentage of familiar users, the level of familiarity with the network, and users’ perceptions of supplied VMS information. In our experiments, compliance rates of 0, 20, 40, 60, 80, and 100 percent are considered. Also, the initial routes are the base case routes.

The planned future locations of these VMS on the Borman expressway as suggested by the Hughes Borman ATMS project (HTMS 1996) are shown in Figure 4. These locations aim at
advising users who are about to enter the Borman expressway. The other potential locations included in our study are intended for users already on the Borman expressway so as to enable them to make route diversion decisions en-route when adverse conditions exist downstream.

**Multiple Information Sources**

In addition to the four single technologies, two hybrid cases (representing combinations of these technologies) are evaluated to analyze the effects of multiple information sources. They are:

(i) Pre-trip and en-route information: Under this general multiple information sources scenario, users may have access to pre-trip information only, en-route information only, both pre-trip and en-route, or neither. In our experiments, it is assumed that 40% of the users have access to pre-trip information and 40% of the users have access to en-route information. This means that some users may have access to both forms of information provision (randomly determined by the simulator). For all users, irrespective of whether they have access to information, the initial paths are identical to their base case steady-state paths. Users with access to pre-trip information modify these initial paths before starting and do not switch en-route. Users with access to en-route information use the boundedly-rational rule to decide whether to switch. As before, users with no information do not switch from their initial paths.

(ii) Pre-trip, en-route, and VMS information: This scenario is similar to (i) except that now VMS are also deployed in the network. All users whose routes consist of one or more VMS signs have access to VMS information. As discussed earlier, a simple compliance rule is used to determine the percentage of users who comply with the VMS route advisories. In our experiments, it is assumed that 20% of all users who encounter the VMS messages comply
with it. Thereby, for en-route users who comply with the VMS message, this message supercedes any information received through the in-vehicle navigation system (which implies that the boundedly rational rule is not employed in this situation). The other assumptions and conditions are identical to (i), with 40% of the users having access to pre-trip information, and 40% with access to en-route information (with possible overlaps).

Simulation Scenarios

To evaluate the effectiveness of the above technologies, three common traffic situations are analyzed. They are:

Scenario I - Peak Period Traffic: the time-dependent O-D demand pattern for a typical afternoon peak period between 3:00-4:00PM is simulated on the Borman network. The O-D demand consists of approximately 40,000 vehicles on the entire network and 7,500 vehicles on Borman. The east bound (EB) Borman is relatively more congested compared to the WB Borman as traffic moves away from the Chicago area during the afternoon peak.

Scenario II - Lane Closure: the peak period O-D demand pattern from 3:00 to 4:00PM is simulated with an incident on the WB Borman expressway link between Kennedy Avenue and Indianapolis blvd. The incident leads to a lane closure (50% reduction in link capacity) for a fifty minute duration. The start time of the incident is 3:05pm.

Scenario III - Link Closure: the peak period O-D demand pattern from 3:00 to 4:00pm is simulated with an incident on the WB Borman expressway link between Kennedy Avenue and Indianapolis blvd. The greater severity of this incident compared to that in Scenario II leads to the closure of the link (100% reduction in link capacity) for a fifty minute duration. The start time of the incident is 3:05pm.
The three scenarios were constructed to reflect different degrees of mobility impairment on the Borman expressway. Since the Borman expressway represents the primary corridor in our network, a comparative analysis of the effectiveness of various technologies on mobility would provide insights on strategies for information provision under ATMS/ATIS technologies.

ANALYSIS OF RESULTS

This section analyzes the results of the three scenarios under the various AIS technologies. The effectiveness of a technology is analyzed based on the performance of the Borman expressway alone as well as the entire Borman Network. This is because the Borman expressway is the most congested part of the study network. Hence, any detours or switching from the Borman expressway affects the surrounding areas. Here, “Borman Total” refers to the Borman expressway alone.

