Evaluation of the Potential Benefits of Advanced Traveler Information Systems

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ABSTRACT

This paper evaluates the potential travel time savings from Advanced Traveler Information Systems (ATIS) that provide drivers with travel time and routing information. We classify ATIS in various levels based on the type of information they use to generate guidance and the timing of the dissemination of the generated guidance to drivers. We present a case study that examines the potential travel time savings of ATIS as well as the implications on travel time variability and reliability and the sensitivity of the results to the accuracy of the information, using real-world data collected from a freeway network in Los Angeles, California.

INTRODUCTION

Advanced Travel Information Systems (ATIS) are designed to provide users with information about the state of the transportation network. ATIS include a technological infrastructure that collects data, processes them to generate traveler information and guidance and disseminates the information to users. A wide array of sensor technologies that monitor traffic conditions, such as inductive loops or video cameras are used for data collection. This data are transmitted to a central management center, where it is automatically processed and analyzed to extract the information of interest, which may include not only route guidance and travel times but also details of incidents, weather and road conditions, speed recommendations and lane-use restrictions. The information is then disseminated to users using various media, such as specialized web sites, variable message signs (VMS) or wireless communication directly to in-vehicle navigation systems.

ATIS has the ability to benefit travelers and fleet operations in several different ways. The most direct would be the travel time savings that result from better routing. Improved routing can also translate into reductions in vehicle emissions, fuel consumption, traffic delays and vehicle maintenance costs. For commercial vehicles, the accumulated time savings may be used to increase the allocation of deliveries per vehicle and so improve the efficiency of the fleet utilization and generate additional revenue. ATIS may not only reduce travel times, but also reduce the variability of these travel times by routing vehicles around incidents and other unexpected delays. This can translate to higher travelers' satisfaction with the transportation system and to shorter and more reliable delivery service for commercial vehicles.

In this paper, we define various classes of ATIS based on the type of information they utilize to generate routing and the timing of the dissemination of the guidance to drivers. We then evaluate the potential travel time savings of the various classes of ATIS using real-world traffic data that was collected from a freeway network in Los Angeles, California. This approach differs from most ATIS evaluations reported in the literature, which are either based on field studies or use various modeling approaches. Field studies are by nature limited to the particular setup, capabilities and limitations of the ATIS system that was tested. It is therefore difficult to deduct from the benefits measured in field studies on the potential benefits of the technology in general. On the other hand the results of model-based evaluations greatly depend on assumptions made about drivers' route choices in the absence and in the presence of information. This dependency may explain some of the fantastic estimates in the range of 40-50% reductions in travel times that have been predicted in some studies. Our analysis overcomes both these issues by evaluating the potential benefits of guidance using real-world travel time data rather than modeled ones, but in a general setting that does not incorporate the characteristics of the implementation of a specific system.

The rest of the paper is organized as follows: in the next section we classify route guidance systems according to the type of information they use to generate guidance and the timing of information dissemination. We then review studies that aimed to evaluate the benefits of ATIS. Next, we present the setup of a case study to evaluate ATIS benefits using real-world data, the results of this case study and a sensitivity analysis to the accuracy of the information generated by the ATIS system. We conclude the presentation with a discussion of the results.

CLASSIFICATION OF ROUTING INFORMATION

A quantification of the benefits of ATIS depends on the type and quality of the information provided. In this paper, we focus on route guidance, i.e., the case that users receive and follow routing directions. Route guidance can be classified based on two important characteristics:

1. The nature of the travel time estimates that are used to generate routing and the data that are used as the inputs to the computation of these travel times.
2. The timing that users receive information and the frequency of updates to this information.

Based on the nature of the data and the travel time estimates used to generate guidance, route guidance can be classified in four levels, with increasing sophistication and computational requirements:

1. **Static**: Route guidance is based on static information about the network, such as distances, speed limits and classification of road facility types. Only a geographic database that represents the transportation network and its characteristics is needed to generate this level of information. Route guidance is generated by calculating static shortest paths using the information stored in the database. The guidance provided by such systems does not capture the effects of time-dependent demand patterns and congestion on travel times. This level of information is currently available in some in-vehicle navigation systems, such as Magellan and Garmin and through internet providers of maps and driving direction services, such as Mapquest and Mapblast (Flammia 1999).
2. **Historic**: Route guidance is based on travel times derived from a historical database that represents past traffic conditions. This database is maintained and updated by the information provider. This level requires collection of traffic information from the field and analysis of these data to estimate link travel times. However, these estimations can be done off-line, and so the real-time effort to generate route guidance is limited to retrieving data from the database and using them to calculate dynamic shortest paths. While the information provided at this level captures the average prevailing traffic conditions, it does not capture day-to-day variability that may be caused by fluctuations in demand and by events, such as incidents and maintenance work. This level of information was implemented in AUTOGUIDE (Belcher and Catling 1987) and in UTCS (Stephanedes et al. 1981).
3. **Instantaneous**: Route guidance is based on real-time estimates of current travel times. These estimates are based on traffic information collected in the field. In contrast with historic information, the data analysis is done in real-time, which sets higher computational requirements on the route guidance system. Algorithms to estimate traffic conditions use the real-time traffic measurements to update a-priori estimates of traffic conditions that are based on historic information. The use of historic data is required since it is unrealistic to expect that the real-time information will provide full coverage of the entire network. The information generated by these

