FINAL REPORT

On-Time Reliability Impacts of Advanced Traveler Information Services (ATIS):

Washington, DC Case Study

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Dr. Karl E. Wunderlich
Matthew H. Hardy
James J. Larkin
Vaishali P. Shah

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MITRETEK SYSTEMS

McLean, Virginia

ABSTRACT

Internet-based Advanced Traveler Information Services (ATIS) provide the urban traveler with estimated travel times based on current roadway congestion. Survey research indicates that the vast majority of current ATIS users are satisfied consumers who feel they save time by utilizing these services on a regular basis. However, in numerous field experiments and simulation studies, ATIS users experience little or no actual reduction in their in-vehicle travel time. This report describes an innovative analytical method (the simulated yoked study), which applies dynamic programming techniques to archives of observed roadway congestion to quantify the impact of regular ATIS utilization by urban commuters. A simulated yoked study comprises efficient modeling of paired driving trials between travelers with or without ATIS, conducted across regional urban networks and over months or years of archived data. In-vehicle travel time, as well as on-time reliability measures, are tracked for each simulated yoked trial participant. Using results from a large-scale case study in the Washington, DC area we show that even though over time ATIS users realize only marginally reduced in-vehicle travel time, they do realize substantial time management benefits from improved on-time reliability and trip predictability.

KEYWORDS: Intelligent Transportation Systems, Federal Highway Administration, benefits, modeling, simulation, HOWLATE, Advanced Traveler Information Systems, travel time, on-time reliability, variability, simulated yoked trials.

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EXECUTIVE SUMMARY

Initiatives to evaluate the impact of Advanced Traveler Information Services (ATIS) over the last ten years have returned what appears to be contradictory results with respect to the time savings of ATIS users: large *perceived* time savings reported by users but marginal to no *observed* in-vehicle travel time savings when measured empirically in field operational tests. This report describes a new methodology developed by Mitretek Systems at the request of the Intelligent Transportation Systems (ITS) Joint Program Office (JPO) of the U.S. Department of Transportation (USDOT) to quantify time savings and other benefits that travelers can expect by incorporating ATIS into their daily commutes.

To this end, Mitretek has developed a process called HOWLATE (Heuristic On-line Web-Linked Arrival Time Estimator) that applies dynamic programming techniques to archived observed roadway travel times data to quantify the impact of regular ATIS utilization by urban commuters. HOWLATE entails the construction of synthetic, retrospective paired driving trials between travelers with and without ATIS, conducted across regional urban networks and over months or years of archived data. In-vehicle travel time and on-time reliability measures are tracked for each paired driving trial participant. Using results from a large-scale case study in the Washington, DC area this report shows that even though ATIS users realize only marginally reduced in-vehicle travel time, they do realize more effective time management as well as improved on-time reliability and trip predictability.

Approach

In order to quantify reliability-related benefits of incorporating ATIS use into a traveler's regular commuting pattern, the HOWLATE method developed by Mitretek Systems utilizes the concept of a *simulated yoked trial*. This new analytical technique entails the efficient reconstruction of millions of hypothetical paired driving trials using archives of roadway travel times. The regional roadway travel time archive is compiled in an automated process that polls a traveler information service provider's website every five minutes and records the estimated link travel times. These archives provide not only estimates of what roadway segment travel times were during the period studied but a record of what was known about current congestion conditions at the time any trip across the region was initiated on any particular day.

ATIS Non-User: Travel Times Based on Past Experience

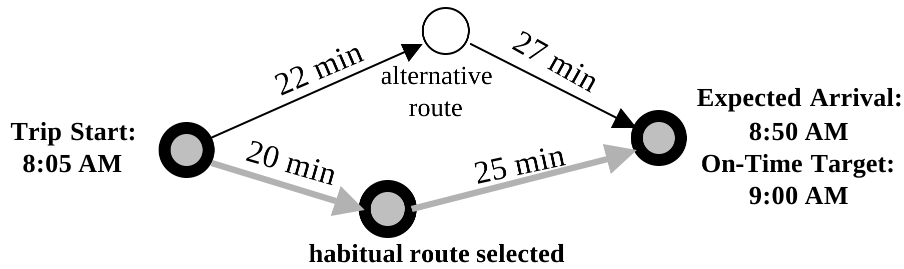

Figure ES-1. ATIS Non-User Route Choice and Trip Timing

ATIS User: Reported Travel Times at 8:00 AM

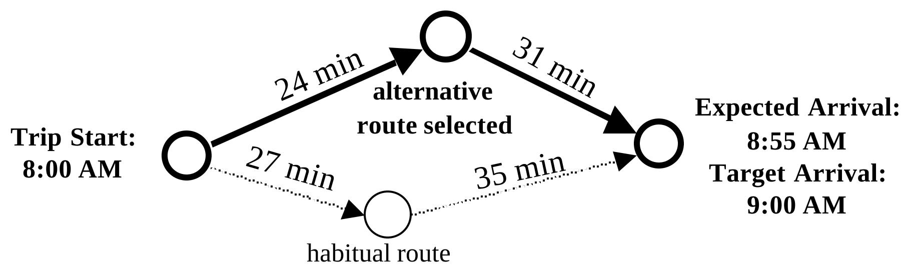

Figure ES-2. ATIS User Route Choice and Trip Timing

A simulated yoked trial consists of two steps. In the first step, traveler path and time of departure choices are established for two travelers: one who utilizes ATIS and one who does not utilize ATIS but relies on prior experience in the network. In the second step, travel times and on-time performance for each traveler are reconstructed based on the trip timing and routes chosen in the first step.

Figure ES-1 illustrates how non-user route choice and trip timing are determined. Based on experience, the non-user has estimates of average link travel times during the commute period and selects the fastest option as the habitual route. The non-user then budgets in additional time to account for expected day-to-day travel time variability to establish a habitual trip start time.

Figure ES-2 illustrates how ATIS user route choice and trip timing are determined. The ATIS user relies on the real-time estimates of travel time provided by the traveler information service provider rather than on past experience. Unlike the non-user, the ATIS users can adapt their trip timing and route choice on a daily basis. Consider a day in which higher-than-average travel times are forecast, particularly for the habitual route. The ATIS user, based on estimates provided at 8:00 AM, makes a decision to leave immediately and travel on the alternative route.

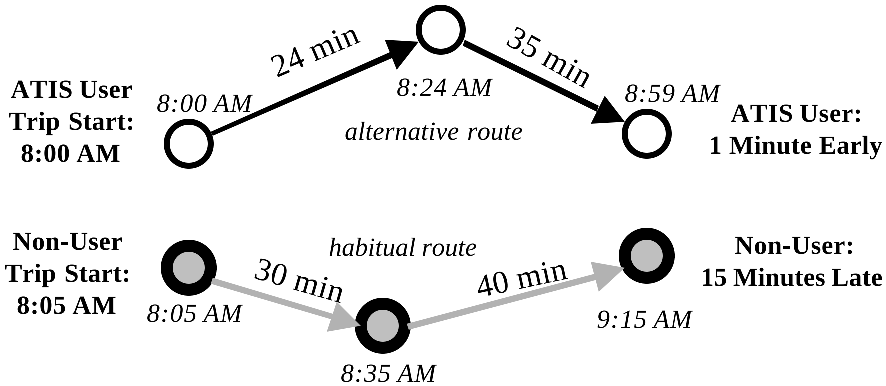

Figure ES-3. Reconstruction of ATIS User, Non-User Travel Experiences

With trip timing and route choice established for both the ATIS user and the non-user, the next step is to reconstruct what those choices implied in terms of travel time and on-time reliability for this particular slightly worse than normal day (Figure ES-3). The reconstruction is based on the travel time archive plus a random component based on the statistical accuracy of the ATIS travel link travel time estimates measured against travel times measured in field trials. In our sample day, congestion worsens over the hour between 8:00 – 9:00 AM. Based on a 8:00 AM start on the alternative route, the ATIS user is determined to have arrived at the destination at 8:59, one minute before the on-time arrival target. Note that the trip has taken four minutes longer than the ATIS user's pre-trip expectation because congestion has worsened over the course of the trip. The non-user, unaware that congestion is worse than normal, remains on the habitual route starting at 8:05 AM and arrives at the destination 15 minutes later than the target arrival time.