Scenario I: Normal afternoon peak period

The results for the pre-trip information scenario are illustrated in Figure 5. The base case, representing the system performance before the installation of the pre-trip information technologies, corresponds to the scenario where 0% of the users have access to information. As illustrated by the graph, both the Borman expressway and overall network perform worse under the base case compared to most scenarios with information. The Borman expressway performs worse than the overall network. The Borman expressway benefits from pre-trip information access up to only a certain market penetration, before widespread information access starts deteriorating its performance as too many users switch to it. It performs best when about 40% of the users have access to pre-trip information, where EB and WB Borman have identical average
travel times. As more traffic exists on the EB Borman during the afternoon peak, the EB Borman expressway is relatively more congested than the WB Borman expressway in the base case. As more users receive pre-trip information, they tend to switch to the otherwise less congested WB Borman from surrounding arterials. Hence, the WB Borman performance worsens with higher market penetrations. The opposite effect holds for the EB Borman, where users switch from this route to a less congested surrounding arterial indicating that the EB Borman benefits from pre-trip information provision. The overall network benefits from increased market penetration, though most of the benefits are accrued when between 40-60% of the users have access to pre-trip information.

The variation of percentage travel time savings with the percentage of users with access to pre-trip information is shown in Figure 6. When all users have access to pre-trip information, the performance on Borman expressway is worse than the base case performance. As discussed earlier, the savings peak at about the 40% market level. Beyond 40%, switches to the Borman congest it so as to gradually negate the benefits over the base case scenario. However, at the network level, opportunities to switch and benefit exist even at about the 80% penetration level because the network is not well congested \emph{a priori}. Users switch to less congested arterials and surface streets and gain travel time savings. These savings also account for the Borman performance deterioration, indicating that substantial benefits can be achieved on the non-Borman part of the network.

The results for the en-route information scenario are illustrated in Figure 7. They are similar to those obtained for pre-trip information scenario. One perceptible difference is that the performance at higher market penetration levels, especially at the 100%, is better compared to the pre-trip information scenario. The Borman expressway performs best when approximately
40% of the users have access to en-route information. These results conform to those of Mahmassani and Jayakrishnan (1991), who found an optimal market penetration level of 25%-50% in their experiments. The average travel times on EB and WB Borman expressway are closer to each other when compared to the pre-trip information scenario. This is because with en-route information users can switch en-route to alternative paths unlike in the pre-trip information case. The percentage travel time savings with en-route information are higher compared with those of pre-trip information, because en-route information enables users to switch to better routes during the trip. This also prevents the loss in savings at higher market penetration levels unlike in the pre-trip information case.

Figure 8 illustrates the average travel time with the percentage of users who comply with the VMS information. The average travel time decreases on Borman expressway up to the 20% compliance rate indicating that the Borman benefits from the switches to the suggested alternative routes. Beyond 20% compliance, the Borman total average travel time remains constant indicating that the Borman route is itself an attractive route. The EB Borman follows the Borman Total curve. The WB Borman average travel time is almost constant across all compliance levels. This is because the WB Borman is not well congested even in the base case, and remains an attractive route. The non-Borman users do not switch because they do not have access to information.

Figure 9 illustrates the percentage average travel time savings over the base case scenario for the various AIS technologies. The various parameters are assumed as follows: (i) 40% of the users have access to pre-trip information in the pre-trip information only scenario, (ii) 40% of the users have access to en-route information in the en-trip information only scenario, (iii) 20% of the users comply with the VMS messages in the VMS scenario, and (iv) the assumptions stated
for the multiple information scenarios. The figure indicates that the best overall network performance is achieved under the en-route information technology. This scenario performs slightly better than even the multiple information sources scenario consisting of pre-trip and en-route information. A key implication of this result is that multiple information sources in a network do not necessarily translate into better system performance. In our experiments, this can be explained by the fact that only a small percentage of users have access to both pre-trip and en-route, while others have access to either pre-trip (40%), en-route (40%), or no information. Thereby, those with access to pre-trip information only in the multiple information sources scenario do not contribute as much to the network savings as the en-route information group as indicated by comparing the pre-trip information only and en-route information only scenarios. Also, for the group of users with access to both pre-trip and en-route information, the pre-trip information may provide “good” paths which preclude some of the them from switching en-route as the savings on an alternative route are within the BR rule threshold. The same effect also explains the reduced savings under the pre-trip, en-route, and VMS multiple information sources (MIS) scenario. However, the savings under this scenario are less compared to the pre-trip and en-route MIS scenario because VMS information concentrates on improving Borman performance only leading to less favorable conditions elsewhere in the network by comparison.