systems provides a snapshot of the current conditions in the network and incorporates knowledge of incidents, maintenance work and other on-going events. However, it may be inaccurate for trip planning purposes since travel times are dynamic and so by the time travelers actually traverse the later parts of their paths the travel times they would experience may differ significantly from the information they based their routing decisions on. Traveler information at this level were evaluated in several studies, such as TravTek in Orlando and PathFinder in southern California (MITRE 1995). Implementations, such as SmartTraveler (2005) are available in various metropolitan areas.

4. **Predictive**: Route guidance is based on predictions of future travel times, which are made in real-time. The traffic data collection requirements are similar to those of the historic and instantaneous levels. However, the real-time computation is more elaborate and involves not only estimation of current conditions but also the use of these estimates as inputs to models that predict short-term future traffic conditions. The information provided at this level captures the effect of daily fluctuations in demand and of various planned events (e.g. maintenance work) and those unplanned ones (e.g. incidents) that have been reported by the surveillance system, but of course does not capture the effect of unplanned events that will occur within the prediction horizon. The generation of information may use statistical or data-based algorithms or be model-based. Statistical methods use real-time traffic measurements to update historical information of travel times in future time periods (e.g. Hoffman and Janco 1990, Koutsopoulos and Xu 1993, Liu and Sen 1995). One of the shortcomings of statistical approaches is that they do not incorporate the effect of drivers' response to the information provided on traffic patterns. These effects may be significant when the information penetration rates increase. Model-based approaches can incorporate these effects using complex simulation-based traffic flow and demand models. The difficulty is that these systems require computationally powerful systems and may result in significant computational delays in the provision of the generated information. Several simulation-based traffic prediction systems, such as DYNASMART (Mahmassani et al. 1994) and DynaMIT (Ben-Akiva et al. 2001) have been developed. However, none of these systems has yet been fully implemented in a traffic management center.

With respect to the timing and setup of information provision, users may receive two types of information:

1. **Pre-trip**: route guidance is received only once, at the beginning of the trip. This guidance is not updated during the trip. Thus, it only captures the information available at the time it is requested (presumably, shortly before the trip begins) and does not incorporate the effects of evolving traffic conditions and events (e.g. incidents) that occur during the trip. Pre-trip information may be provided to drivers in several different ways, such as websites and phone services. It does not necessitate tracking vehicles or the use of in-vehicle units.
2. **En-route**: route guidance is also provided during the trip. New guidance is disseminated when it becomes available (e.g. periodically every few minutes when new data have been processed or after reports on new incidents are received and accounted for in the guidance), and so the latest information from the field is

incorporated. En-route information may be provided through various media and communication technologies. The most comprehensive would require two-way communication between the traffic control center and an in-vehicle unit, and the capability to track the location of the vehicle so that new guidance can be tailored to the specific vehicle. With this setup the information may be available everywhere on the network. Other types of information provision systems can be designed with more limited availability and detail, but also lower communication requirements. For example, guidance may be provided through beacons located at the side of the road. Vehicles receive basic information at the beacons and can then calculate their own routing. An advantage of this setup is that it eliminates the need for vehicles to communicate their location to the central system. However, the generic information provided to drivers may not be relevant to their specific trips. The amount of information provided to vehicles and the quality of the routing that the in-vehicle unit calculates based on this information are limited by the capacity of the communication channels and by the computational power available in the vehicle. Furthermore, beacons may not be deployed in all parts of the network, and so information may not be available in some areas. Similarly, information provided through VMS does not require any communication with the vehicle. However, VMS can only provide a limited amount of generic information, which is only available at a limited number of specific locations.

The two dimensions of information can be combined to a conceptual map of the various ATIS possibilities, as shown in Table 1. Within this table, the level of information incorporated into the ATIS, and the related computational effort and equipment requirements become more complex as we move from the upper left corner to the lower right corner. Note that the static and historical levels of information are based on off-line processing of network data in the case of static information and traffic measurements from previous days in the case of historic information. Thus, they do not incorporate any real-time information and so are fully available pre-trip. Therefore, the distinction between pre-trip and en-route information provision does not apply to these levels.