A critical conceptual difference between the simulated yoked study and previous ATIS field evaluations is that the paired trials are organized around the principle of *destination and target time of arrival* rather than on *simultaneous release from trip origin*. This implies that pairs of travelers (ATIS users and non-users) are yoked pairs in the sense that they both make regular trips at the same times of day with a fixed target time of arrival at the same destination. In the previous yoked driver experiments conducted as field tests, trip starts between control and experimental vehicles are essentially simultaneous. The use of target arrival times allows for *quantifiable reliability measures* to be defined and tracked along with in-vehicle travel time: on-time reliability, lateness risk, early schedule delay (time wasted by arriving too early), and late schedule delay (total accumulated lateness). Moreover, we can track traveler pre-trip expectation (e.g., knowing a late arrival is likely) versus performance, a measure of trip predictability.

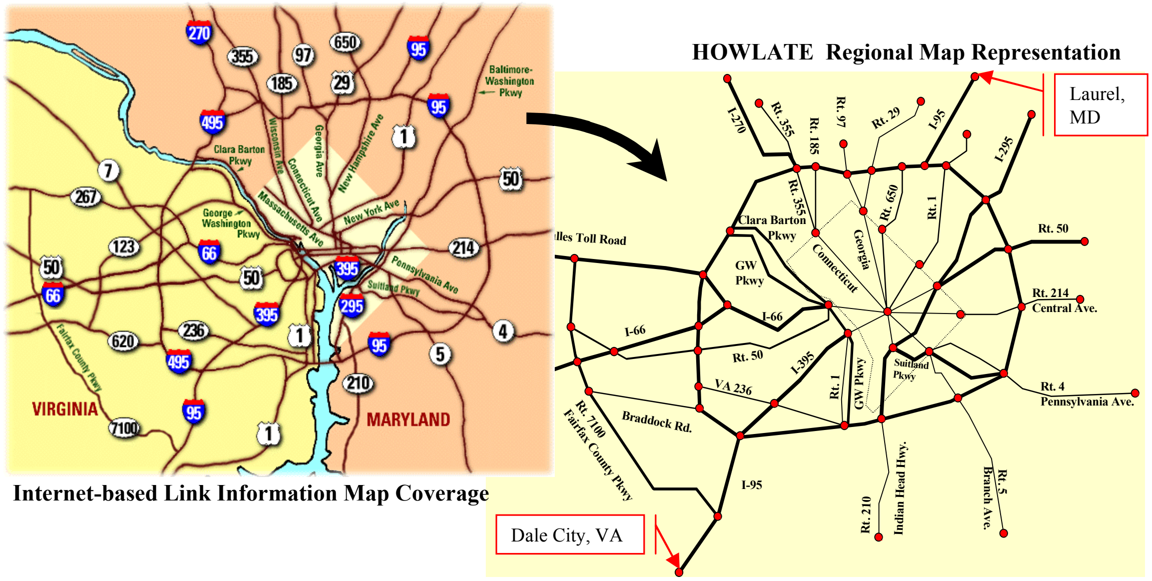

Figure ES-4. Washington DC Area Case Study Network

Washington DC Case Study

The network used for the Washington DC HOWLATE case study was based on the facilities covered by the SmarTraveler service (left half of Figure ES-4). Travel times are reported on a range of roadways throughout the region, spanning over 1200 square miles. The links covered by SmarTraveler were transformed into a more detailed representation for use in HOWLATE. The transformed network (right half of Figure ES-4) features 55 nodes, each of which represent a potential trip origin or trip destination; and 169 links, most of which correspond to freeway, expressway, and major arterial facilities within the region. Travel times were archived for 18 weekdays in August 1999 and 21 weekdays in September 1999. These daily profiles include the reported SmarTraveler travel times in the regional network at five-minute intervals from 6:30 AM to 6:30 PM. The August data was used to establish the habitual routes and trip start times of ATIS non-user, while on-time performance was evaluated using the September data.

Simulated yoked studies were conducted with ATIS users and two types of ATIS non-users, with target times of arrival at 15-minute intervals between 6:30 AM-6:30 PM. The first ATIS non-user type is considered *conservative* with respect to on-time reliability and chooses habitual time of trip start with a large additional time buffer to account for expected trip time variability. The second ATIS non-user type is more *aggressive*, and chooses a later habitual time of trip start. *Optimal* performance is also determined by finding the route and departure time (assuming perfect hindsight) that would have resulted in precise on-time arrival on the fastest possible route.

Results

Commuter	On-Time Reliability	Lateness Risk	Early Schedule Delay (ESD) Average Monthly ESD	Early Schedule Delay (ESD) Maximum Observed ESD	Late Schedule Delay (LSD) Average Monthly LSD	Late Schedule Delay (LSD) Maximum Observed LSD	In-Vehicle Travel Time	Trip Distance
Conservative Non-User	90%	10%	2.8 hours	43 min	13 min	28 min	62.1 min	80.8 km
Aggressive Non-User	78%	22%	1.4 hours	29 min	36 min	43 min	63.1 min	80.8 km
ATIS User	92%	8%	1.6 hours	32 min	7 min	19 min	62.2 min	81.2 km
Optimal Performance	100%	0%	0 min	0 min	0 min	0 min	61.3 min	80.8 km

Table ES-1. Laurel to Dale City Commute, 6:30 AM – 6:30 PM Target Arrivals

Table ES-1 presents a summary of travel performance throughout the month of September for a sample Laurel to Dale City commute. Note that the ATIS users have a better on-time performance than even the conservative non-users, while experiencing only 20% of the late schedule delay experienced by the aggressive non-users. The average monthly schedule delay figures are averaged over all target times of arrival. The maximum observed schedule delay figure is the maximum delay experienced by any one simulated yoked trial participant. These improvements in on-time reliability and predictability are achieved with marginal or no change in average travel time (or travel distance). This implies that relatively small, judicious adjustments to trip start timing combined with route choice can result in improved on-time reliability even though in-vehicle travel time may only decline marginally. The Laurel-to-Dale City trip is one of the longest in the network, with a number of alternative routes, so we may expect that the benefits of ATIS may not be indicative of all possible trips in the network. However, when the complete network is analyzed (55 origins x 54 destinations x 49 target arrival times), ATIS users experience similarly improved on-time reliability relative to both conservative and aggressive ATIS non-users, particularly in the AM and PM peak periods (Table ES-2).

Commuter	On-Time Reliability	Lateness Risk	Early Schedule Delay Average Monthly ESD	Early Schedule Delay Maximum Observed ESD	Late Schedule Delay Average Monthly LSD	Late Schedule Delay Maximum Observed LSD	In-Vehicle Travel Time	Trip Distance
Conservative Non-User	92%	8%	66 min	50 min	6 min	40 min	31.5 min	33.6 km
Aggressive Non-User	81%	19%	25 min	41 min	24 min	125 min	32.1 min	33.6 km
ATIS User	97%	3%	41 min	35 min	2 min	37 min	31.4 min	34.3 km
Optimal Performance	100%	0%	0 min	0 min	0 min	0 min	30.0 min	34.1 km

Table ES-2. Summary: All DC Trips,
AM Peak (6:30-9:30) and PM Peak (3:30-6:30) Target Arrivals

Key Findings

The key finding of this work is that the two pieces of evidence from survey and field research are not in fact conflicting. As survey research suggests, ATIS users do realize significant benefits in terms of time management – better on-time reliability, reduced early and late schedule delay, as well as more predictable travel. They do this, however, without significantly reducing the amount of in-vehicle travel time accumulated over a month or year of regular trip-making. Therefore, the field trials constructed to measure reduced in-vehicle travel time have likely accurately reflected the reality of regular ATIS use.

Traditional cost-benefit analysis in the transportation area is geared primarily at the monitization of in-vehicle travel time measures. Therefore, if ATIS deployments are evaluated purely on these time-savings, the benefits of ATIS will likely be grossly underestimated. ATIS users value improved travel reliability and this benefit can be quantified through simulated yoked studies. The value of improved on-time reliability is not easily nor directly monitized, but it is clear that many types of travelers can benefit from ATIS. Trucks delivering auto parts in a just-in-time manufacturing process may highly value any improvement in on-time reliability or reduction in early schedule delay. Commuters face an on-time requirement not only on the home-to-work leg of their daily trip-making, but increasingly on the work-to-home return trip in order to meet daycare pickup requirements and other commitments. Improved reliability and predictability of travel are also likely good surrogates for reduced commuter stress. From this common sense perspective, it is clear that the benefit of improved travel reliability and predictability from ATIS will outweigh whatever small return is generated from the monitization of aggregate in-vehicle travel time reductions.

Overall, ATIS use proved advantageous in efficiently managing the traveler's time. Specific quantitative examples selected from the Washington DC case study include:

- Peak-period commuters who do not use ATIS were three to six times more likely to arrive late compared to counterparts who use ATIS;
- Cases where ATIS clearly benefits the user (e.g., ATIS user on-time, non-user late) outweighed cases where ATIS clearly disadvantages the user by five to one;
- ATIS users in peak periods are more frequently on-time than conservative non-users, yet they experience only two-thirds as much early schedule delay as non-users;
- Late shock, the surprise of arriving late, is reduced by 81% through ATIS use.

