

Information Impacts on Traveler Behavior and Network Performance: State of Knowledge and Future Directions

Ramachandran Balakrishna · Moshe Ben-Akiva · Jon Bottom · Song Gao

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Abstract Advanced Traveler Information Systems (ATIS) have the potential to maximize the operating efficiency of existing transportation infrastructure. Such systems rely on the generation and dissemination of guidance in order to allow drivers to make informed choices about travel mode, route and departure time, etc. The evaluation of the effectiveness of ATIS requires multi-dimensional study encompassing the analysis of various choice situations arising in the real world, constructing models that explain driver response to information in different contexts, and developing algorithms that can generate traveler information. Since driver confidence in the ATIS is directly related to the accuracy, relevance and usefulness of the information, a key aspect is the collection of relevant field data that can instruct model development and ATIS evaluation before real-world deployment. This paper aims to provide a synthesis of both the state of the art and the state of the practice of ATIS modeling and evaluation. We review the literature related to data collection and driver response model development, and classify the same according to the

R. Balakrishna
Caliper Corporation
Tel.: +1-617-5274700
E-mail: rama@caliper.com

M. Ben-Akiva
Massachusetts Institute of Technology
Tel.: +1-617-2535324
E-mail: mba@mit.edu

J. Bottom
Steer Davies & Gleave Inc.
Tel.: +1-617-3912310
E-mail: Jon.Bottom@sdgworld.net

S. Gao
University of Massachusetts at Amherst
Tel.: +1-413-5452688
E-mail: songgao@ecs.umass.edu

specific choice situations they address. We provide a conceptual discussion of the general framework within which traveler information may be generated, including key ATIS design parameters that may impact the performance of (and consequently, driver confidence in) the system. We also present brief empirical results from past simulation-based evaluations of ATIS, and conclude with recommendations for future research directions in order to further real-world ATIS deployment

Keywords Advanced Traveler Information Systems · ATIS · driver response · over-reaction · prediction-based guidance generation

1 Introduction

With steadily growing levels of vehicle ownership and vehicle miles traveled, traveler information has been identified as a potential strategy towards managing travel demand, optimizing transportation networks, and better utilizing available capacity. Towards this goal, Advanced Traveler Information Systems (ATIS) have been conceptually designed with sophisticated travel behavior models and high-fidelity network performance models, made increasingly feasible through the rapid advances in computing power. Crucial components of this problem domain are the modeling of individual drivers' response to traveler information, and the development of algorithms that can generate accurate guidance of relevance to real-world trip-makers. In this paper, we (a) undertake a detailed literature review to conceptually explore the multifarious dimensions of driver response to information and models of driver response, (b) discuss the key issues in information provision and the factors critical to the successful generation of such information, and (c) provide a flavor for the state of the art of research evaluating the potential benefits of ATIS.

The remainder of this paper is structured as follows: Section 2 undertakes a broad discussion of the different types of route guidance as well as key ATIS design parameters that are likely to impact the effectiveness of the guidance system. Section 3 is a detailed review of the state of the art and practice dealing with the collection of driver response data, the estimation of mathematical models of said choices, and various real-world situations that might allow drivers the opportunity to respond to guidance. Section 4 illustrates the process of evaluating the effects and phenomena associated with the provision of route guidance, mostly with the use of traffic simulation modeling tools. Section 5 concludes with a summary of the state of the art, and suggests directions for research on appropriate data collection, driver response modeling, ATIS evaluation and testing.

2 Generation of Travel Information

This section discusses the generation of information intended to assist travelers make better travel choices. In other words, the principle underlying the

provision of information involves the improvement of the decision making of individual travelers, rather than improvement of network performance overall.

In the discussion below, the term “message” will generally be used to refer to the content disseminated by a travel information provider to its users. However, the terms “information” and “guidance” will also be used interchangeably, and are not meant to imply a particular type (e.g. descriptive, prescriptive or other) of message content. Further, as a majority of the studies in the literature focus on the auto mode, we use the words “traveler” and “driver” interchangeably.

The discussion in this section considers in turn travel information attributes, guidance based on prevailing conditions and guidance based on predicted conditions. The presentation of these two specific guidance approaches highlights the advantages and disadvantages of each, as well as technology and models typically used in their implementation.

2.1 Information attributes

In this section we briefly describe some of the information attributes that can characterize the messages provided by different travel information systems. This discussion serves to prepare a more detailed discussion below of two specific information generation approaches.

Based on historical, prevailing, predicted conditions: Messages provided to a traveler can be based on typical conditions that have been observed in the past, on measurements and estimates of conditions prevailing at the time the request for information is made, or on predictions of what future conditions will be at the time the traveler is at a particular location.

Descriptive, prescriptive, mixed: The messages provided to a driver can describe network conditions, or recommend a particular action based on the network conditions, or both (“Take route XYZ, severe congestion ahead”).

Network coverage: A travel information system might cover only the major transportation facilities in an area, or alternatively might attempt to take into account all facilities.

Information precision: Messages provided by an ATIS will typically provide time and/or delay information intentionally rounded to some level of precision, commensurate with the accuracy of the data sources and processing, to avoid saturating drivers with excessive details.

Information accuracy: Accuracy will be limited by the nature and extent of the data collected and used to generate travel information, and by the ways in which the information is processed.

Information latency: The information disseminated to travelers may not be completely up to date because of lags in data collection, time required for data processing, and compliance with a periodic information update cycle: for example the guidance generator might have a policy of updating messages every 15 minutes in non-incident conditions.

Other: A variety of other information attributes can be mentioned: push or pull access mode (information that is disseminated automatically to travelers or that must be specifically requested by them); message medium (graphical, text, spoken); the specific message format; etc.

2.2 Guidance based on prevailing conditions

As noted above, one approach to guidance generation consists of providing information based on the conditions that prevail over the network at approximately the time that the information is generated (Chen and Mahmassani [1991]). This information might simply report on those conditions (descriptive guidance), or might suggest travel options based on the conditions (prescriptive guidance), or both. In any case, the messages sent to travelers reflect the guidance system's estimate of conditions prevailing over the network at the time of guidance generation: there is no attempt to forecast future conditions, although the estimation of prevailing conditions might well combine real-time sensor measurements with historical information on typical traffic conditions.

2.2.1 Advantages of this type of guidance

With experience, a user of a transportation system is likely to develop a more-or-less accurate mental model that extrapolates from a "snapshot" of prevailing network conditions to an estimate of what the experience is likely to be on alternative travel options. (This model involves both the user's understanding of network dynamics, as well as her interpretation and assessment of the messages received from the information system.) Thus, upon receiving messages about prevailing conditions, the user may be able to transform these into a valid basis for a travel choice.

Advanced traveler information systems that focus on prevailing conditions, while not simple, are arguably less complex than those that attempt to provide guidance messages based on forecast future conditions, as discussed below.

2.2.2 Disadvantages of this type of guidance

The mental models that users apply to extrapolate from prevailing to experienced conditions are, almost by definition, unlikely to be accurate in many situations of non-recurrent congestion. (There are of course exceptions to this.) Thus, in these situations providing guidance on prevailing conditions may not be as helpful to travelers as it is under "normal" travel conditions.

2.2.3 Technology and models for guidance generation

Guidance generation technology for systems based on prevailing conditions must collect real-time data from a variety of deployed traffic sensors, and process these data into an estimate of the prevailing network state that is

sufficient to base the generation of guidance messages on. Depending on the nature of the system and its messages, the estimated network state might be characterized by attributes at the link level (travel times, delays, queue lengths) or route level, with disseminated messages reflecting these attributes (Ben-Akiva et al. [2001]).