The VMS scenario provides the best savings for the Borman expressway itself. As above, this can be explained by the fact that VMS messages and advisories focus on enhancing the Borman performance only, when compared to other technologies which have a network-wide objective. This also explains the superior Borman expressway performance under the pre-trip, en-route, and VMS MIS scenario compared to the pre-trip and en-route MIS scenario.

**Scenario II: Lane closure**
The system performance under VMS here is very similar to the corresponding performance under Scenario I. When a lane is closed on the WB Borman, its average travel time is higher than that of the EB Borman despite the VMS information because of the reduced capacity due to the incident. As in Scenario I, a 20% compliance with VMS information results in the best Borman performance. Beyond 20% percent switch from the Borman, the Borman itself represents an attractive route for users. Hence, at higher compliance rates, many users comply with the information and stay on the Borman.

The reduction in average travel time with the reduction in incident duration is shown in Figure 10. The average travel time on the Borman decreases with a reduction in incident duration, highlighting the potential effectiveness of Hoosier Helpers as a primary component of IMS. The benefits are primarily accrued for the Borman expressway itself as anticipated, because the incident is located on it.

The percentage average travel time savings over the base case for the AIS technologies are shown in Figure 11. The results emphasize the higher value of information (provision) under incidents for all technologies. The pre-trip information only scenario results in substantially larger savings here compared to Scenario I highlighting the intrinsic value of information in the presence of incidents. By receiving pre-trip information on the incident, potential users of WB Borman can partially or completely avoid the incident, gaining substantial travel time savings compared to Scenario I. The same effect is observed under all information technologies by comparing Figures 9 and 11. The system performs best under the pre-trip and en-route MIS scenario. Unlike in Scenario I, en-route information to users belonging to the pre-trip and en-route information MIS group can be valuable resulting in savings which are higher than the BR rule threshold, because of the incident conditions on WB Borman. Also, for the pre-trip
information only group under this MIS scenario, the \textit{a priori} knowledge of the incident helps in partially or completely avoiding an incident affected route. The system performs well under the other MIS scenario and the en-route information only scenario, indicating the value of en-route information under incidents. More users divert from the WB Borman en-route due to better travel opportunities elsewhere. IMS, whose effect is primarily characterized here in terms of reduced incident clearance times, is not very effective compared to other technologies. This is because of the assumption that users do not switch as they lack access to information. Thereby, users who travel on WB Borman are negatively impacted by the incident and do not switch. Thus, the savings under IMS are primarily due to the faster incident clearance unlike the other scenarios where the possibility of avoiding the incident route exists.

On the Borman, the VMS scenario performs best because its sole objective is to enhance Borman performance, as discussed in Scenario I. The two MIS scenarios also perform well on the Borman indicating that multiple information sources can be beneficial in the presence of incidents. The significantly higher savings on the Borman for the pre-trip and en-route MIS scenario in Scenario II compared to Scenario I indicates that en-route switching information for users on WB Borman is more valuable, and will likely result in a route switch because the alternative route provided by the AIS is substantially better.

\textbf{Scenario III: Link closure}

The closure of a link on the primary freeway has a catastrophic effect, especially on the Borman, as evidenced by the high average travel times in Figure 12. As in previous scenarios, most savings are obtained at the 20% average compliance level. Since link closure represents a severe incident, the difference in the EB and WB Borman average travel times is much higher in
Scenario III compared to Scenario II. For the same reason, reducing incident clearances times under IMS can result in dramatic savings here both for the Borman and the overall network unlike in Scenario II. The incident severity also explains the significantly higher percentage travel time savings compared to Scenario II in Figure 13.

The pre-trip information only, en-route information only, and pre-trip and en-route MIS scenarios perform well indicating the inherent worth of information under incidents, as previously discussed. However, the scenarios involving compliance with VMS information do not perform as well for the Borman Network because VMS aims at enhancing Borman expressway conditions only. Due to the fifty minute link closure, the WB Borman users do not benefit as much as when they avoid using the WB Borman route altogether (as can be achieved through pre-trip and en-route information based scenarios). Between the two scenarios that have VMS, the VMS only scenario performs worse because users who access the WB Borman upstream of the incident are negatively impacted by it for some duration even if they ultimately switch from it, whereas some users in the MIS scenario benefit either from pre-trip or en-route information. For the same reason, percentage savings on the Borman itself are higher under the en-route information only scenario and the two MIS scenarios, as shown in Figure 13.