Conclusions and Future Work

The HOWLATE methodology offers a new, valuable tool to the ATIS evaluator that complements the existing field study, traffic simulation and survey research techniques. It can quantify and precisely categorize benefits of time management, trip predictability, and travel reliability that other techniques cannot. Survey research can only provide qualitative assessments of ATIS user time savings or improved on-time reliability. Traffic simulation analysis cannot efficiently assess the implications of complex ATIS user behaviors. HOWLATE can be applied at a fraction of the cost of a comparable field study. This said, the benefits quantified by HOWLATE are restricted to consideration of user, not system impact. HOWLATE cannot be easily extended to assess system-level impacts of increasing ATIS market penetration nor can HOWLATE address impacts of ramp metering or other traffic control strategies. These applications are best considered using field studies or traffic simulation models. Likewise the perceived benefit of ATIS to a user cannot be measured nor quantified within HOWLATE. Field studies of ATIS are still required to examine the effect of having a “human-in-the-loop” for travel decision-making. HOWLATE adds a new dimension of potential analysis that can be conducted in conjunction with these other techniques.

Planned near-term extensions of this work include the adaptation of HOWLATE for the evaluation of en route as well as pre-trip ATIS, and the consideration of more complex traveler behavior, as well as the impact of traffic reports on commercial radio.

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1.0 Introduction

In the last decade, numerous Advanced Traveler Information Services (ATIS) have been deployed in the United States for urban metropolitan roadway systems. These typically Internet-based services are designed to advise the traveler just before a trip begins, allowing for the estimation of trip travel time based on current or predicted congestion. In some cases, trip travel times are directly calculated for the prospective traveler; in other cases travelers must indirectly estimate travel times based on a combination of incident reports, prevailing freeway speed displays, and their own experience. A recent survey of Internet-based traveler information services (Soolman and Radin, 2000), identifies 85 sites offering roadway congestion information, covering 42 of the 78 largest metropolitan areas in the United States. Prior to 1990, Internet-based traveler information services were virtually unknown.

Concurrent with the growing number of Internet-based traveler information services, survey research on travelers who used ATIS consistently found them to be highly satisfied information consumers. A market survey (CRA and Associates, 1996) commissioned by the Federal Highway Administration (FHWA) provides evidence from multiple sources that travelers using ATIS find frequently-updated, detailed traffic information to be highly useful. For example, eighty percent of surveyed users of the Boston SmarTraveler service rated themselves as “highly satisfied” (Englisher *et al.*, 1993). More recent survey research (Jensen *et al.*, 2000; Schintler, 1999; Lappin 2000) continues to support the notion of a user base that highly values the service provided.

In particular, survey research shows that ATIS users feel they are saving significant amounts of time by utilizing these services on a regular basis. In a synthesis of results from a number of studies, Lappin (2000) concludes that the most important *perceived* benefit by ATIS users is time saved. Jensen *et al.* found that in a survey of users of the Smart Trek service in Seattle, 93 percent of respondents agreed with the statement: “using traffic information on the Web has helped me to save time.” Results of a similar survey in the Washington, DC metropolitan area (Schintler, 1999) finds over 85 percent of ATIS users feel confident they are saving time. Stress reduction is also cited as an important benefit, although this is rated lower than saving time (Lappin, 2000). Three quarters of the respondents in Jensen *et al.* reported “lower stress” from ATIS use, while Schintler found over 85 percent of respondents reported “reduced anxiety.”

Finding, confirming, and quantifying this time savings perceived by ATIS users has proven somewhat difficult, however, despite a range of field experiments and simulation studies sponsored by the FHWA and other public sector agencies. Federal interest in quantifying this benefit is high: public sector agencies are heavily invested in ATIS, either as a service provider itself or in partnership with private sector service providers. Without a quantification of actual (not perceived) benefits, the real value of deploying, operating or supporting ATIS cannot be fairly weighed against the costs associated with service provision.

The effort to quantify the benefit a traveler would accrue from the use of deployed ATIS has thus far concentrated on measuring in-vehicle travel times of users and non-users. The analysis techniques applied in the effort can be divided into two broad categories: field experiments featuring coupled driving trials ("yoked driver studies") and corridor-level traffic simulation studies. In a *yoked driver study*, two subjects in a field study are directed simultaneously to drive from one point in a network to another and report experienced travel time. The experimental subject is allowed to consult ATIS when determining route choice, while the control subject does not consult ATIS. *Corridor simulation studies* involve the application of complex traffic models, most typically traffic micro-simulations, to an urban corridor network of freeway and arterial streets. No field study is conducted, but thousands of *simulated* vehicles are tracked on a second-by-second basis, and behavioral rules for navigation through the network are implemented using different assumptions for ATIS users and non-users.

Several yoked driver studies involving in-vehicle devices (which include a pre-trip congestion report) have been conducted. A test of the Pathfinder system in California (JHK and Assoc., 1993) featured over 3,000 experimental trials in a frequently congested urban freeway corridor. Although roughly one-third of the drivers in the trials who had access to real-time congestion reports from an ATIS felt they saved travel time, statistical analysis against the control vehicles showed no significant travel time savings. In the TravTek operational test (Inman *et al.*, 1995), 36 yoked trials were conducted in the Orlando area on a mixed freeway/arterial network. Here, drivers receiving route guidance based on current congestion did not experience lower in-vehicle travel times than drivers who did not receive the service. The ADVANCE test (Schofer *et al.*, 1997) on an arterial network near Chicago reported only a 4 percent reduction in travel time for drivers using an ATIS. Across all of these studies, the disappointing results were attributed to a similar set of factors: the trips in the yoked trials were too short (<12 miles); the networks on which the trials were conducted contained few viable alternative routes; incidents causing unexpected congestion occurred infrequently; and technical problems.

Partially in response to a lack of evidence in the field of in-vehicle travel time savings, a number of corridor-level traffic simulation efforts were also initiated in an attempt to quantify the impact of deployed ATIS. Corridor simulations can consider larger networks and longer trips at a lower cost than field trials. In addition, the modeler can implement a range of incidents and unexpected congestion phenomena directly. Examples include Van Aerde and Rakha (1996) in a modeling study conducted concurrent to the TravTek field test, Hadj-Alouane *et al.* (1996) and Underwood *et al.* (1998) in the Detroit metropolitan area, and Glassco *et al.* (1996, 1997) considering a range of urban and inter-urban networks. The results of these simulation studies are fairly consistent: in-vehicle travel time savings of 10% or more attributed to drivers using ATIS under incident conditions, but only marginal travel time savings were identified under normal (non-incident) conditions.

More recent corridor-level evaluations in the Seattle region (Bunch *et al.*, 1999; Wunderlich *et al.* 1999) as well as in San Antonio (Carter *et al.*, 2000) include the analysis of a scenario set that contains combinations of unexpected surges in travel demand, incident patterns and weather impacts. These scenarios are weighted by likely probability of occurrence – for example, a snowstorm scenario is far less likely than one featuring clear weather, near-average demand, and a handful of minor incidents throughout the corridor. Significant travel time savings are observed under conditions of intense, unexpected congestion but total travel time savings on an annualized basis for ATIS users is small.

A common caveat among the simulation studies is the requirement to adopt relatively simple traveler behavior models for both ATIS users and non-users in order to be efficiently implemented within a traffic simulation. These simplified behavior models often exclude the consideration of real-world variables such as small shifts in trip start timing (plus/minus 15 minutes), the predisposition of drivers to remain on a well-known habitual route, and the level of familiarity of drivers with alternative routes in the network. In addition, the traffic simulation models adapted for these studies are primarily designed to be system (network-wide) evaluation tools concerned with design aspects such as intersection geometry and traffic signal operations. In this respect they are not ideal for the design and conduct of detailed, controlled experimentation for the purposes of ATIS evaluation. For example, none of the models used in the above studies could be configured to generate directly paired and simultaneous travel time trials between ATIS users and non-users. Finally, the simulation studies all suggest that the trip lengths in the corridors examined (<20 miles) may have been too short to realize the most significant reductions in in-vehicle travel time.