The sophistication with which the network state estimates are prepared can vary considerably, from local estimates of link speeds based e.g. on inductive loop detectors, to processing systems that combine multiple types of real-time data (local speeds and volumes from loop detectors, point-to-point volumes and travel times from toll tags, video feeds from traffic management applications, etc.) with historical data in a network-level filtering approach.

2.3 Guidance based on predicted conditions

An alternative approach to guidance generation involves predicting future network conditions, and basing the guidance messages on these predictions (Kaysi [1992], Papageorgiou et al. [2007]). More specifically, predictive guidance attempts to reflect in its messages the conditions that are expected to prevail at network locations at the time the traveler will actually arrive there, rather than those that prevail at the time the guidance is disseminated.

2.3.1 *Guidance consistency*

Guidance that is based on predicted conditions must confront a fundamental problem: when travelers receive the guidance and react to it, their reactions may invalidate the predictions on which the guidance was based, thus rendering the guidance irrelevant or worse. For example, guidance that is based on predictions of impending congestion on one of two parallel routes may cause travelers to shift to and congest the other route, leaving the original route relatively uncongested and leading to overall higher levels of delay (Ben-Akiva et al. [1991]). Guidance is said to be *consistent* when it is based on predictions that are realized (within the limits of modeling accuracy) after the guidance is disseminated and travelers react to it (Bottom [2000]). Note that this definition does not necessarily require that travelers comply with prescriptive guidance messages, only that their reactions, whatever they might be, are correctly anticipated when forecasting the conditions that were used to generate the guidance messages.

If relatively few travelers are affected by guidance, then their reactions to it are unlikely to have a significant effect on future network conditions, and consistency may not be an important issue. On the other hand, if many travelers react to guidance, and if their reactions affect network conditions in a significant way then, as noted, failure to ensure predictive guidance consistency may result in ineffective or counterproductive travel guidance.

2.3.2 Advantages of this type of guidance

It seems intuitive that, other things being equal, guidance that accurately reflects the conditions at a network location at the time a traveler actually reaches there is likely to be a more relevant basis for decision-making than guidance that simply reflects the prevailing or historical conditions at that location at the time the guidance is disseminated. In a dynamic network, such changes can be significant enough that guidance based on conditions prevailing at or around the time the messages are disseminated may be a seriously inaccurate reflection of the actual conditions that would be encountered during a trip on the various travel options available (Bottom et al. [1999], Rathi et al. [2008]).

A number of currently-active commercial travel information services provide guidance based on predictions of travel conditions (although it does not appear, based on publicly-available information from these services, that guidance consistency is a concern). The commercial viability of these offerors suggests that the market recognizes a value in predictive guidance.

2.3.3 Disadvantages of this type of guidance

Predictive guidance is considerably more complex to generate than other forms of guidance. The discussion below of technologies and models used for this type of guidance explains some of the requirements. As a related matter, the accuracy of network flow and conditions forecasts will almost inevitably be lower than that of estimates of the prevailing network state, although it does not necessarily follow that the effectiveness and usefulness to travelers of guidance based on such forecasts will also be lower than guidance based on state estimates.

Although there is increasing recognition of the potential of predictive guidance, relatively few currently-deployed systems provide such information. Those that do appear to be based on models that combine data on prevailing conditions with information on historical travel conditions and patterns, and current and near-term perturbations (weather, special events) in an extrapolation model, but do not consider the effect of the guidance itself on future network flows and conditions – in part, because the penetration of these systems in the market is still too low to produce significant impacts on the network.

This being the case, there is currently no empirical evidence on the effectiveness of consistent predictive guidance in practice. Assessments of such systems, or of alternative designs for them, must currently rely on simulation testing, as discussed in Section 4 below.

2.3.4 Technology and models for guidance generation

Predictive guidance generation is based on estimates of prevailing conditions and so, as noted, requires the deployment of the same sorts of sensor and

communications technology that would be required by a system for generating network-level guidance based on prevailing conditions (Kaysi et al. [1995]).

Guidance generation systems that are not concerned with consistency would extrapolate future conditions in any of a variety of ways, typically taking account of historical traffic patterns and conditions (using a database that is continually updated with information from the real-time data feed and network state estimation), as well as available information on current and near-term perturbations (weather, work zones, incidents, special events, etc.) There is no explicit attempt to account for traveler reactions to the guidance, or for the impacts of those reactions on network conditions. Guidance messages (descriptive, prescriptive or mixed) are generated from the predicted conditions.

Systems for generating consistent guidance require data processing capabilities that include (i) forecasting models capable of predicting the evolution over time of future network flows and conditions from their prevailing state following the dissemination of particular guidance messages; and (ii) algorithms for generating guidance messages in a way that ensures mutual consistency between them and the condition and flow forecasts that they reflect (Kaysi et al. [1993]). It is worth noting that travel forecasting models that are sensitive to the effects of guidance messages on traveler behavior are still the subject of research, and that algorithms for generating consistent guidance can be quite computationally intensive.

2.4 Summary

This section summarized attributes of traveler information, and discussed the features and technological characteristics of information systems based on prevailing and on predicted travel conditions. We now present a review of literature relevant to drivers' response to various types of information, and under different choice circumstances.

3 Driver Response to Travel Information

In this section, we present a synthesis of empirical studies of individual traveler response to ATIS, including both revealed preference (RP) and stated preference (SP) studies.

A traveler makes decisions based on her knowledge of the available alternatives and their attributes, subject to time and cognitive capacity constraints. Such knowledge is obtained through both personal experience and exogenous information, and is usually limited by the inability to explore all available alternatives, the inherent uncertainties of external influences (e.g., bad weather, incidents) and the collective effects of other travelers' decisions in the system. ATIS provides exogenous information that could potentially expand travelers' knowledge of the decision environment, and improve decision quality.

Travel information can be characterized by its attributes (see Section 2 for a detailed discussion of information typology) along many dimensions. We

focus on real-time (or dynamic) information that reflects travel conditions at or close to the decision time, in contrast to static information that usually describes the average decision environment over a relatively long period. However, as both dynamic and static information contribute to the formation of the traveler's knowledge and are usually not separable, we also have some discussions of static information when appropriate. Note that the time scale is by nature continuous and thus the notion of dynamic and static information is also relative.

In the remainder of this section, we start with a discussion of data collection methods for the study of traveler response to ATIS. Next we discuss travelers' valuation of and willingness to pay for real-time information. We then present evidence of information impacts on travelers' learning process. Next we turn to how drivers respond to ATIS, both in the short run and the long run. Note that this is not intended as a comprehensive literature review; rather we focus on empirical studies since 2000, unless the last major development of a research area was before 2000. For pre-2000 studies on driver response to ATIS, the reader is referred to Lappin and Bottom [2001].

3.1 Data Collection Methods

Due to the relatively limited deployment of ATIS on a large enough scale, most collected data suitable for modeling come from SP surveys or laboratory experiments. RP questions are usually simple qualitative ones, and used for summary statistics rather than modeling. SP and RP data are combined in some situations to improve the model estimation efficiency (e.g., Polydoropoulou et al. [1996]). Some researchers have made an effort to validate SP data against RP data (e.g., Khattak et al. [1994], Bonsall et al. [1997]).