TABLE 1 CLASSIFICATION OF ROUTING INFORMATION

<table>
<tr><td></td><td colspan="4">Nature of Information</td></tr>
<tr><td rowspan="2">Timing of Information</td><td rowspan="2">Static</td><td rowspan="2">Historic</td><td>Instantaneous / Pre-trip</td><td>Predictive / Pre-trip</td></tr>
<tr><td>Instantaneous / En-route</td><td>Predictive / En-route</td></tr>
</table>

ATIS EVALUATIONS

A number of studies have been conducted that evaluated the benefits of ATIS by quantifying the time savings that may be derived from the information. Table 2 summarizes the results of these studies. Most studies were based on various modeling frameworks. These studies can be classified in two groups: those that used analytical traffic assignment models; and those that were conducted with dynamic traffic simulators. Evaluations based on traffic assignment generally assume that drivers who do not receive information (uninformed drivers) select routes in a way that corresponds to a stochastic user equilibrium (SUE) assignment. It is also assumed that the impact of information on recurring traffic conditions is to reduce or completely eliminate travel time perception errors. Therefore, in the presence of information, traffic flows correspond to either SUE with smaller spread parameters or to deterministic user equilibrium for informed drivers. A somewhat different approach was taken by Kanafani and Al-Deek (1991), who assumed that informed drivers are routed according to system optimum assignment. However, this has been shown to be an unrealistic assumption (e.g. Hall 1993). A significant drawback of the traffic assignment approach is that these models cannot capture the impact of ATIS in incident conditions, which may be when ATIS is most useful. Furthermore, the results are very sensitive to the parameters of the model, such as the assumed variability of perceptions of travel times of informed and uninformed drivers. In most studies the values of these parameters were set arbitrarily, which may explain some of the significant variability in the estimated of travel time saving among the various studies. It is therefore not surprising that while all studies demonstrate that ATIS have the potential to reduce travel times, they are inconclusive about the extent of that reduction, with results ranging from 1% to 40% for informed drivers.

TABLE 2 SUMMARY OF STUDIES OF ATIS TIME SAVINGS

Authors	**Remarks**	**Time Saved (%)** Informed / Uninformed / All
Stochastic User Equilibrium		
Levinson (2003)		Up to 30-40 / 20-30 / NA
Lo and Szeto (2002)	Market penetration depends on benefits	All: 4-5.4
Adler et al. (1999)		3-6 / 0-2 / 0-3
Kanafani and Al-Deek (1991)	System optimum guidance	All: up to 4
Koutsopoulos and Lotan (1990)	2 real-world case studies	All: up to 7.1/4.6
Dynamic Simulation – Recurring Congestion		
Wunderlich (1998)	Instantaneous	Recurring / Heavy day Informed: 4-4.9 / 3.2-12.9
Emmerink et al. (1996)	Historic or instantaneous	Historic -12-12 / -4-4 / -7-4 Instantaneous: 0-16 / -1-4 / -1-5
Van Aerde and Rekha (1996)	Instantaneous	7-12 / 0-8 / 0-10
Gardes and May (1993)	Instantaneous	All: 3.7-6.2
Mahmassani and Chen (1991, 1993)	Instantaneous	-15-40 / -20-10 / -20-20

Mahmassani and Jayakrishnan (1991)	Instantaneous	Up to 12 / 3 / 5
Al-Deek et al. (1989)	Instantaneous	Freeway / urban Informed: up to 20-37 / 25-31
Dynamic Simulation – Capacity Reduction (Incidents, Construction)		
Anderson and Souleyrette (2002)	Instantaneous pre-trip or en-route (VMS, HAR)	Pre-trip / en-route All: 0.4-18.3 / up to 19.4
Yang et al. (2000)	Instantaneous or predictive	3-4 / 2-3 / 2-3
Bottom et al. (1999)	Predictive	All: 2.3-20
Wunderlich (1998)	Instantaneous	Informed: 6.9-8.1
Hadj-Alouane et al. (1996)	Historic or instantaneous	Historic: 5.9 / 1.7 / 2.1 Instantaneous: 5.9 / 1.4 / 1.7
Emmerink et al. (1995)	Instantaneous	25-30 / 4-25 / 5-25
Al-Deek and Kanafani (1993)	Pre-trip	All: Up to 25-40
Gardes and May (1993)	Instantaneous	All: 5.3
Field Tests		
Carter et al. (2000)	Incident delay, San Antonio	Informed: 8.1
Schofer et al. (1996)	Instantaneous, ADVANCE	Informed: 0-1.6 compared to historic
Inman et al. (1995)	Yoked driver experiment, Orlando	Informed: 15, similar for instantaneous and historic
Tsuji et al. (1985)	Tokyo	Informed: 11.5
Simulated Experiments		
Abdalla and Abdel-Aty (2004)	Instantaneous pre-trip or en-route	Pre-trip / en-route Informed: 5.3-6.0 / 9.6-12.4
Jung et al. (2002)	HOWLATE simulated yoked experiment	Familiar / unfamiliar drivers Informed: 3.0 / 5.4
Shah et al. (2001, 2003)	HOWLATE simulated yoked experiment	Instantaneous / predictive Informed: 0.3 / 4.8
Vasudevan et al. (2003)	HOWLATE simulated yoked experiment	Informed: 0.1-0.7
Wunderlich et al. (2002)	HOWLATE simulated yoked experiment	Familiar / unfamiliar drivers Informed: 1.0 / 2.2