The conundrum facing a public-sector decision maker planning new or continued investment in ATIS revolves around two conflicting pieces of evidence: large *perceived* traveler time savings but little *empirical* evidence supporting this perception. This paper argues that there are significant time management benefits that accrue to regular users of ATIS in terms of on-time reliability and predictability of travel, but not necessarily in terms of the most frequently utilized measure, reduction of in-vehicle travel time. ATIS users can significantly reduce the amount of time wasted by arriving too early at their destination, as well the frequency and magnitude of late arrivals. ATIS users manage the uncertainty of urban roadway travel in a more effective manner, resulting in more predictable and less stressful long-term roadway commuting. These benefits can be quantified and potentially monitized in order to support public sector decision-making on ATIS investment. It is quite likely that the value of these benefits to the traveler in terms of travel reliability far outweigh the value of small reductions to traveler in-vehicle travel time.

In order to quantify reliability-related benefits of incorporating ATIS use into a traveler's regular commuting pattern, the HOWLATE method developed by Mitretek Systems utilizes the concept of a *simulated yoked trial*. This new analytical technique entails the efficient reconstruction of millions of hypothetical paired driving trials using archives of roadway travel times. The regional roadway travel time archive is compiled in an automated process that polls a traveler information service provider every five minutes and records the estimated link travel times. These archives provide not only estimates of what roadway segment travel times were during the period studied but a record of what was known about current congestion conditions at the time any trip across the region was initiated on any particular day.

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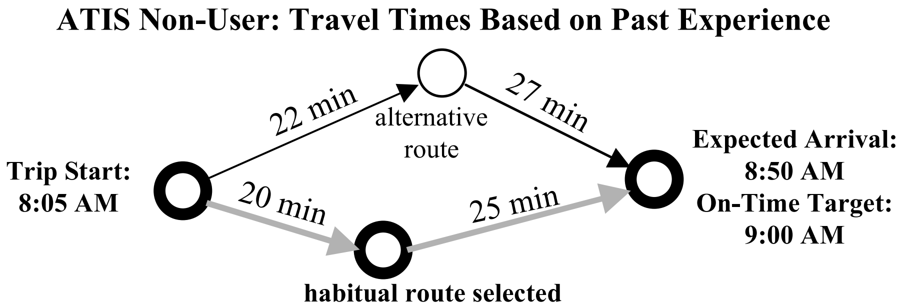

Figure 1-1. ATIS Non-User Route Choice and Trip Timing

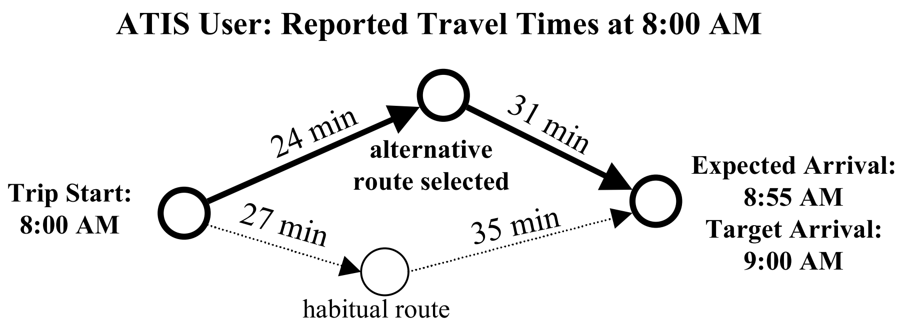

Figure 1-2. ATIS User Route Choice and Trip Timing

Figure 1-2 illustrates how ATIS user route choice and trip timing are determined. The ATIS user relies on the real-time estimates of travel time provided by the traveler information service provider rather than on past experience. Unlike the non-user, the ATIS user can adapt his trip timing and route choice on a daily basis. Consider a day in which higher-than-average travel times are forecast, particularly for the habitual route. The ATIS user, based on estimates provided at 8:00 AM, makes a decision to leave immediately and travel on the alternative route.

With trip timing and route choice established for both the ATIS user and the non-user, the next step is to reconstruct what those choices implied in terms of travel time and on-time reliability for this particular slightly worse than normal day (Figure 1-3). The reconstruction is based on the travel time archive plus a random component based on the statistical accuracy of the ATIS travel link travel time estimates measured against travel times measured in field trials. In our sample day, congestion worsens over the hour between 8:00 – 9:00 AM. Based on a 8:00 AM start on the alternative route, the ATIS user is determined to have arrived at the destination at 8:59, one minute before the on-time arrival target. Note that the trip has taken four minutes longer than the ATIS user's pre-trip expectation because congestion has worsened over the course of the trip. The non-user, unaware that congestion is worse-than-normal, remains on the habitual route starting at 8:05 AM and an arrival at the destination 15 minutes later than the target arrival time.

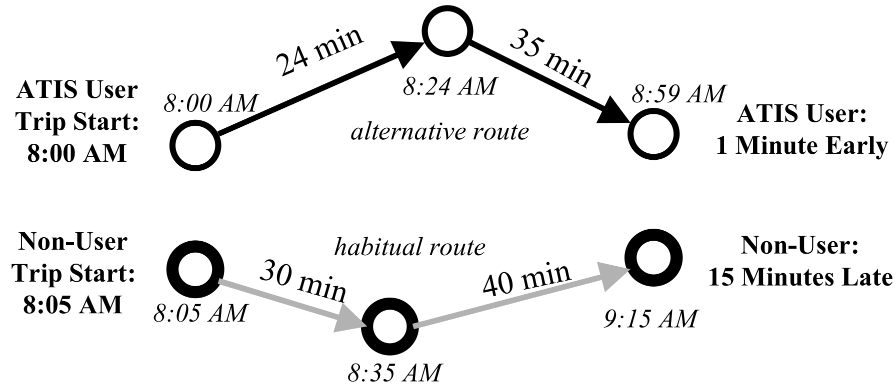

Figure 1-3. Reconstruction of ATIS User, Non-User Travel Experiences

The use of target arrival times allows for *quantifiable reliability measures* to be defined and tracked along with in-vehicle travel time: on-time reliability, lateness risk, early schedule delay (time wasted by arriving too early), and late schedule delay (total accumulated lateness). Moreover, since we have a set of arc costs corresponding to what the traveler expects at the start of the trip (either a late, on-time, or early arrival at the destination), we can track the expectation of the traveler versus performance, a measure of trip predictability. An example of this predictability measure is the percentage of instances in which ATIS users were aware before a trip began that they were likely to be late on days they actually did arrive at their destination later than the target arrival time.

Section 2 presents the Heuristic On-line Web-Linked Arrival Time Estimation (HOWLATE) methodology developed for the study. HOWLATE comprises a web-based travel time archiving application, statistical error distributions for archived link travel time data from the web against sample field data collection, and the yoked study simulator. Section 2 provides a description of the travel time archiving software, as well as detailed algorithmic statements of the travel habituation and the yoked study simulator.

Section 3 presents the Washington DC case study conducted for the months of August and September 1999. As an example, measures of effectiveness used to measure travel reliability and predictability are demonstrated for a 84 km commute between Laurel, Maryland and Dale City, Virginia. Aggregate results are also reported for another 2969 sample commutes drawn from the Washington DC regional roadway network.

Section 4 reviews the implications of this work with respect to ATIS evaluation and public sector investment planning. Section 4 also explores potential extensions to this work.

Appendix A reproduces the Hardy et al (2000) paper on the accuracy of travel time estimates obtained from ATIS in the I-66/Rte. 50 corridor in the DC region. Preliminary results from this study are used to set critical parameters in the yoked study simulator described in detail in Section 2 for the DC case study described in Section 3.

Appendix B provides an algorithmic statement of key routines called within the yoked study simulator (Section 2).

2.0 The HOWLATE Methodology

The HOWLATE methodology (Figure 2-1) brings together the necessary data for the implementation and analysis of large-scale simulated yoked studies. The first module is the *travel time archiver*, a software application that monitors ATIS link travel time reports via the Internet and stores these reports at five-minute intervals. The archiver compiles and saves a daily profile of link travel time by time of day, every weekday over a period of several months. Section 2.1 provides details on the archiver architecture and implementation.

A key input required for simulated yoked studies is statistical distributions of error between the ATIS link travel time reports and observed travel times. For the Washington DC case study to be discussed in Section 3, distributions are based on preliminary findings from a travel time study (Hardy *et al.*, 2000) conducted on one freeway and one arterial facility from the regional network. A detailed description of this study is provided as Appendix A. The travel times experienced during this study were then compared against estimates of travel obtained from the Internet-based SmarTraveler (www.smartraveler.com) service at the moment the test car was about to traverse the roadway link. The analysis provided a statistical sample for developing a model of estimation error, as well as insight on how specific SmarTraveler operational procedures impact travel time accuracy. For example, the study found that travel time on freeway links was typically overestimated during uncongested conditions. This overestimation of uncongested travel time is related to a SmarTraveler policy not to issue a travel time estimate that implied travel faster than speed limit. The test car drivers in Hardy *et al.*, were directed to follow the flow of traffic, and therefore experienced shorter travel times than the SmarTraveler estimates during uncongested conditions.