Notable data collection efforts and studies that have used the data include:

- RP and SP surveys from TravInfo field operation test (San Francisco): Khattak et al. [1999], Mehndiratta et al. [2000a], Yim et al. [2002], Khattak et al. [2003], Wolinetz and Khattak [2004].
- RP and SP surveys from Puget Sound Regional Council's panel travel diary study: Mehndiratta et al. [2000b], Tsirimpa et al. [2007].
- Route choice simulator experiments developed by Bonsall and collaborators: Bonsall et al. [1997].
- Laboratory experiments in a three-route highway network developed by Mahmassani and collaborators: Mahmassani and Liu [1999], Srinivasan and Mahmassani [2003].
- Laboratory experiments in a relatively more realistic network developed by Abdel-Aty and collaborators: Abdel-Aty and Abdalla [2004, 2006].

3.2 Valuation of and Willingness to Pay for Information

Some common questions about ATIS are: What kind of information do users want? How much are users willing to pay for the information? These questions are related. A traveler responds to information as the information changes the decision environment. For example, it could suggest route alternative unknown to the traveler or indicate a work zone downstream. Changed decisions suggest that the traveler perceived benefits from the change, otherwise she would not have made the change. In addition, information might provide benefits even though no changes are made, such as reduced anxiety or the validation of a choice already made. The valuation of and willingness to pay (WTP) for information are conceivably directly related to the perceived benefits of information, which in turn depend on a variety of information attributes. It is thus probably more informative to talk about the WTP for a certain information attribute.

For example, Mehndiratta et al. [2000a] estimated the WTP for information attributes such as update frequency, coverage, and customization using the 1998 survey carried out among a small sample of people who had called TravInfo in April 1997. More frequent updates were found to be the highest priority among the range of possible information enhancements explored in the survey, followed by an extension of coverage to include major arterials in addition to freeways. The authors also cautioned that the absolute values of WTP should not be used to inform pricing decisions due to the nature of the data. Molin and Timmermans [2006] collected SP data on a number of categories of attributes for transit information, including ticket pricing, transfers, real-time information, private transport, walking route, destination, on-board comfort and service, and planning options. Attitudinal questions about the importance of the attributes were asked and the WTP for each attribute category was estimated from trade-off questions. The rankings of information attributes from the two approaches were the same, with real-time information being the first and additional planning options the second.

Broadly speaking, three approaches have been used to estimate the WTP for information, almost all based on hypothetical situations (with the advent of for-fee ATIS markets, more RP studies could become available). A direct question was asked in Aultman-Hall et al. [2000] about the most a user would pay per call before she would stop using the traffic advisory telephone service (TATS) in the Greater Cincinnati and northern Kentucky area. Most WTP studies ask the user to make choices involving tradeoffs among systematically varied combinations of price and information attribute levels, and estimate a utility maximization model based on the data. The WTP can then be derived as the negative ratio of the marginal utilities of a certain information attribute and price. Khattak et al. [2003] used a slightly different approach with a similar idea, where the stated frequency of using TATS was regressed over combinations of information price and attributes, among others. The authors concluded that respondents were willing to accept a small per-call fee for customized travel information services based on the positive coefficient of

the indicator variable of customized travel information priced at 25 cents/call. The third is the experimental economics approach, where human subjects participate in laboratory experiments and are granted an initial endowment to buy information, as is done in Denant-Boemont and Petiot [2003]. All three methods potentially suffer from the deficiency of SP data, which is that due to the lack of actual commitment subjects tend to overstate their WTP. The third approach potentially has less of a problem as real monetary transactions are involved, though still in a hypothetical situation.

3.3 Information Impacts on Day-to-Day Learning

Exogenous information directly influences a traveler's perception of her travel decision environment; combined with personal experience it could alter the traveler's habits and knowledge of the transportation system. Polydoropoulou and Ben-Akiva [1999] described successive stages in the learning process of ATIS users including: awareness, consideration set formation, choice set formation, trial use, repeat use, and travel response. Conventional travel behavior analysis has been mainly done in a static framework, most notably using random utility models estimated on cross-sectional data. In this work, the level of knowledge is not explicitly considered and simplified assumptions of perfect information are made. In the study of traveler response to ATIS, however, information has to be explicitly considered. Thus it is only natural that we abandon the perfect information assumption and model the process of forming habit and establishing knowledge and how it is affected by different types of information. Mahmassani and Chang [1986], Iida et al. [1992] and Mahmassani and Liu [1999] are among the earlier efforts in studying empirically the day-to-day learning process. In the past decade there has been an increasing level of interest in this problem, from both transportation professionals and researchers in psychology and economics, e.g., Barron and Erev [2003], Srinivasan and Mahmassani [2003], Avineri and Prashker [2005], Avineri and Prashker [2006], Selten et al. [2007], Ben-Elia et al. [2008], Ziegelmeier et al. [2008], Bogers [2009], Lu et al. [2011].

To the best of our knowledge, all empirical studies of day-to-day learning in the literature are based on laboratory experiments, which is not surprising given the difficulty in collecting long-term longitudinal disaggregate data. We also distinguish between two types of experimental settings: competitive and non-competitive. In a non-competitive experiment, the alternative attribute values (e.g. route travel times) are generated through an underlying sampling process by the experimenter, and are usually unknown to the subject and not affected by her decisions. In a competitive (game-like) experiment, many subjects make decisions simultaneously and the alternative attributes are determined collectively by a group of subjects' decisions. For example, in a route choice experiment, underlying link volume-delay functions are specified by the experimenter, but the actual travel times are determined by applying the number of subjects choosing a particular route as an input to the delay functions.

Some of the major research questions to be answered from a day-to-day learning study include: How fast do users learn (usually indicated by the declining number of switches among alternatives)? Do users eventually behave “rationally” as speculated in most static choice behavior or traffic equilibrium assignment models? All studies provide users with immediate feedback on chosen alternatives (usually routes in a route choice context) to emulate the reality that a traveler always knows her own travel time after the trip is finished. In addition various types of pre-trip, post-trip and en-route information were provided.

A subject switches among alternatives mainly for two purposes: exploration and exploitation. Intuitively more information in addition to personal experience (pre-trip, en-route, or post-trip) should reduce the extent of exploration as it helps the subject learn about the decision environment faster, as was shown in, e.g., Avineri and Prashker [2006], Ben-Elia et al. [2008], Lu et al. [2011], and Iida et al. [1992]. However, post-trip information on unchosen alternatives could also generate regret and actually increase the switch propensity, as shown in, e.g., Srinivasan and Mahmassani [2003] and Lu et al. [2011]. As for pre-trip or en-route real-time information on prevailing traffic conditions, it generally increases the switches at the point of information provision, as a subject is provided the opportunity to exploit better alternatives revealed by the information, especially in the case of an accident (see, e.g., Mahmassani and Liu [1999], Srinivasan and Mahmassani [2003], Bogers [2009], Lu et al. [2011]). However, route switches upstream of the information provision node might actually decrease since the information reduces the uncertainty level of the network in general, as shown in Lu et al. [2011].

Information other than personal experience could potentially give the subject a better picture of the decision environment and make the “perfect information” assumption usually needed for utility-maximization choice models or equilibrium traffic assignment models more valid. However in reality our decision environment can never be completely deterministic, and risk attitude is an important factor in decision making. The impacts of information on subjects’ revealed risk attitudes vary considerably, and do not necessarily result in a trend towards an “optimal choice” as predicted in a “perfect information” based model. In a non-competitive environment, for example, Avineri and Prashker [2006] found that pre-trip static information on expected route travel times in a non-competitive environment did not result in more subjects minimizing expected travel times; rather it increased the heterogeneity in risk attitudes, and actually decreased the propensity to choose the route with the less expected travel time, while Bogers [2009] found that the most elaborate information scenario, with both post-trip information on unchosen routes (often dubbed foregone payoff, or FP information) and en-route real-time information, produced the highest travel time savings. In a competitive environment, Ziegelmeyer et al. [2008] found that FP information did not significantly increase the subjects’ ability to find optimal departure times, and Lu et al. [2011] found that FP information either increased or decreased the average travel time depending on whether en-route real-time information was

provided, and suggested that information impacts in a competitive route choice environment depended to a large extent on the network structure, and more information could make things worse off as in a conventional Braess paradox.