**CONCLUDING COMMENTS**

This study proposes a framework for evaluating alternative AIS technologies and demonstrates the ability to estimate network traffic conditions under various scenarios without conducting high cost operational tests. While simulation results from a single network preclude definitive generalizations, the experiments suggest that access to multiple information sources does not lead to benefits which are additive, and does not necessarily lead to the best system
performance. Under incident situations, the value of information is further emphasized, and all AIS technologies perform better here than in non-incident scenarios. In general, en-route information leads to the best system performance compared to the other AIS technologies. However, the additional benefits over pre-trip information are rather small, especially under certain incident situations. Moreover pre-trip information is relatively easy to implement and is an immediate possibility when compared to en-route information. The VMS technology mostly benefits the road facilities it targets and/or the areas in its immediate vicinity.

The study suggests an optimal value for the fraction of users with information at which the network performs best. It is true for any source of information, though it may take different values for different sources of information. Also, it may vary with traffic conditions (congestion level) and network conditions (incidents, etc.). This has key implications for designing traveler information systems. The response of users under multiple information sources is not well understood. There is a need to develop procedures that determine how users respond to information from multiple sources. A limitation in this regard is the lack of actual field data.

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REFERENCES


FIG. 1. Framework for the Analysis of AIS Impacts

User Behavior Data

Yes

Is Day = 0 ?

No

Day-to-day Perception Updating Model

Steady-state Traffic Pattern before AIS Technologies: Initial Paths for Users

AIS Strategy

Traffic Simulator (DYNASMART)

Is Steady-state Reached ?

Yes

STOP

No

Day = Day + 1

Is Steady-state Reached ?

Yes

STOP

No

Input Data

• Network Structure
• Demand Data
• Signal Data
• Incident Data
• Control Data

Mobility Impacts

• Travel Times
• Travel Speeds

Air Quality Impacts

• Emissions (e.g. CO, NOX)
• Acceleration, Deceleration Characteristics

Safety Impacts

• Accidents

Traffic Flow Pattern under AIS

• Network-level Performance Measures
• Link-Level Performance Measures
FIG. 2. Framework for Analysis of Mobility Impacts of AIS

User Behavior Data

Day-to-day Perception Updating Model

Steady-state Traffic Pattern before AIS Technologies: Initial Paths for Users

AIS Strategy

Traffic Simulator (DYNASMART)

Traffic Flow Pattern under AIS

Input Data

- Network Structure
- Demand Data
- Signal Data
- Incident Data
- Control Data

Mobility Impacts

- Travel Times
- Travel Speeds

• Network-level Performance Measures
• Link-level Performance Measures
FIG. 3. The Borman Expressway Network

Peeta, Poonuru and Sinha
FIG. 4. VMS Locations on Borman

VMS locations suggested by Hughes Project
Potential other VMS locations
FIG. 5. Variation of Average Travel Time with the Percentage of Users with Pre-trip Information under Scenario I
FIG. 6. Variation of Percentage Travel Time Savings (over the base case) with the Percentage of Users with Pre-trip Information under Scenario I
FIG. 7. Variation of Percentage Travel Time Savings (over the base case) with the Percentage of Users with En-route Information under Scenario I
FIG. 8. Variation of Average Travel Time with the Percentage of Users Complying with VMS Information under Scenario I
FIG. 9. Comparison of Percentage Travel Time Savings (over the base case) under Various AIS Technologies under Scenario I
FIG. 10. Variation of Average Travel Time with the Reduction in Incident Duration due to IMS under Scenario II
FIG. 11. Comparison of Percentage Travel Time Savings (over the base case) under Various AIS Technologies under Scenario II
FIG. 12. Variation of Average Travel Time with the Percentage of Users complying with VMS Information under Scenario III
FIG. 13. Comparison of Percentage Travel Time Savings (over the base case) under Various AIS Technologies under Scenario III