The distributions of error, combined with the ATIS travel time report profiles collected by the travel time archiver, facilitate the construction of multiple "actual day" profiles through independent Monte Carlo trials. Since we cannot know precisely what the actual travel times were on the roadway links, we randomly sample from a set of likely values. In this case, the set of likely ATIS travel times are determined from the error distributions based on the field study. Each random sample is analyzed as if it were the actual travel times, and is called a *realization* of the Monte Carlo trial. Multiple realizations can be constructed from each day in the travel time archive (in the DC Case Study discussed in Section 3, we constructed ten realizations) and an average result reported.

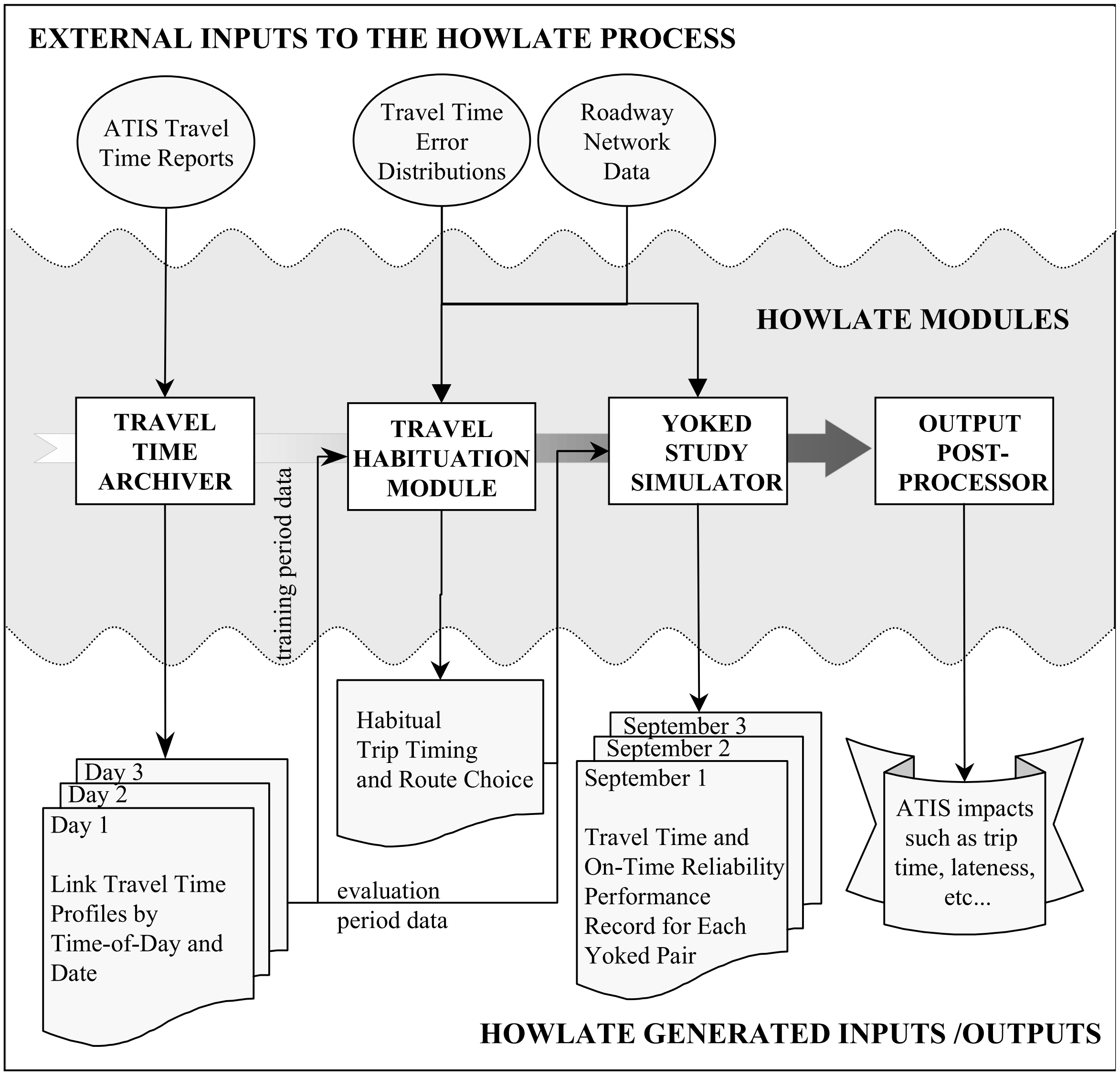

Figure 2-1. Overview of HOWLATE Method

In order to conduct a simulated yoked study trial, habitual time of trip start and route choice must be determined for the non-ATIS traveler. To facilitate the identification of habitual time of trip start and route choice, the ATIS travel time archive is separated into two periods: training and evaluation. The training period (for the DC case study, one month) represents the time period in which non-ATIS drivers settle into habitual travel choices that meet a target on-time reliability threshold. This is modeled in the *travel habituation module* by obtaining a single realization ("actual day profile") for each of the weekdays in the training period. Average link travel times at five-minute intervals are obtained across all days in the training period using the actual day profiles. Fastest time-variant paths and associated path travel times are then identified using the technique of Kaufman *et al.* (1991) with respect to each origin-destination-target time of arrival. These fastest paths with respect to average travel times are selected as the habitual route for ATIS non-users. Using average travel times to determine habitual route choice is straightforward and computationally efficient. We do not know, however, how realistically this assumption mirrors this aspect of traveler behavior. More complex habituation modeling can be incorporated as a component of HOWLATE when additional empirical data become available.

We estimate travel time variability for each habitual path by computing the variability of its travel time over the days in the training period. The time of habitual trip start is determined by subtracting the average habitual path time from the target arrival time at the destination and then subtracting an additional time buffer proportional to the amount of travel time variability. The buffer size is computed under the assumption that day-to-day variation in travel times in the training period is normally distributed. Travelers who are very concerned about being late choose larger time buffers to produce a higher probability of being on-time. Thus, a conservative traveler with a 95% on-time reliability requirement has a larger time buffer for variability than an aggressive traveler with a 80% on-time reliability requirement.

After habitual routes and trip start timings are determined in the travel habituation module, one realization of travel congestion in each day of the evaluation period is generated. Details of the experimental (ATIS) and control (non-ATIS) travel behavior policies are set for all origin-destination-target time of arrival combinations in the network. Details include the on-time requirement for the ATIS non-user, as well as the flexibility of the ATIS user to adjust trip starts in real time. ATIS user preference to remain on the habitual route can also be modeled using a travel time threshold. The ATIS user does not divert from the habitual path unless a faster alternative path is predicted to result in greater time savings than the threshold value.

Simulated yoked trials are conducted using a single Monte Carlo realization for each day in the evaluation period. The ATIS non-user departs from the origin at the habitual trip start time and traverses the network on the habitual path (no diversion). The ATIS user determines trip start time by checking the travel time predicted by the information service for the current fastest path. The first check is initiated at a set time (e.g., 15 minutes) prior to the habitual start time. The user postpones a trip start by five minutes if taking the current fastest path is projected to provide an early arrival at the destination by ten minutes or more. When a trip can no longer be postponed, the ATIS user selects the fastest current path (subject to the habitual route preference threshold) and traverses the network without any en route diversion. Trip start postponement is allowed to continue until a preset limit is reached (e.g., 15 minutes after habitual trip start time).

Travel time duration and on-time performance are computed for both the ATIS user and the ATIS non-user by traversing the roadway network using the time-variant travel times associated with the actual day realizations. For comparison, an optimal travel time duration and trip start timing (corresponding to a perfectly timed arrival at the destination) is also determined in a separate calculation by applying the method of Kaufman *et al.* fixing the time of trip end at the destination at the target arrival time and working backward in time until the origin is reached. A record for each yoked trial is generated and these records are assembled into daily profiles, one for each day in the evaluation period.

These records of each simulated yoked trial are then analyzed in the *output post-processor* module. The post-processor accumulates performance measures such as on-time reliability and in-vehicle travel time for ATIS users and ATIS non-users. These performance measures can be separated out by records from peak or off-peak periods, or by trip features such as trip length.

Additional realizations of traffic conditions in the evaluation can be analyzed by generating a new set of "actual" conditions through random trial. Note that because of the randomness inherent in the Monte Carlo technique, a traveler may be on-time in one realization and late in another, even though they are both representations of what might of happened on a particular day in the evaluation period.