3.4 Traveler Response to Real-Time Information

Individuals make travel and travel-related decisions at various time scales. Travel demand is derived from the need to participate in social and economic activities, such as going to work and visiting friends. The locations of these activities thus determine the origins and destinations of trips, and in particular residential and employment location choices that are usually made in a long run. The scheduling of daily activities includes travel as an integral part, and real-time travel information potentially will affect activity schedules. Mode choice is a relatively shorter-term decision, while departure time and route decisions are made in an even shorter term. Further down along the time scale, real-time adjustment of some of these decisions are made possible by ATIS, for example, route diversion to avoid an incident. These decisions are inter-related, and individual traveler response to ATIS potentially span across all of them. We first give an overview of the likely responses in the short term, namely, temporary deviations from habitual travel and schedule decisions, and then discuss how ATIS could potentially influence long-term decisions.

3.4.1 Short-term response

Real-time traveler information provided by ATIS potentially reduces the level of uncertainty in the decision environment of a traveler, and could prompt a traveler to change her previous choices that were made without the updated information. Since the decisions have to be made in real-time, the traveler has to rely on options at her disposal at that time and her existing knowledge of the environment, if no exogenous guidance is available. Therefore the likelihood of a choice change depends on, among others, the availability of alternatives and traveler's familiarity with them.

Departure time choice. Many RP surveys show that departure time and route changes are among the most frequent responses to ATIS, see, for example, Aultman-Hall et al. [2000], Yim et al. [2002], Martin et al. [2005]. Furthermore, a Mitretek study [Shah et al., 2001] provides evidence from simulated yoked driver experiments involving the Washington DC area that pre-trip ATIS more likely to produce departure time changes than route choice changes. These findings are not surprising, given that alternative departure times are always available, and a traveler is most likely familiar with the consequence of choosing an alternative departure time if she sticks to the same mode/route.

One of the major benefits of real-time information is to avoid schedule delay (defined as the difference between the preferred arrival time and the actual arrival time for a given commute) at the destination, especially for

trips with a rigid arrival time requirement. A traveler usually has to reserve enough “buffer” time by leaving home early to account for the unexpected trip delay to ensure arriving on time. With pre-trip real-time information, the departure time can be adaptive to actual traffic conditions and as a result, the traveler might be able to depart just in time in any situation to arrive on time. This flexibility in departure time enables better use of the previous “buffer” time at home, and/or reduce expected schedule delay [Shah et al., 2001], which is a major explanatory variable in departure time choice studies Mahmassani and Liu [1999], Jou [2001].

Route choice. It is straightforward to change routes, if the traffic network is dense enough to provide viable alternative routes and the traveler is familiar with them. However the level of network knowledge potentially varies significantly among the traveler population [Ramming, 2002], and it is conceivable that in some situations, a traveler does not feel like deviating from her familiar route(s) and stepping into the unknown.

Many surveys have the respondents’ reported route choice changes as one of the major responses to ATIS, see, e.g., Aultman-Hall et al. [2000], Yim et al. [2002], Dai [2002], Martin et al. [2005]. Route choice is arguably the most researched area of traveler response to ATIS, with a particularly large body of research in binary route switching decision-making in response to VMS or radio information in real life, or more advanced hypothetical ATIS in SP surveys. However as we mentioned in the introductory paragraphs, there is a lack of generalizable model or method to predict that $x\%$ of travelers receiving information with an array of attributes a, b, c, \dots, d will switch to route y .

Some researchers [Razo and Gao, 2010, 2011, Tian et al., 2011] study the the response even before the information is received for travelers with look-ahead abilities. A traveler does not need to commit to a particular route, but can decide later at a switching point based on then revealed traffic conditions, and pick the route with a lower travel time for the remaining trip. The option value of downstream real-time information thus could potentially make a collection of alternatives that share a common starting link more attractive than other links out of the same decision node. Therefore the travelers respond to the information upstream of the actual point where it is received. Empirical studies of the look-ahead behavior have been carried out with SP data only. On the other hand, there have been a large number of algorithmic studies, which generate optimal routing decisions depending on traffic conditions revealed by real-time information in a stochastic network [Hall, 1986, Polychronopoulos and Tsitsiklis, 1996, Pretolani, 2000, Miller-Hooks and Mahmassani, 2000, Waller and Ziliaskopoulos, 2002, Gao and Chabini, 2006, Gao and Huang, 2011], and a recent and comprehensive literature review can be found in Gao and Chabini [2006]. These algorithmic studies are potentially useful for choice set generation in RP studies of such look-ahead behavior in real networks.

Such deficiency is largely due to the lack of detailed field observations of route choice changes. Earlier field observations focused on switchings at VMS locations, see. e.g., Emmerink et al. [1995b], Chatterjee and McDonald

[2004]. Richards and McDonald [2007] showed that it was difficult to capture a meaningful sample size of respondents passing an “active” VMS in a real-life incident scenario. Less than 1% of the commuter sample stated that they had diverted to an alternative route during the travel diary week as a result of VMS information, although this did correspond to 53% of those 45 drivers originally intending to travel past the incident location. More detailed tracking of individual route choices has been made possible by the advent of Global Positioning System (GPS) technologies. For example, Papinski et al. [2009] compared travelers’ planned and actually taken routes (observed by GPS) and found that 20% of surveyed travelers switch routes for various reasons (one of them was ATIS). There have been a large number of GPS data collection efforts throughout the world, especially with the ever increasing popularity of GPS-enabled smart phones, and it is expected that better empirical evidence of route choice response to ATIS can result from these efforts and more quantitative conclusions can be drawn.

Mode choice. Generally real-time information is not found as the major drive of mode switch in many surveys. e.g., Henk and Kuhn [2000], Yim et al. [2002]. Aultman-Hall et al. [2000] found that mode change happened only 5.7 percent of the time after the callers received information from a TATS, lowest among all inquired trip-making changes. These results are intuitive, as mode switch on the spot requires the immediate availability of an alternative mode and enough familiarity with both modes. An en-route traveler virtually cannot have these conditions met, and only pre-trip changes are possible. Conceivably a regular commuter with spare vehicles in an urban area with well-developed transit system might be able to change mode after receiving real-time information, however the frequency of such changes must be much lower than that of departure time or route changes. Dziekan and Kottenhoff [2007] studied the benefits of displaying real-time information at stops of public transport, and found that although passengers appreciated the benefits, empirical evidence of actual mode switching was still lacking.

There are a number of experimental studies of mode choice changes in response to ATIS, e.g., Abdel-Aty and Abdalla [2006] and Chorus et al. [2011]. However, it is questionable how realistic the settings were, given that mode choice is mostly habitual and significantly affected by the context (e.g, the availability of a spare vehicle and/or a viable transit route).

Destination choice and trip cancellation. The change of destination and cancellation of the trip could happen only when the trip is discretionary, since generally there are no alternative work locations and not going to work is not an option, see, e.g., Henk and Kuhn [2000], Aultman-Hall et al. [2000], Yim et al. [2002], Martin et al. [2005].