Studies that use dynamic traffic simulation models typically assume that uninformed drivers select routes based on perceived travel times. These travel time perceptions are derived from past experiences. Informed drivers receive real-time travel time information, update their perceptions and as a result may switch routes. With this approach, the impact of ATIS may be studied both in situations of recurring congestion and in the presence of incidents and other events that reduce capacity. Most of these studies only evaluated the case of instantaneous travel time information, which is available both pre-trip and en-route. Emmerink et al. (1996) also analyzed the case that drivers receive pre-trip historic travel times that are result of the collective experiences of all drivers on the previous day. They found that using this historic information may result in negative benefits. In another study that evaluated both historic and instantaneous information, Hadj-Alouane et al. (1996) did not find significant differences between the two information levels. Similarly, Yang et al. (2000) who compared the benefits of instantaneous and predictive information did not find significant differences between the two. Bottom et al. (1999) evaluated predictive information. While they did not study other types of information, the travel time savings they reported are well within the range of values found in other studies for instantaneous information.

Many of the studies listed use small test networks, which may produce unrealistic results. Furthermore, the choice of modeling parameters (e.g. route choice behavior of uninformed drivers), properties of the network and scenarios to be studied (e.g. locations and severity of incidents, demand levels, market penetration of ATIS) can significantly affect the evaluation results. Thus, while these studies provide valuable insight to the mechanisms that govern the travel time savings, they do not present realistic estimates of the extent of these savings.

More reliable estimates of the benefits of ATIS also require empirical studies of real-world data, rather than model-based experiments, in order to eliminate the effect of the modeling assumptions and to incorporate the impact of various factors that occur daily and significantly affect traffic flow, but are often ignored in traffic models, such as minor incidents and interruptions. A number of field experiments have been conducted for this purpose. These studies are mostly based on yoked driving experiments, in which pairs of drivers are instructed to travel from the same origin to the same destination, departing at the same time. One of the drivers in each pair receives travel information or guidance, while the other does not. These studies report travel times savings of up to 15% for drivers with access to information. Two of the studies, Schofer et al. (1996) and Inman et al. (1995), compared the benefits from historic and instantaneous information. Both studies did not find significant differences between the two information levels, which is consistent with the results of the simulation studies that addressed this question.

While field studies provide the most direct evaluation of ATIS benefits, they involve significant costs. As a result, the studies that have been conducted are limited to small sample sizes of trips. These trips are often relatively short, and so may exhibit only a limited number of viable alternative routes (Wunderlich et al. 2001). Furthermore, the results of field studies heavily depend on the capabilities and limitations of the specific guidance system being used. Therefore, they do not necessarily indicate on the potential benefits of the technology in general. Several researchers conducted simulated experiments in order to overcome these difficulties. Abdalla and Abdelhai (2004) designed a computer-based experiment in which participants were asked to route simulated vehicles along the links of a map representation of a familiar real-world road network. Participant that received information were able to reduce their travel times compared to the no information case. The travel time savings were roughly doubled when information was received en-route compared to the case of pre-trip information only. A different approach was adopted in several simulated yoked driver experiments conducted using the HOWLATE system (Wunderlich et al. 2001). This system generates simulated yoked trips. It assumes that simulated drivers try to complete their trips at a target arrival time, and that they can change their departure times and route choices to avoid early or late arrivals. Information is provided pre-trip only using a database of link travel times.

Realized travel times for the simulated yoked trips are randomly drawn from the distribution of travel times in the database. The system was applied to simulate trips in various metropolitan areas. It yielded significant reductions in schedule delays, but only minor travel time reductions of 1% or less for familiar drivers. However, since these studies are based on the assumption that drivers minimize their schedule delay and not their travel times these results are not directly comparable with other studies. Furthermore, the evaluation results depend on assumptions made about the error in the information provided to drivers and about the departure time and route choices of both informed and un-informed drivers (i.e. their habitual routes).

The evaluation approach we adopt in this paper, which is described in further detail in the next section, is similar to that of HOWLATE in that we also use a database of travel times collected from a real network to simulate yoked trips. However, there are also several important differences between the two. As noted above HOWLATE is based on the notion of target arrival times. This assumption is suitable for some but not all drivers and trip purposes. Lappin et al. (2000) found that only about a third of current users of web-based ATIS services do so in order to be able to arrive on-time. The application of on-time arrival behavior requires additional assumptions about the arrival time windows and the dis-utilities of early or late arrivals. These assumptions may introduce unnecessarily additional modeling error that can impact the evaluation results. We adopt the more common approach of measuring travel times of the various trips. In addition, we consider both pre-trip and en-route information and evaluate all levels of information discussed above. Finally, we note that results obtained when comparing the travel times of informed drivers against those of uninformed ones strongly depend on the assumptions about the behavior of the latter (Mahmassani and Chen 1991). In order to avoid this dependency we compare the benefits from various information levels against the naïve static information level and not against uninformed drivers.