2.1 Travel Time Archiving

In an effort to collect and organize travel time data from ATIS providers, Mitretek built a series of web-based software applications. The goal of these applications for the Washington, DC case study was to obtain and archive travel time data gleaned from the 33 separate SmarTraveler web pages covering the Washington, DC area. This process of generating a travel time archive comprises three activities: web retrieval, data checking and cleaning, and data manipulation. The web retrieval portion of the process downloaded each web page's travel time data and archived it for later use. After all data for a given day was stored, the process detected and corrected data errors. Finally the last part of the of the process transformed the data into a daily text file that contains travel time information for each of the 5 minute intervals between 6:30AM and 6:30PM, the time period in which SmarTraveler actively reports data.

An initial prototype that Mitretek developed to collect this data was written in Visual Basic for Application (VBA) within the Microsoft Access platform. This program archived data directly into an Access database after which an operator had to perform data cleaning and manipulation manually. This approach was eventually abandoned because of two factors: serial page-by-page downloading proved so slow that often fewer than the required 33 web pages could be archived in the required 5-minute time interval. Second, the manual manipulation of data for error identification proved too cumbersome for long-term archiving. Because of these two factors, Mitretek built a new faster and more automated program. The second program, Webget, is a DOS-based program written in Python. Python is a free programming language that has many useful tools for interacting with the Internet and supports the multi-threading of subroutines. The Webget program also cleans the data from the SmarTraveler network and converts it to a new network used for the HOWLATE process, all in an automated fashion.

The web retrieval is a vital part of the ATIS archiving program simply because if no data is received from the web, the program can do little else. Therefore, Mitretek invested a significant amount of time optimizing web retrieval performance and reliability. Web retrieval reliability can be problematic since the program is downloading information from an unpredictable source, the Internet. Two distinct problems can arise when downloading data from the web: format changes and connectivity drops.

Transportation data on the Internet can be in any form: tables, numeric, text, or any other form that a web publisher sees fit. This variation causes problems when trying to download information based on the web page's Hyper Text Mark-up Language (HTML). HTML has much more information than the user sees through an Internet browser, including HTML tags, Java code, and user comments. To process the HTML text string efficiently, the application performing the download must be directed to the desired data and to skip the rest of the unneeded information. When downloading from SmarTraveler, Mitretek had to scan the HTML text and search for where the travel time data was located and in what format. Changes in the way that SmarTraveler displayed data occurred frequently. For instance, the HTML text for a web page sometimes contained an extra space or lacked an HTML tag causing errors when downloading the data. To overcome these problems Mitretek developed a system of pattern matching to allow the Webget program to sort through the HTML and hunt for a distinct pattern in the HTML that would indicate the location of the desired travel time data. Mitretek's use of pattern matching reduces the chances of downloading errors as result of minor format changes in the HTML page.

Internet connectivity also has an impact on the ability to consistently download error-free data. Poor Internet connectivity results in missing data within a daily archive, while good Internet connectivity yields a complete and comprehensive archive. The Internet consists of a series of both local-area and wide-area networks interconnected at various points to provide a seemingly single network to end-users. Since each network may be maintained by different organizations, component failures may result in communication breakdowns at various points.

The web retrieval program downloads a different web page for each of the 33 major roads in the Washington DC area covered by SmarTraveler every 5 minutes. The program utilizes three techniques to accomplish this in a efficient, reliable way: multi-threading, call loops and automatic disconnects. Multi-threading allows a program to run multiple copies of the same code in parallel with each other. Webget, written in Python, spawns copies of the HTML retrieval subroutine to run the web download portion of the code in parallel rather than in series. This allows for a much faster download process because time wasted waiting for a response from the server is minimized.

Implemented within the web download portions of the program are a series of call loops. These control loops attempt to download data over and over again until a connection is made or until a 5 minute time period has expired. The call loop strategy strives to secure the connection, for, if the first connection is unsuccessful, the second, third, etc. are additional opportunities to connect.

The third critical technique implemented in Webget is an automatic web disconnect. This feature is important in avoiding unterminated pieces of code occupying computer memory. Poor memory management can result in a range of pathologies – including program crashes and operating system lock-up.

Mitretek also generated code self-diagnostics to provide an easy-to-understand screen display that would show any errors the program would encounter. Although the programs ran on their own approximately 95% of the time, Mitretek had to ensure that any major errors like web address changes, web format changes, or Internet connection loss for a significant period of time could be handled.

After the data is retrieved and assembled in a preliminary archive, the information is checked for missing or incorrect data. This checking process fills in small data gaps that may result from short download interrupts. Each day's worth of preliminary data is checked to make sure that no more than 40 minutes worth of time is missing for any link in the network and that not more than 15 minutes worth of time is missing concurrently. Under these guidelines, days that have 40 minutes or more of data or an extended period of time missing are thrown out. For the days that have some minor data loss (one to three missing data points) Mitretek used simple linear interpolation to fill in these missing data points. The Webget process operated cleanly and with few errors, resulting in a fewer than one day in ten thrown out for excessive errors. Interpolated data makes up less than 2 percent of the archives used in the DC case study.

2.2 Travel Habituation and Simulated Yoked Study Algorithm

This section presents a detailed algorithmic statement for the travel habituation module and the yoked study simulator. Both HOWLATE components make frequent use of two different time-variant fastest path calculation algorithms: reverse time and forward time. For fastest paths for a fixed destination node and arrival time, we employ a variant of Kaufman *et al.*. This *reverse time* application of Kaufman *et al.* finds fastest paths from all nodes (origins) in a network to a particular destination node, and is noted by $\grave{\mathrm{D}}(d, \tau, c_\ell(t))$, where d is the destination node, τ is the target time of arrival and $c_\ell(t)$ is the set of link travel times. For fastest paths for fixed origin, fixed destination, and trip start time, we employ a variant of the A-Star algorithm (Perl, 1993) for computational efficiency. The *forward time* fastest path calculator is noted by $\mathrm{D}'(o, d, t^0, c_\ell(t))$ where o is the trip origin node, t^0 is the trip start time (d and $c_\ell(t)$ defined as above). The implementations of these fastest path algorithms are provided in Appendix B.

In addition to the fastest path routines, another repeated operation is the forward traversal of arc costs to assemble a path cost. This procedure does not optimize -- it is simply an accounting procedure that follows a fixed path, and is noted by $\mathrm{T}'\left(\mathbf{P}_{o,d}, t^0, c_\ell\left(t^0\right)\right)$, where $\mathbf{P}_{o,d}$ is the path from trip origin to trip destination, t^0 is the trip start time and $c_\ell(t)$ the set of link travel times traversed. A detailed statement of the forward traversal routine appears in Appendix B.

Define the roadway network, L, as a set of unidirectional arcs linking two nodes, $\ell{:}(a,b)$. Each link ℓ is characterized by a facility type, f_ℓ, a congestion threshold, ξ_ℓ, and a link length in kilometers, δ_ℓ. From travel time error distributions, obtain the mean error by facility type (arterial or freeway) and congestion level (congested or uncongested), μ_f^κ, and the coefficient of variation for error by facility type and congestion level, σ_f^κ.

Travel Habituation Module. From the archive of link travel times, define the ATIS estimate of travel time for each link $\ell \in L$, $\hat{c}_\ell^k(t)$; where $k = 1,2,3 \cdots N$ in a training period of N days, and $t = 0,1,2 \cdots T$, a series of five-minute time slices in day k. Note that $\hat{c}_\ell^k(t)$ is defined as the travel time to traverse link ℓ when arc traversal begins at time t.