For discretionary trips, the effects of ATIS on shopping trip destination choice was investigated in a set of internet based stated preference surveys by Kraan et al. [2000] and Mahmassani et al. [2003]. In the survey, respondents were asked to make a (simulated) shopping trip from a central location in Austin, Texas to a major suburban mall. It was found that respondents who

were less familiar with the Austin area were more likely to switch destination, but not route. We postulate that this result might be explained by the fact that individuals are more likely to have landmark knowledge than route knowledge, as defined in Freunds Schuh [1992] and reviewed in Ramming [2002].

Yim et al. [2002] summarized empirical evidence from several behavioral surveys conducted in the San Francisco Bay Area between 1995 and 1999, and found that noncommuting drivers changed their travel choices more than commuting drivers, including the occasional cancellation of trips, perhaps reflecting the flexibility inherent in nonwork trips.

Daily activity schedule adjustment. As travel is part of a daily activity schedule, the impact of real-time information can potentially extend beyond the trip-making itself and reach related activities.

With a more precise estimate of trip time, travelers could make minor changes to activities at both ends of the trip and derive more utility from the given amount of time. For example, if a bus rider knows that the bus is delayed from a real-time bus location information system, she could stay at office and make good use of the time (say, finish up a report) rather than wait at the bus stop (especially when the weather is bad). Similarly, if a driver learns of a severe incident downstream on her way to an appointment, she could notify relevant people to make other arrangements. Empirical evidence of minor activity adjustments at trip ends is generally connected to departure time choice change, see, e.g., Shah et al. [2001], Dziekan and Kottenhoff [2007].

A major change of activity schedules might be related to trip cancellation, destination change, and/or a major change of departure time (e.g., moving the trip from AM to PM, rather than from 7:00am to 7:30am). People schedule the activities that they need to accomplish in a day based in part on the time taken by each activity and the time required to travel between activities in different locations, thus a major change of the timing and/or locations of a trip usually accompanies re-arrangements of other activities. Although conceivable, such empirical evidence is not as common, with only two studies in the literature to the best of our knowledge. Sun [2006] conducted a laboratory experiment, where activity re-scheduling is explicitly explored as one of the responses to ATIS. Subjects were found to be willing to reschedule activities as well as change travel choices when notified of abnormal traffic conditions. Tsirimpá [2010] developed a model system that include two models for travelers' response to ATIS estimated on RP and SP data from the Athens metropolitan area. The first model incorporates decisions (including modifying activity daily schedule) before or during the first primary tour, after acquiring traffic information from current traffic information systems. The second model concerns en route traffic information acquisition from ATIS and incorporates decisions, such as add activity, delete activity, and change the sequence of activities. The model estimation results, indicates that travelers are willing to change their daily activity pattern, provided that they would be confident of the reliability of the information content.

Stress and anxiety reduction. Many surveys have found that trip-makers appreciate having travel information available even if they do not or cannot modify their trip-making behavior in any way because of it, see, e.g., Yim et al. [1999], Petrella and Lappin [2004]. Lee [2000] has attempted to make the notion of travel stress relief more precise by arguing that the value of time spent in travel includes at least two distinct components: the opportunity cost of the activities foregone by traveling, and the disutility of the travel experience itself. Reduced stress and anxiety improve the travel experience, and likely reduce the value of time.

3.4.2 Long-term response

Habitual trip-making behavior adjustments. The responses discussed in the previous section are temporary deviations from regular travel choices and/or activity schedules. If real-time information is available for a long time period, a traveler's habitual choices might change as well. Real-time information provides a traveler with more flexibility in travel choices and activity schedules, which will result in more efficient use of time. The option value of information in route choice as discussed in the previous section on short-term responses could potentially be realized in the context of all travel choices and activity schedules, provided that alternative travel options or schedules exist and it is feasible to switch in real-time. In addition, even if a change is impossible due to the lack of alternatives, real-time information could have psychological benefits (e.g., reduced anxiety), which over time might also encourage a habitual preference to the alternatives with real-time information.

The study of habitual behavior requires longitudinal behavioral data at the individual level and is generally lacking. Among the limited RP evidence, Uchida et al. [1994] surveyed commuters in a three-route corridor in Osaka, Japan following the installation of a variable message sign (VMS) network that provided predicted travel time information, and found that drivers showed a reluctance to switch away from their habitual route, but over time, roughly 40% of respondents reported that they had changed their habitual route as a result of the ATIS.

Historical information might be useful in influencing habitual choices. Bogers [2009] conducted a series of laboratory experiments on binary route choice where subjects were provided with post-trip information of the travel time on unchosen routes. Such information might affect habitual choice, as travelers were provided the opportunity to evaluate both their chosen and unchosen alternatives. Kenyon and Lyons [2003] worked with a number of focus groups in the UK on mode choice and found that mode choice was mostly automatic and habitual, based upon subconscious perceptions of the viability and desirability of travel by modes other than the dominant mode. Their results suggested that presentation of a number of modal options for a journey in response to a single enquiry could challenge previous perceptions of the utility of non-car modes, overcoming habitual and psychological barriers to consideration of alternative modes.

Residence and/or employment location choice. The variety of changes brought about by ATIS in the trip-making context could lead people to reconsider their decisions regarding residential and/or employment location. As one example, if more predictable travel times became available from an ATIS, households could move farther away from job locations while still maintaining the same average commute time. Again, rearrangements in daily activity schedules brought about by ATIS could allow more time for outdoor activities, and incite households to take advantage of this by moving. Through these kinds of effect, ATIS could ultimately have an impact on urban form and structure. Boyce [1988], in an early paper, evoked this possibility.

However there is little empirical evidence, largely due to the limited deployment of ATIS. Argioliu [2008] (see also Argioliu et al. [2008]) studied how three ITS-related concepts affect office location choice, namely, automatic car lane, automatic bus lane and people mover from park and ride, which potentially increased the accessibility of office locations. ATIS however was not explicitly studied. Rodriguez et al. [2011] found that in a laboratory experiment, providing multi-modal accessibility information to people who were relocating enhanced the attractiveness of locations that support multiple travel modes.

3.5 Summary of driver response literature

Our review of the driver response literature indicates that the available information tends to be highly specific to particular situations. In the data analysis and modeling efforts, an indicator variable is usually used to represent a specific information system, leading to results that are difficult to generalize. As mentioned before and also discussed in Section 2, there are a large number of information types, and presumably a general model should include an array of ATIS attributes that characterize the information type. To calibrate such a model, however, will require more deployments, more experience with deployed systems, and more research and analysis.

4 Evaluating the effectiveness of ATIS

Owing to their complexity ATIS should be evaluated thoroughly before being implemented. ATIS evaluation can take place either through field tests or in a laboratory. Well-conducted field tests are more likely to reveal the ground truth reliably, since they are based on real-world conditions and actual drivers. However, such tests are generally very expensive and potentially disruptive, restricting the range and scope of strategies that might be evaluated. Public officials and administrators may also be wary of the potential for adverse effects resulting from some or all of the proposed strategies. Laboratory evaluation thus has many advantages, since it can take place in a controlled environment and identify issues before the ATIS is actually deployed. Traffic simulation tools provide unique opportunities for laboratory testing and evaluation,

owing to their rich and flexible modeling capabilities that can capture time-varying travel demand, detailed driver behavior, demand-supply interactions, and network performance. Such flexibility nevertheless comes with the need to ensure that the models are accurate reflections of observed processes and phenomena. Simulation-based ATIS evaluation is therefore conditional on the availability of well-calibrated choice models that faithfully capture individual drivers' response to the range of situations observed in the field. This topic is naturally rather complex, relying on specialized data collection and model estimation methodologies. The reader is referred to Polydoropoulou [1997] and Polydoropoulou and Ben-Akiva [1999] for an in-depth review and treatment of this subject, one that continues to generate significant research interest.