CASE STUDY

The objective of this study is to quantify the potential impact of the various levels of information provided by ATIS on travel times. Using real-world traffic data, we evaluate and compare the time savings that may be derived from different levels of information. The data were collected from the Los Angeles highway system, shown in Figure 1 . The graph representation of this network includes 51 nodes and 162 links. The Los Angeles Department of Transportation maintains an extensive network of inductive loop detectors, which are located every half a mile along the major highways shown in the figure. Using the measurements from these sensors, time-dependent link travel times on each link in the network at 5-minute intervals are calculated (see Chen 2003 for details). Travel time data collected on five days during January 2004 were used in the evaluation. There were no major incidents reported in the network on these days. Several minor incidents were recorded at various locations in each of the days. Such incidents are a regular occurrence in this network. However, only general descriptions of these incidents were available, without specific details about their locations and durations.

The evaluation was conducted as follows: First, the origins, destinations and departure times of the simulated trips were selected. 20 origin-destination (OD) pairs with at least two viable paths connecting each were used in the evaluation. Origins and destination nodes were chosen among the nodes at the boundaries of the network. The OD pairs were selected such that the generated trips would pass through different parts of the network. The evaluation period included two 3-hour peak periods: 7-10AM and 4-7PM. A total of 200 trips were generated for each information level. The travel times recorded in the database were used as the "true" travel times that would have been experienced in the network by drivers making these hypothetical trips. We then evaluated five different levels of information that correspond to the classification of routing information that was presented above. For each one of the trips that were generated and for each one of the information levels, the route that would have been recommended by the guidance system was calculated. The recommended route in each case is the shortest travel time route based on the travel time information that is available at that level. For each of the recommended routes the "true" travel times that would have been experienced on that route were calculated. The estimation of the travel time savings at each level was based on the comparison of these experienced travel time.

The five information levels that were considered, the travel time information available at each level and the algorithm for the calculation of the recommended routes are summarized in Table 3. The shortest path calculations mentioned in the table were made using the Dijkstra algorithm (Dijkstra 1959) in the static case and the DOT algorithm (Chabini 1998) in the dynamic case.

An important assumption underlying our evaluation is that the response to information does not affect traffic conditions. This assumption holds if the market penetration of ATIS is small and so the number of drivers that change their routes in response to the information is negligible. As the market penetration of information provision services increases this will no longer be a realistic assumption. The information drivers receive would affect the route choices of significant numbers of drivers. As a result, traffic flows and travel times on the network would be affected. Several of the studies listed in the previous section investigated the impact of the market penetration of information on travel time savings. At the level of the individual informed driver, the travel time savings generally decrease when the market penetration increases (e.g. Emmerink et al. 1995, 1996).

We further assume that the information provided in all cases is error-free, given the level of data available. For example, in the case of instantaneous information, drivers receive a complete and accurate account of the current travel times on all the links in the network (but have no knowledge of travel times in future time periods). This assumption is clearly an idealization of any traffic surveillance and route guidance system. However, it is useful in benchmarking the potential travel time savings that may be obtained using route guidance. In our analysis we also investigate the impact of relaxing this assumption and introduce a random error term in the travel time information. In the case of error-free predictive information, there is no need to update the information provided to drivers pre-trip and so there is no difference between pre-trip and en-route information. In the evaluation we therefore consider predictive information as a single category.

Put together the assumptions that the information is error-free and that drivers' response to it has no impact on traffic flow imply that our results should be interpreted as a potential upper bound on the travel time savings that individual drivers may obtain from the various information levels.