Apply Monte Carlo randomization using $\hat{c}_\ell^k(t)$ based on an assumption of normally distributed error with parameters μ_f^κ and σ_f^κ to obtain an single realization of actual travel times, $\widehat{c}_\ell^k(t) \forall \ell \in L;\ k = 1,2,\cdots N;\ t = 1,2,\cdots T.$ Link travel times are reported in seconds, and travel times between five minute lattice points are calculated using linear interpolation. Note that the randomization is applied independently for each day, link, and time slice. A check is made to make sure that the randomization does not violate first-in-first-out consistency, that is, a situation in which traversing a link later would result in an earlier arrival at the downstream node. Consistency is checked and enforced using Equation 2-1.

$$\text{if } \widehat{c}_\ell^k(t) - \widehat{c}_\ell^k(t+1) > 300 \text{ then set } \widehat{c}_\ell^k(t+1) = \widehat{c}_\ell^k(t) - 300. \qquad (2\text{-}1)$$

Next, average actual link travel times during the training period are generated for each link, $\ell \in L$:

$$\widehat{c}_\ell(t) = \frac{\sum_k \widehat{c}_\ell^k(t)}{N} \qquad (2\text{-}2)$$

For each destination node d and target arrival-at-destination time τ, where $\tau = 1,2,3 \cdots \Psi$, a lattice of 15 minute target arrival times during the day, perform the method of Kaufman *et al.* from d at time τ using the average arc costs calculated in Equation 2-2. This returns the average fastest path, $\overline{\mathbf{P}}_{o,d,\tau}$, and an experienced average travel time, $\overline{p}^{1}_{o,d,\tau}$ for each combination of origin, o, destination, d , and target time of departure, τ .

$$\text{`D}\left(d,\tau,\hat{c}_{\ell}(t)\right) \rightarrow \overline{\mathbf{P}}_{o,d,\tau}\ ,\ \overline{p}^{1}_{o,d,\tau}\ \forall\, o,d,\tau \tag{2-3}$$

The fastest path, $\overline{\mathbf{P}}_{o,d,\tau}$, is considered the habitual path. Next, we establish habitual trip timing from the observed variability in trip travel time on $\overline{\mathbf{P}}_{o,d,\tau}$ during the training period. For each day k in the training period, traverse $\overline{\mathbf{P}}_{o,d,\tau}$ forward at time $\tau - \overline{p}^{1}_{o,d,\tau}$ using travel times to obtain $\overline{p}^{k}_{o,d,\tau}$, the travel time on the habituated path.

$$\text{T}'\left(\overline{\mathbf{P}}_{o,d,\tau}, \tau - \overline{p}^{1}_{o,d,\tau_{\tau}}, \hat{c}^{k}_{\ell}(t)\right) \rightarrow\ \overline{p}^{k}_{o,d,\tau}\ \forall\, o,d,\tau \tag{2-4}$$

From the vector series $\left\{\overline{p}^{k}_{o,d,\tau} : k = 1, 2, \cdots N\right\}$, compute $\overline{p}_{o,d,\tau}$, the average path travel time and $\overline{\sigma}^{\overline{\mathbf{P}}}_{o,d,\tau}$, the standard deviation of travel time on the habitual path. Now we can compute the habitual time of trip start: $t^{0}_{o,d,\tau} \forall\, o,d,\tau$.

$$t^{0}_{o,d,\tau} = \tau - \left(\overline{p}_{o,d,\tau} + Z_{X\%}\overline{\sigma}^{\overline{\mathbf{P}}}_{o,d,\tau}\right) \tag{2-5}$$

Here, $Z_{X\%}$ is the Z-statistic for X$^{\text{th}}$ percentile of the normal distribution. Note that the value of the Z-statistic reflects the on-time reliability requirement of the traveler. Using a large value here creates a more conservative traveler who budgets more buffer time in order to gain higher on-time reliability. A lower value here reflects the planning of a more aggressive traveler who is willing to budget smaller amounts of time for travel time variability and is willing to risk more frequent late arrivals.

<u>ATIS Non-User Performance</u>. From the archive of link travel times, define the ATIS estimate of travel time for each link $\ell \in L$, $\hat{c}^{j}_{\ell}(t)$; where $j = 1,2,3 \cdots M$ in the evaluation period of M days. Note that we use the j subscript to denote days in the evaluation period, whereas k is the subscript for days in the training period.

Using the same procedure as in the training period, apply Monte Carlo randomization to each $\hat{c}_\ell^j(t)$ to obtain a single realization of actual travel times for the evaluation period, $\widehat{c}_\ell^j(t)\,\forall\,\ell\in L; j=1,2,\cdots M; t=1,2,\cdots T.$ Next, we recover habituated paths and trip start times identified in the training module, $\overline{\mathbf{P}}_{o,d,\tau}$ and $t_{o,d,\tau}^0\,\forall\, o,d,\tau$.

For each day j in the evaluation period, and for each o,d,τ, traverse $\overline{\mathbf{P}}_{o,d,\tau}$ forward from time $t_{o,d,\tau}^0$, using actual arc costs for day j to determine ATIS non-user experienced travel time on the habituated path, $\widehat{\overline{p}}_{o,d,\tau}^j$.

$$\mathrm{T}'\left(\overline{\mathbf{P}}_{o,d,\tau}, t_{o,d,\tau}^0, \widehat{c}_\ell^j(t)\right) \rightarrow \quad \widehat{\overline{p}}_{o,d,\tau}^j \tag{2-6}$$

Given that we know the time of trip start, the target arrival time and experienced travel time, we can identify whether or not the ATIS non-user arrived on-time, i.e., $t_{o,d,\tau}^0 + \widehat{\overline{p}}_{o,d,\tau}^j > \tau$ and other metrics. A complete set of performance metrics are defined later in this section.

<u>Optimal Travel Performance</u>. Here, we apply the method of Kaufman *et al.* for all d,τ,j with the time-variant travel times associated with actual conditions in the evaluation period, $\hat{c}_\ell^j(t)$. This identifies the optimal path, $\widehat{\mathbf{P}}_{o,d,\tau}^j$, and travel time, $\widehat{p}_{o,d,\tau}^j$, on day j for all o,d,τ.

$$\text{`D}\left(d,\tau,\widehat{c}_\ell^j(t)\right) \rightarrow \quad \widehat{\mathbf{P}}_{o,d,\tau}^j,\ \widehat{p}_{o,d,\tau}^j \tag{2-7}$$

Note that by definition, the departure at time $\tau - \widehat{p}_{o,d,\tau}^j$ on path $\widehat{\mathbf{P}}_{o,d,\tau}^j$ results in a perfectly timed arrival at the destination at time τ. Thus, optimality here refers to the latest possible trip start on the fastest possible path that results in on-time arrival at the destination.

<u>ATIS User Performance</u>. First, the parameters that define the ATIS user behavior must be defined. Using the habitual trip start time $t_{o,d,\tau}^0$ as a reference, we define in multiples of five minutes the point at which the user first consults ATIS prior to making a trip, $t_{o,d,\tau}^0 - e^-$. A maximum latest trip start relative to $t_{o,d,\tau}^0$ is also defined, $t_{o,d,\tau}^0 + e^+$. A route diversion indifference threshold is

defined as ε . If the current fastest path is not the habitual path, the ATIS user will not divert onto the new path unless it would result in an travel time savings of at least ε over the habitual path.

To determine the ATIS user performance, we recover archived and actual link travel time files for the roadway network in the evaluation period, $\hat{c}_\ell^j(t)$ and $\widehat{c}_\ell^j(t)$, respectively. Then, for each o, d, τ we simulate the behavior of the ATIS user. The first check with the service occurs at $t' = t^0_{o,d,\tau} - e^-$. A current candidate fastest path is obtained using the travel times the service is reporting at that moment, that is; we perform A-Star forward time fastest path calculations assuming link travel times fixed at $t = t'$ (Equation 2-8). The candidate fastest path is noted $\dot{\mathbf{P}}^j_{o,d,\tau}$ and has a travel time estimate of $\dot{p}^j_{o,d,\tau}$.

$$\mathrm{D}'\left(o, d, t', \hat{c}_\ell^j(t')\right) \rightarrow \dot{\mathbf{P}}^j_{o,d,\tau},\ \dot{p}^j_{o,d,\tau} \tag{2-8}$$

The ATIS user checks to see if an immediate trip start results in an unacceptably early arrival at the destination (Condition 2-9). The threshold for early arrival acceptance is Δ , here set to ten minutes.

$$t' + \dot{p}^j_{o,d,\tau} < \tau - \Delta \tag{2-9}$$

If Condition 2-9 is true and trip postponement does not exceed the maximum late start, $t' < t^0_{o,d,\tau} + e^+$, then t' is incremented by five minutes and a new candidate fastest path is generated using Equation 2-8. Otherwise, the current t' is used as the time of trip start, $\tilde{t}^j_{o,d,t} = t'$.

Next, we forward traverse the habitual path, $\overline{\mathbf{P}}_{o,d,\tau}$, using arc costs fixed at $\tilde{t}^j_{o,d,\tau}$ to identify the current estimate of travel time on the habitual path $\hat{\bar{p}}^j_{o,d,\tau}$ (Equation 2-10).

$$\mathrm{T}'\left(\overline{\mathbf{P}}_{o,d,\tau}, \tilde{t}^j_{o,d,\tau}, \hat{c}_\ell^j\left(\tilde{t}^j_{o,d,\tau}\right)\right) \rightarrow \hat{\bar{p}}^j_{o,d,\tau} \tag{2-10}$$

Next, we perform a check to see if the alternative route provides a travel time low enough relative the habitual path to warrant diversion (Condition 2-11).

$$\hat{\bar{p}}^{j}_{o,d,\tau} - \dot{p}^{j}_{o,d,\tau} > \varepsilon \tag{2-11}$$

If Condition 2-11 is true, then we calculate the experience of the ATIS user based on the assumption that a route switch (diversion) has occurred. Otherwise, we assume that the ATIS user remains on the habitual path (no diversion).