4.1 Evaluating the economic benefits of ATIS

The economic benefits that an ATIS user derives from ATIS services are very closely tied to the user's response to ATIS: they are both aspects of the same internal evaluation and decision-making process. The discussion in Section 3 covered many aspects of ATIS user response, ranging from relatively simple behavioral responses like route switching to complex responses such as re-arranging the daily activity schedule. This range exceeds the gamut of responses conventionally considered in transportation benefit evaluation exercises, which tend to focus on travel cost and time savings, and indicates that considerable care must be taken in thinking about and quantifying ATIS benefits.

For example, travelers' re-arrangement of their daily activity schedules may lead to more rather than less time being spent in travel, as they are able to carry out more activities because of more precise trip planning information. If one were to ask such travelers if they were better off because of ATIS, they would reply affirmatively, even though they spend more time traveling: the benefits that they derive from the additional things they do more than offset the disutility of the time spent traveling.

Because understanding of individual traveler response to ATIS is still relatively primitive, research into the impacts of ATIS tends to focus on network-level effects, using simulation tools that incorporate assumptions about traveler response. The remainder of this section discusses current research in this area.

4.2 Evaluation parameters

ATIS are characterized by a host of models, modeling assumptions, input parameters and design criteria. ATIS evaluation should therefore consider the effects of the associated modeling, design and operational choices.

The surveillance system is characterized by the location, type, and number of sensors in the field. Sensors can also have measurement errors. The

detection and communication of incidents and their severity will also impact the effectiveness of the ATIS. Typically, there may be delays in obtaining and transmitting information about an incident, and uncertainty about its duration. The importance of such design characteristics of the surveillance system can thus be evaluated. The data and guidance communication interfaces between different ATIS entities can be modeled and their performance assessed. Some important aspects include latency in information transmission, and errors in the information.

ATIS design parameters such as the estimation and prediction horizon lengths, the frequency of information updating, and the time resolution of the provided guidance influence ATIS effectiveness. The computational time required to generate predictive guidance depends on the size of the network and the available computational resources (this time also determines the minimum feasible time between information updates). The information generation module may also use a number of models to simulate demand aspects of the transportation system (such as route choice and departure times) and network performance (such as queue formation and dissipation). These models can be imperfect reflections of the ground truth, and the associated modeling errors must be studied and their impact on the effectiveness of the generated guidance assessed.

4.3 Evaluation frameworks

Different frameworks for the evaluation of ATIS are described in Balakrishna et al. [2005]. ATIS can be evaluated either in a (simulation) laboratory or in the real world. A real-world test uses real-time traffic data directly from the surveillance system. In contrast, a laboratory test replaces online communications with either an archived data set of past surveillance observations, or a simulator of the real world surveillance system.

The evaluation can be either without guidance dissemination (open loop) or closed loop. When guidance is not disseminated to any drivers, the evaluation compares estimated and predicted network performance measures (which form the basis for the generation of guidance) with corresponding real-world traffic measurements. When some or all drivers have access to the information generated by the ATIS, the evaluation provides a feedback mechanism for informing equipped drivers of the current guidance strategy and for evaluating the resulting driver response to the disseminated information.

4.3.1 Experimental design

The previous classification results in four possible evaluation approaches:

1. **Laboratory evaluation without ATIS.** Archived surveillance data are used to estimate current network state. State predictions for future time

periods are evaluated through comparisons with the corresponding observations in the archived data set. A simulation laboratory (such as a microscopic traffic simulator) may also be used to compare the predicted network state with the ground truth to establish the benefits of prediction. This step is critical in assessing the appropriateness of the models within the guidance module and could provide valuable feedback for model refinement. Such validation tests with the DynaMIT system have been conducted on networks in Irvine, California [Balakrishna et al., 2004], lower Westchester County, New York [Antoniou et al., 2004], and Hampton Roads, Virginia. Similar studies with DYNASMART have focused on networks in Fort Worth, Texas [Huynh et al., 2003] and Knoxville, Tennessee. Several papers have also addressed the impacts and benefits of variable message signs, high occupancy tolls, and hybrid DTA approaches on network performance [Chiu and Mahmassani, 2002, Doan et al., 1999, Murray et al., 2001].

2. **Laboratory evaluation with ATIS.** A simulation laboratory replaces the real world. Traffic data from the simulated surveillance system are transmitted in real time to the guidance generation system. Prediction-based guidance is delivered to equipped drivers in the microscopic simulator, and network performance measures are computed to ascertain the effectiveness of the guidance. This test helps validate the models that capture route choice and response to information but requires that the simulation laboratory first be calibrated against real data. Laboratory evaluations with the dissemination of guidance are limited. Yang et al. [2000] report on MITSIMLab for the evaluation of ATIS. Mahmassani and Jayakrishnan [1991], Stephanedes et al. [1989] and Jayakrishnan et al. [1994] study simulation-based evaluations of route diversion. Jayakrishnan et al. [2001] provide a brief qualitative discussion on the possibility of coupling the mesoscopic simulator DYNASMART with the microscopic program PARAMICS. In their framework, DYNASMART uses a simplified network abstracted from the PARAMICS model to generate paths. These paths are subsequently input to PARAMICS. Guidance about these paths may be used by PARAMICS drivers, thus allowing for the testing of ATIS.
3. **Real-world evaluations without ATIS.** Traffic data received in real-time from the actual surveillance system in the field are used to perform state estimation, state prediction, and guidance generation. The predicted network state is compared with actual sensor measurements as they become available, to validate the congestion reduction capability of the guidance generation system. This step also involves the testing of the communication interfaces between the surveillance system and the guidance module. Real-world evaluations of DTA-based prediction models, without actually disseminating guidance, have been documented on large-scale networks: DynaMIT has been applied in lower Westchester County, New York; downtown Los Angeles, California; and Hampton Roads, Virginia. DYNASMART has been tried in Houston, Texas. These tests are steps towards real-world, closed-loop ATIS operations in a traffic management center (discussed next).

4. **Real-world evaluations with ATIS.** The feedback loop is closed with real equipped drivers on the network receiving the generated guidance. Limited field tests with guidance dissemination have been reported. Smith and Perez [1992] present the evaluation of INFORM, a traffic management system designed for Long Island, New York. Similar evaluations of ATIS include TravInfo [Miller, 1998] and ADVANCE [Saricks et al., 1997].

Few papers discuss detailed simulation tests designed to objectively assess the quality of route guidance. Some such papers are reviewed next, and their primary results and conclusions summarized.

4.3.2 Select results

Kaysi [Kaysi et al., 1993, 1995] considered ATIS design and identified the importance to system effectiveness not only of accurate real-time traffic information, but also of a predictive capability able to forecast the effects on traffic conditions of drivers reactions to ATIS messages that they receive. Simulation methods were used to investigate the impact on congestion reduction of system design parameters such as message update frequency and routing strategy. He recognized the phenomenon of overreaction, in which a significant number of motorists respond similarly to ATIS messages, and so exacerbate or displace congestion, and showed that it could be reduced through frequent updates or strategies that explicitly attempt to spread traffic over multiple routes.

Emmerink et al. [1995a] provide an early attempt to quantify the network impacts of ATIS under non-recurrent congestion. The paper provides a qualitative discussion on the factors and issues, including expectations about drivers' psychological behavior, that might determine the effectiveness of ATIS. Using a network with a single OD pair and several routes, the authors empirically analyze the effects of ATIS market penetration and information update frequency. The findings illustrate the concept of over-reaction: as more drivers begin to use the ATIS, network benefits increase before tapering off or even worsening (Figure 1).