FIGURE 1 THE LOS ANGELES HIGHWAY SYSTEM

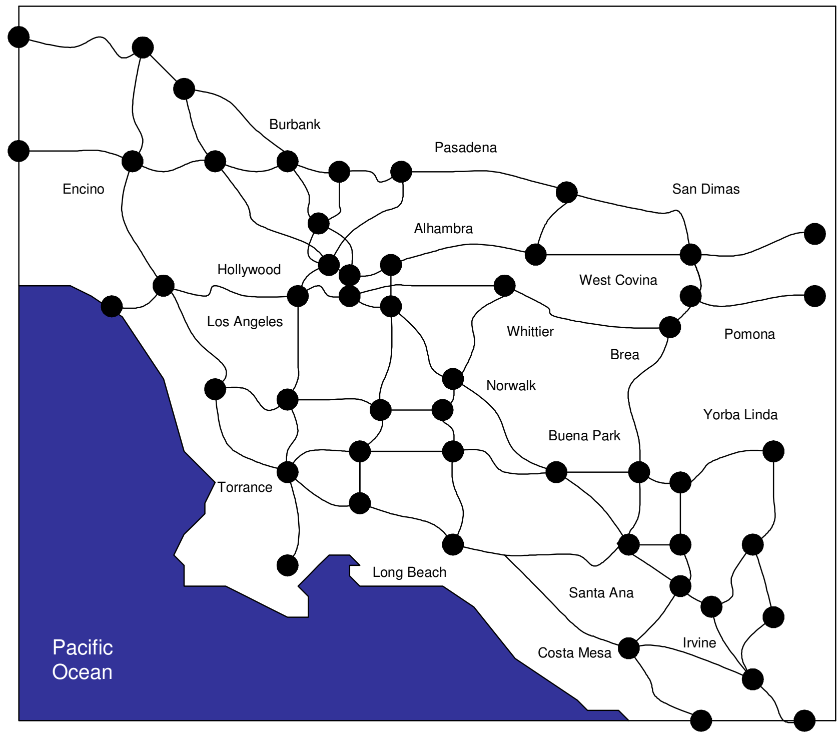

TABLE 3 INFORMATION LEVELS, TRAVEL TIMES AND ROUTING

Information Level	Travel Time Information	Routing
Static	Calculated as the length of a link divided by the speed limit.	Static shortest path from origin to destination based on the provided travel times.
Historical	Time-dependent travel times from the previous day.	Dynamic shortest path from origin to destination based on the provided time-dependent travel times.
Instantaneous / Pre-trip	Travel times from the current time interval.	Static shortest path from origin to destination based on the current travel times at the departure time.
Instantaneous / En-route	Travel times from the current time interval. Provided at every decision point (node) on the route.	Static shortest path from current location to destination based on the current travel times. This path is re-evaluated at every decision point (node).
Predictive	Time-dependent “true” travel times.	Dynamic shortest path from origin to destination based on the provided “true” time-dependent travel times.

RESULTS

Travel Times

The travel times for the AM peak trips, PM peak trips and all trips for the various levels of information are shown in Table 4. The reported travel times in this table and subsequent ones are the averages of all the trips that were simulated over all five days and all the 20 OD pairs that were analyzed. Travel time savings in comparison to the static information level are also shown. Recall that the static information represents current practice in many in-vehicle route guidance services.

The results indicate that ATIS offer potential travel time savings of up to 14% compared to static information. These numbers are well within the range of results reported in the literature. However, the high-end time savings of up to 40-50% that are reported in several of the studies presented in Table 2 are not supported by our results. The results are also consistent with the hierarchy of the information levels. Time savings increase with the sophistication of the information provided. They are also generally larger for the PM peak, which is more congested. Historical information seems to not offer significant time savings over the static information. However, this may be an underestimate of the travel time savings from this level of information. Historic information was modeled using travel times from the previous day. A more robust routing policy that uses information from a time-series of data over a longer period may smooth out non-recurring events and improve the quality of guidance. It is also important to note that under the assumption of perfect information, the predictive routing correspond to the actual optimal travel time routes (i.e. drivers on these routes actually experience the shortest travel times). Therefore the travel times savings obtained for this information level provide an upper bound on any potential ATIS travel times savings.

TABLE 4 AVERAGE TRAVEL TIMES FOR DIFFERENT INFORMATION LEVELS

	AM peak		**PM peak**		**All Trips**	
Information Level	**Travel Time (min.)**	**Savings (%)**	**Travel Time (min.)**	**Savings (%)**	**Travel Time (min.)**	**Savings (%)**
Static	75.6	-	88.4	-	82.0	-
Historical	74.9	0.8	87.0	1.6	80.9	1.3
Instantaneous / Pre-trip	71.3	5.6	83.6	5.5	77.4	5.5
Instantaneous / En-route	70.0	7.3	79.0	10.7	74.5	9.1
Predictive	68.4	9.5	76.2	13.8	72.3	11.8

Travel Time Variability

Travel time savings may not be the only desirable property of ATIS. Another important goal is to reduce the variability of travel times. In fact most studies in this area (e.g. Jackson and Jucker 1981, Senna 1994, Small et al. 1999, Bates et al. 2001, Liu et al.

2004) show that on average travelers value a reduction in the travel time variability by 10-50% or even higher more than a comparable reduction in the mean travel time. For commercial companies, reduced travel time variability translates to higher efficiency of the fleet operations by shortening the lead times that are required in order to guarantee satisfying customer service thresholds.