Figure 1 further indicates that over-reaction at higher ATIS usage levels may be minimized or even eliminated by the providing more frequent information updates, so that drivers may adapt their route choice decisions more closely with the evolving network conditions. A maximum travel time improvement of about 25% is reported.

Levinson [1999] reviews several studies that assess the impact of ATIS on network travel times. His discussion reveals that travel time savings have been found to vary over a wide range, between 2.7% and 55%. Wunderlich et al. [2001] analyze a survey for the Washington, D. C. area, concluding that ATIS improved on-time reliability without a significant reduction of in-vehicle travel time.

Bottom et al. [1999] discuss consistent, anticipatory route guidance in the framework of fixed-point problems and present a detailed analysis of different solution algorithms to tackle the same. The paper evaluates various guidance

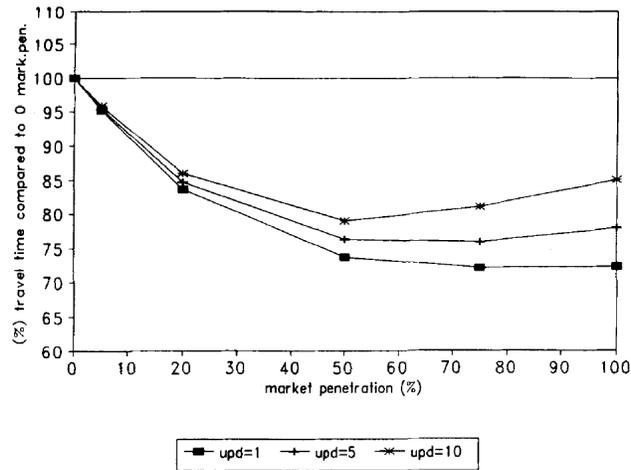


Fig. 1 ATIS Impacts by Usage Level and Update Frequency [Emmerink et al., 1995a]

generation parameters by using a microscopic traffic simulator to reflect real-world drivers and their reactions to guidance generated in a rolling horizon. The study confirmed that shorter guidance recomputation intervals (the time between two successive horizons) led to higher speeds and lower travel times. A similar effect was observed when more frequent updates were initiated within each guidance recomputation interval. It was found, however, that the overall benefits of guidance dissemination reduced on either side of a horizon length of 30 minutes. The authors hypothesize that very short prediction horizons are unable to account for demand patterns that change in the future, while poorer quality forecasts further in the future also somehow reduce the overall quality of the generated guidance.

Balakrishna et al. [2005] analyze the impact of several key ATIS parameters by using an evaluation framework similar to the one in Bottom et al. [1999]. The paper focuses on three aspects: the frequency with which new guidance is disseminated to drivers, the market penetration of ATIS services, and the extent of errors in predicting future demand. DynaMIT, a simulator designed to generate consistent, anticipatory route guidance, was applied to an incident scenario on a freeway network from Boston, Massachusetts. A greater update frequency (or a shorter update interval) was found to significantly decrease travel times (Figure 2(a)). The results also indicate that the marginal benefit of a very high update frequency may not justify the additional computational resources required to support it. The choice of update frequency may thus depend on other factors, such as the computational power available or the desired level of network performance.

Figure 2(b) illustrates the effect of market penetration rates on the effectiveness of ATIS. While the average travel time generally decreases with greater ATIS usage, there is evidence of slight over-reaction with high market penetration. However, over-reaction may be reduced or even eliminated

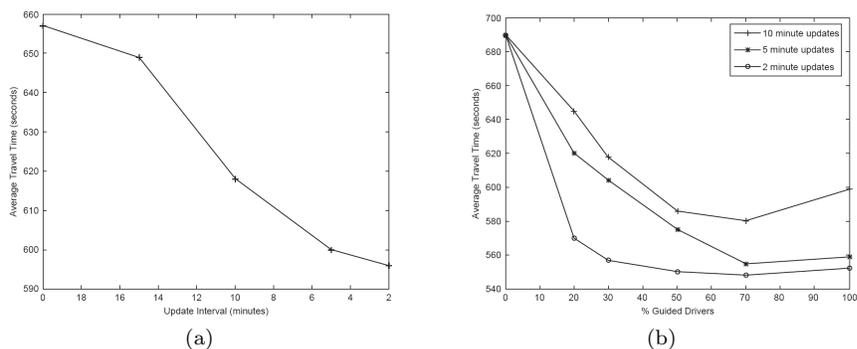


Fig. 2 (a) Impact of Update Frequency (b) Impact of Guidance Penetration.

through more frequent guidance dissemination. Differences between these results and those from previous studies may reflect the impact of the network, demand characteristics, assumptions regarding ATIS design, and the overall structure of the evaluation methodology (which underlines the importance of establishing a simulation-based laboratory for detailed testing).

Prediction-based ATIS must assess the short-term evolution of future demand in order to predict the evolution of network congestion. Demand prediction models adjust historical demand patterns according to recent sensor measurements, usually a two-step process involving state estimation (to match immediately previous time intervals to real-time sensor data) followed by demand prediction that extrapolates these deviations into the future. Balakrishna et al. [2005] study the impact of demand prediction errors on guidance quality. Figure 3 shows that systematically over- or under-predicting network demand results in a deterioration in the benefit of ATIS. Further, it is better to over-predict the demand rather than estimate fewer vehicles for the short-term future.

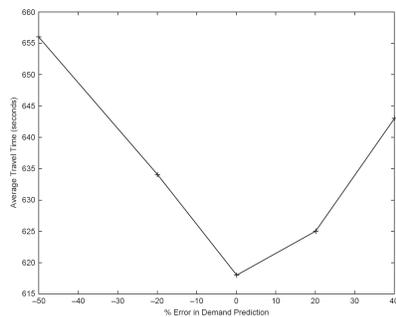


Fig. 3 Impact of Demand Prediction Error

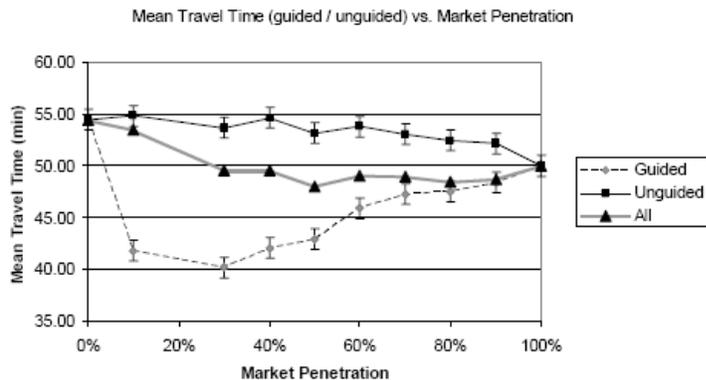


Fig. 4 Guided vs. Unguided Mean Travel Time

Florian et al. [2006] evaluate the impact of ATIS using an incident scenario on a simple network with two route alternatives. The simulation experiments focused on varying levels of guidance penetration. The paper reports that the mean travel times improve only until about 50% guidance penetration. Mean travel times are mostly flat beyond this point, with only a slight degradation in performance. An analysis of the distribution of mean travel times between guided and unguided drivers (Figure 4) indicates that the mean travel time for guided drivers approaches that for unguided drivers at higher levels of ATIS market penetration. Further, DynaMIT guidance is beneficial to both guided and unguided drivers. However, as more guided drivers switch to the alternative path, they impose increasing congestion costs on each other, and must therefore share the benefits. Travel time reliability for guided drivers remained higher (with lower standard deviation) than for unguided drivers.