Travel times on the various OD pairs are not comparable and therefore we used the coefficients of variation (COV) of travel times for each OD pair, rather than the standard deviation itself, to measure the travel time variability with the various information levels. The COV are given by:

$$COV_i = \frac{s_i}{tt_i} \quad (1)$$

tt_i and s_i are the average and the standard deviation of the travel times for drivers following the route guidance on OD pair *i*, over the 5 days, respectively.

Table 5 reports the average values of COV over all OD pairs for the various information levels. The reduction in travel time variability in comparison to the static information is also shown. In percentage terms, the various ATIS levels significantly reduce travel time variability compared to the static information, much more than they reduce the average travel times. As with travel times, the impact of information increases with the sophistication of the information provided and is larger for the more congested PM peak period.

TABLE 5 TRAVEL TIME VARIABILITY FOR DIFFERENT INFORMATION

LEVELS

Information Level	AM peak		PM peak		Overall	
	COV of Travel Time	Reduction (%)	COV of Travel Time	Reduction (%)	COV of Travel Time	Reduction (%)
Static	0.126	-	0.228	-	0.177	-
Historical	0.110	12.9	0.182	20.5	0.146	17.8
Instantaneous / Pre-trip	0.109	13.4	0.140	38.5	0.125	29.5
Instantaneous / En-route	0.093	26.5	0.127	44.2	0.110	37.9
Predictive	0.072	42.7	0.117	48.9	0.095	46.7

Information Reliability

There may be cases where drivers who act on the information they receive end up worse off. In order to be accepted by users, an ATIS service must be reliable enough that travel time increases do not occur frequently, and that when they do occur, their magnitude is not significant. Table 6 presents the fractions of trips that the guidance led to an increase in the travel time and the worst-case trips, i.e., the trips with the highest increase in travel times, both in terms of absolute travel times and in terms of percentage of the trip travel time. In all cases the comparison is against the static information level.

The results demonstrate that in general the information reliability improves with the sophistication of the methods used. However, this is not always the case for individual trips. For example, en-route instantaneous guidance outperforms but does not dominate the pre-trip only alternative. This result is expected given the dynamic changes in travel times that cannot be anticipated by instantaneous information. The study network includes many long sections with significant travel times. This means that drivers may not be able to switch from their previously selected routes for some time even if new information that prompts them to do that is available en-route. Note that travel times are based on perfect information for each level. This explains the zero entries for the predictive information level, which correspond to the realized best routes and so cannot be improved upon. However, with the other levels, significant fractions of trips are experiencing longer travel times, with significant worst-case travel time increases. Furthermore, the worst-case trips are in most cases not the same ones across information levels. This result may suggest that the reliability of information can be improved if guidance is provided based on a combination of the travel time estimates using various types of information (static, historic, instantaneous and predictive). For example, guidance provided based only on instantaneous travel times may over-estimate the impact on travel times due to minor incidents. These incidents may considerably affect current travel times but may not have a significant impact on travel times in subsequent time periods. Combining the instantaneous travel times with historic information may reduce the over-estimation in such cases.

TABLE 6 DIS-BENEFITS FOR DIFFERENT INFORMATION LEVELS

Information Level	**AM peak**		**PM peak**		**Overall**	
	Fraction of Trips (%)	**Worst-case Trip (min.)/(%)**	**Fraction of Trips (%)**	**Worst-case Trip (min.)/(%)**	**Fraction of Trips (%)**	**Worst-case Trip (min.)/(%)**
Historical	22.5	12 / 19.4	27.5	61 / 141.9	25.0	61 / 141.9
Instantaneous / Pre-trip	11.0	11 / 22.4	18.0	38 / 44.1	14.5	38 / 44.1
Instantaneous / En-route	15.0	28 / 22.4	8.0	13 / 22.0	11.5	28 / 22.4
Predictive	0	0 / 0	0	0 / 0	0	0 / 0

SENSITIVITY ANALYSIS

So far we have assumed that the only source of error in the guidance is that the information available at various levels is incomplete (e.g. no real-time information with historic data). This clearly does not hold in reality, since the available data (e.g. real-time traffic measurements) and the guidance generation from these data (e.g. traffic prediction) will also add errors. It is therefore important to relax this assumption and study the impact of the accuracy of the guidance on the results.

To study the sensitivity of the results to the accuracy of the information, we introduce random errors into the travel time information that is used to route drivers.