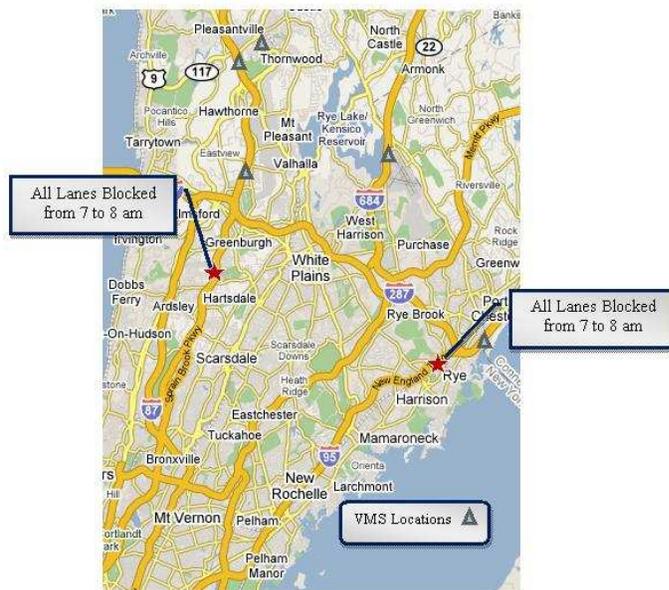
In recent work, Paz and Peeta [Paz and Peeta, 2009a,c] propose a route guidance generation method that integrates both the information provider's network control objectives as well as its real-time estimation of driver response behavior. The model of traveler response to guidance has a fuzzy multinomial logit structure, where the systematic utility component is obtained using aggregate if-then rules. In Paz and Peeta [2009b], the authors describe an on-line approach to calibrate and refine the behavior model based on discrepancies between the dynamic actual and estimated system states. They use simulation experiments of the Borman expressway network in Indiana to test the effectiveness of the proposed approach.

A recent application [Rathi et al., 2008] involves the simulation-based evaluation of predictive route guidance disseminated through variable message signs (VMS) on the Lower Westchester County network in New York state. The paper attempts to reduce network travel times when incidents disrupt highly congested commuter traffic traveling north to south on freeways and parkways. Figure 5 shows the study network and the locations of the incidents that were considered. The two 1-hour incidents were modeled as separate sce-

Table 1 Lower Westchester County: Incident Scenarios and Statistics

Scenario	Mean TT (sec)	Vehicle Hrs	Vehicle Hrs Saved
No Incident	956.4	53533	-
Incident	1532.6	85852	-
VMS - 1 Pred Iter	1261.8	70673	15179
VMS - 2 Pred Iters	1266.2	70920	14932
VMS - 3 Pred Iters	1239.4	69419	16433
VMS - 4 Pred Iters	1246.9	69841	16011
VMS - 5 Pred Iters	1239.9	69451	16401

scenarios to isolate the impacts on the surrounding OD pairs. VMS locations (shown as triangles in the figure) were selected to provide drivers with route switching options upstream of the incidents.

**Fig. 5** Lower Westchester County Network and Incidents [source: Google]

The evaluation was closed-loop - DynaMIT's travel time guidance generated with a prediction horizon of 30 minutes was disseminated to those drivers in MITSIMLab who had access to en-route information. The use of VMS to disseminate guidance had the expected effect of reducing the impact of the incident, indicated by Table 1. Performing three prediction iterations was found to yield the maximum savings in travel time and vehicle hours traveled.

A comparison of trip frequencies by travel time indicated that a significant number of vehicles with lower travel times had shifted to a higher travel time range due to the incident. VMS guidance caused a substantial drop in

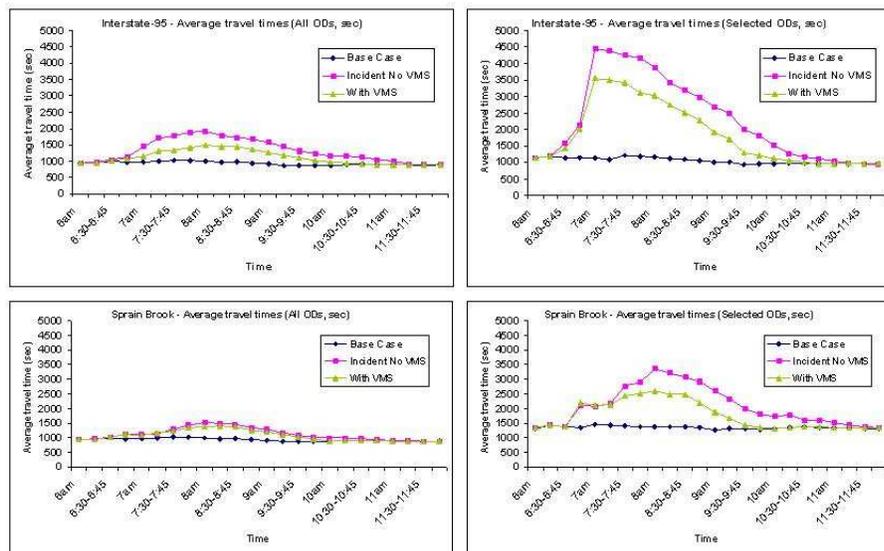


Fig. 6 Lower Westchester County: Results by Departure Time

the number of trips with large travel times. Predictive route guidance significantly decreased the average travel times for those departing in time intervals most affected by the incident (Figure 6). The Lower Westchester County case study thus reinforces the congestion mitigating potential of route guidance on congested, real networks.

4.4 Summary of results

Given that real-world ATIS implementations are bound to be expensive, it is not surprising that the laboratory evaluation of ATIS has drawn considerable research interest. While several papers have focused on determining the network impacts of ATIS, the quantitative benefits are hard to generalize. Contributing factors include case study situations that vary in the ATIS market penetration, network size and topology and demand characteristics, and the type of guidance disseminated. However, the results largely seem to agree on the qualitative aspects of the said benefits, and advocate for predictive information at a suitably high update frequency. Given the speculative nature of the studies thus far encountered, a natural direction for the future is in the rigorous and objective testing of ATIS on real-world networks with a strong focus on collecting detailed behavioral response data to support the various hypotheses, rather than relying on often uncalibrated simulation tools to fill this current gap.

5 Conclusion

This paper undertook a detailed review of three key aspects in the modeling, design, evaluation and deployment of ATIS: (a) models of drivers' behavioral response to ATIS under diverse contexts, (b) ATIS design concepts and parameters, and (c) the mostly simulation-based evaluation of ATIS properties and network performance. Our review illustrates that ATIS research methodologies are largely based on limited field data supported by an assortment of simulation models and outputs. Key limitations of the current state of the art are the lack of substantial RP data about drivers' real-world responses to ATIS, and the rudimentary nature of the choice models embedded in most simulation tools. These two drawbacks in effect reinforce each other, since more complex behavioral models require RP data for calibration and validation.

The future, however, looks promising. Technological advances are lowering the traditional barriers to collecting large volumes of relevant information at the level of individual users of the transportation infrastructure. Rapid adoption of instrumented devices such as GPS navigation units, bluetooth devices and smart phones can help boost sample sizes as well as the accuracy with which driver choices are reported back to the modelers and planners. It is hoped that such rich RP datasets will facilitate the move from simplistic, hypothetical driver response models to realistic, well-calibrated and validated models that may then be integrated into network simulation tools for practical analyses that reflect the ground reality. Such models may include an array of ATIS attributes, each with multiple levels, introducing unprecedented sensitivity and fidelity into the driver response models. A comparison of subsequent results similar to those reviewed in this paper should be highly interesting and instructive.

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