Thus, the travel times that the route guidance is based on, for each information level, are given by:

$$\widehat{tt_{im}} = tt_{im} + \varepsilon_{im} \qquad (2)$$

$\widehat{tt_{im}}$ and tt_{im} are the travel times on link i that are provided as information and the true values of these travel times for information level m, respectively. ε_{im} is the corresponding error term, which is assumed to be normally distributed with a zero mean and 5% coefficient of variation:

$$\varepsilon_{im} \sim N\left(0, 0.05tt_{im}\right) \qquad (3)$$

We used random draws from the distributions of errors to generate realizations of the travel time information for each link in the network and calculated the route guidance based on these travel times. Table 7, Table 8 and Table 9 summarize the results of the sensitivity analysis with respect to travel time savings, the variability of travel time and the information reliability, respectively. As expected, travel time savings are consistently smaller compared to those reported in Table 4 for error-free information. The inaccuracy in information seems to affect travel times in all information levels similarly and on average reduces travel time savings by 0.5%, which corresponds to a rate of 0.1% time savings loss for every 1% error in the information. The results related to the variability of travel times were also similar to those observed with error-free information. The variability of travel times decreased with the sophistication of the information being used to generate routing. Furthermore, contrary to our a-priori expectations, the error in the information did not have a significant impact on variation of travel times, which remained in most cases roughly equal to that of the travel times that were realized with guidance based on perfect information. Finally, the results of the worst-case performance of the guidance also maintained the hierarchy of the information levels. The fraction of trips in which followings the route guidance resulted in longer travel times compared to the base case decreased with the information levels. This trend is similar to the results of the error-free information. However, in absolute terms, a higher fraction of trips experienced dis-benefits and the worst-case trips were slightly longer compared to the case of error-free information.

TABLE 7 AVERAGE TRAVEL TIMES FOR DIFFERENT INFORMATION LEVELS

WITH 5% ERROR

Information Level	**AM peak**		**PM peak**		**All Trips**	
	Travel Time (min.)	**Savings (%)**	**Travel Time (min.)**	**Savings (%)**	**Travel Time (min.)**	**Savings (%)**
Static	75.6	-	88.4	-	82.0	-
Historical	75.6	-0.1	87.4	1.1	81.5	0.6
Instantaneous / Pre-trip	71.8	5.0	82.9	6.3	77.3	5.7
Instantaneous / En-route	70.5	6.7	79.7	9.9	75.1	8.4

Predictive	68.5	9.3	76.7	13.2	72.6	11.4

TABLE 8 TRAVEL TIME VARIABILITY FOR DIFFERENT INFORMATION LEVELS WITH 5% ERROR

Information Level	**AM peak**		**PM peak**		**Overall**	
	COV of Travel Time	**Reduction (%)**	**COV of Travel Time**	**Reduction (%)**	**COV of Travel Time**	**Reduction (%)**
Static	0.126	-	0.228	-	0.177	-
Historical	0.122	3.7	0.142	37.7	0.132	25.6
Instantaneous / Pre-trip	0.108	14.5	0.140	38.7	0.124	30.1
Instantaneous / En-route	0.094	25.5	0.135	40.8	0.115	35.3
Predictive	0.074	41.2	0.121	46.9	0.098	44.9

TABLE 9 DIS-BENEFITS FOR DIFFERENT INFORMATION LEVELS WITH 5% ERROR

Information Level	**AM peak**		**PM peak**		**Overall**	
	Fraction of Trips (%)	**Worst-case Trip (min.)/(%)**	**Fraction of Trips (%)**	**Worst-case Trip (min.)/(%)**	**Fraction of Trips (%)**	**Worst-case Trip (min.)/(%)**
Historical	27.9	22 / 35.4	31.3	61 / 141.9	29.6	61 / 141.9
Instantaneous / Pre-trip	16.7	11 / 32.8	19.7	32 / 32.9	18.2	32 / 32.9
Instantaneous / En-route	18.0	33 / 27.7	8.3	17 / 25.7	13.2	33 / 27.7
Predictive	3.3	5 / 8.2	0.7	1 / 3.5	2.0	5 / 8.2

CONCLUSION

In this paper we evaluated the potential benefits of route guidance generated by ATIS. We used real-world data from Los Angeles, California to evaluate guidance that is based on different types of information with increasing levels of sophistication and complexity. The case study results show that ATIS-based routing may lead to travel times saving of up to 14%. It may also reduce the travel time variability by up to 50%, depending on the type of information. Reductions in both travel times and travel time variability are generally higher for the more congested PM peak period compared to the

AM peak period. The results suggest that implementation of ATIS can lead to significant economic benefits to individuals, commercial fleet operations and society as a whole.

The potential benefits of route guidance, especially in terms of travel time variability, increase with the sophistication of the methods used to estimate the travel time information. However, these benefits are not without a cost. In particular, the cost of providing en-route information may be higher compared to pre-trip information. In the most comprehensive form en-route information provision requires two-way communication between the traffic control center and an in-vehicle unit, and the capability to track the location of the vehicle. More limited communication can also be used, but would also result in more limited access to new information in terms of spatial and temporal availability as well as the level of detail. Furthermore, there may be cases that the route guidance is counter productive. We found that up to 25% of trips may take longer if drivers act on the information they receive. These numbers decrease with the sophistication of the information generation methods. Further research is needed in order to test whether and how the robustness of the information could be improved if guidance was based on travel time information that combines the various sources, such as static, historic and real-time.

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