<u>*Diversion*</u>. Set pre-trip switch indicator $x^{j}_{o,d,\tau} = 1$. Set expected pre-trip travel time $\hat{p}^{j}_{o,d,\tau} = \dot{p}^{j}_{o,d,\tau}$. Traverse $\dot{\mathbf{P}}^{j}_{o,d,\tau}$ forward, using time-variant actual arc costs for day j, departing at $\tilde{t}^{j}_{o,d,t}$ to generate the experienced travel time for the ATIS user, $\tilde{p}^{j}_{o,d,\tau}$:

$$\mathrm{T}'\left(\dot{\mathbf{P}}^{j}_{o,d,\tau}, \tilde{t}^{j}_{o,d,\tau}, \hat{c}^{j}_{\ell}(t)\right) \rightarrow \tilde{p}^{j}_{o,d,\tau} \tag{2-12a}$$

<u>*No Diversion*</u>. Set pre-trip switch indicator $x^{j}_{o,d,\tau} = 0$. Set expected pre-trip travel time $\hat{p}^{j}_{o,d,\tau} = \hat{\bar{p}}^{j}_{o,d,\tau}$. Traverse $\overline{\mathbf{P}}_{o,d,\tau}$ forward, using time-variant actual arc costs for day j, departing at $\tilde{t}^{j}_{o,d,t}$, to generate the experienced travel time for the ATIS user, $\tilde{p}^{j}_{o,d,\tau}$:

$$\mathrm{T}'\left(\overline{\mathbf{P}}_{o,d,\tau}, \tilde{t}^{j}_{o,d,\tau}, \hat{c}^{j}_{\ell}(t)\right) \rightarrow \tilde{p}^{j}_{o,d,\tau} \tag{2-12b}$$

2.3 Measures of Effectiveness

We define six core measures of effectiveness: three reliability measures, one predictability measure, and two other measures. Additional predictability measures are discussed in Section 3.3

Travel Reliability Measures: On-time reliability is defined as the proportion of simulated yoked trials wherein a user type arrives at the destination node at or prior to the target arrival time. An ATIS user is on-time when $\tau \geq \tilde{t}^{j}_{o,d,\tau} + \tilde{p}^{j}_{o,d,\tau}$ and a non-user is on-time when $\tau \geq t^{0}_{o,d,\tau} + \bar{\bar{p}}^{j}_{o,d,\tau}$.

Just-in-time reliability is defined as the proportion of simulated yoked trials wherein a user type arrives at the destination node both on-time and no more than 10 minutes (600 seconds) early. An ATIS user is just-in-time when $0 \le \tau - \tilde{t}^{j}_{o,d,\tau} + \tilde{p}^{j}_{o,d,\tau} \le 600$. An ATIS non-user is just-in-time when $0 \le \tau - t^{0}_{o,d,\tau} + \hat{\bar{p}}^{j}_{o,d,\tau} \le 600$.

Schedule delay is defined as the difference between the actual arrival at the destination and the target time of arrival, i.e., $\tilde{t}^{j}_{o,d,\tau} + \tilde{p}^{j}_{o,d,\tau} - \tau$ (for ATIS users) or $t^{0}_{o,d,\tau} + \hat{\bar{p}}^{j}_{o,d,\tau} - \tau$ (for ATIS non-users). If schedule delay is negative, it is called *early schedule delay.* If it is positive it is termed *late schedule delay*.

Travel Predictability: Rate of late shock is the percentage of trips in which a pre-trip expectation that the trip will result in an on-time arrival actually results in an arrival at the destination node later than the target time of arrival. Late shock is defined as $\tau > \tilde{t}^{j}_{o,d,\tau} + \hat{p}^{j}_{o,d,\tau}$ but $\tau < \tilde{t}^{j}_{o,d,\tau} + \tilde{p}^{j}_{o,d,\tau}$ for ATIS users and $\tau > t^{0}_{o,d,\tau} + \hat{\bar{p}}^{j}_{o,d,\tau}$ for ATIS non-users (who always expect an on-time arrival).

Other Measures: *In-vehicle travel time* and *trip distance* measures are collected for each simulated yoked trial.

3.0 Washington, DC Regional Case Study

The network used for the Washington DC HOWLATE case study is based on the facilities covered by the SmarTraveler service (left half of Figure 3-1). Travel times are reported on a range of freeway and arterial facilities throughout the region, which spans over 1200 square miles in Maryland, Virginia and the District of Columbia.

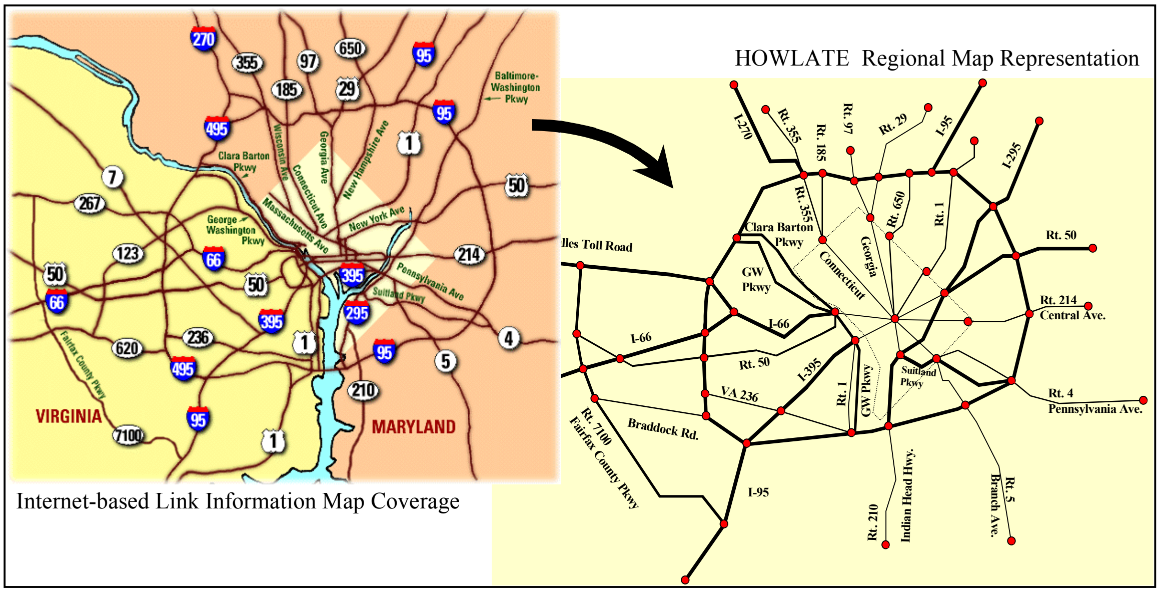

Figure 3-1. Washington DC Area Case Study Network

The SmarTraveler network is made up of a series of major roads and highways that cover the Washington DC area. This network, however, does not include all of the major intersections that are required to accurately depict route choice within the region. An example of this lack of intersection detail is the SmarTraveler depiction of I-66, which extends from the west of Washington DC to the east just inside the city. This major Interstate is broken up into two different parts for the SmarTravaler network: from the Centreville in the west to I-495 and from I-495 to the DC city limits. The SmarTraveler segmentation eliminates transfers to both Route 50 and Route 7100 that cross I-66. Without these two route interchanges included in the HOWLATE network, a realistic route choice cannot be assessed.

Therefore, Mitretek created a new network based on the SmarTraveler network with new links that included all intersections onto any needed arterials and/or highways. This new network can be seen in the right half of Figure 3-1. In order to implement the new more detailed network representation in HOWLATE, a method had to be developed to map travel time reports from the high-level SmarTraveler network to the more detailed HOWLATE representation. In the I-66 example, two high-level links are transformed into four segments in the HOWLATE representation. The HOWLATE network's new I-66 segments are Centerville to Route 7100, Route 7100 to Route 50, Route 50 to I-495, and finally I-495 to the DC City line. In order to derive a travel time on each segment, Mitretek weighted each segment by the ratio of its length to the total length of the high-level link (Figure 3-2). This assumption is somewhat limiting since most congestion does not happen evenly on roadway segments but at a few bottlenecks. However, this is an intrinsic limitation of the data set that can only be remedied by having more detailed data in the archive. Therefore, for this initial test of the HOWLATE system, uniform congestion along high-level links is assumed.

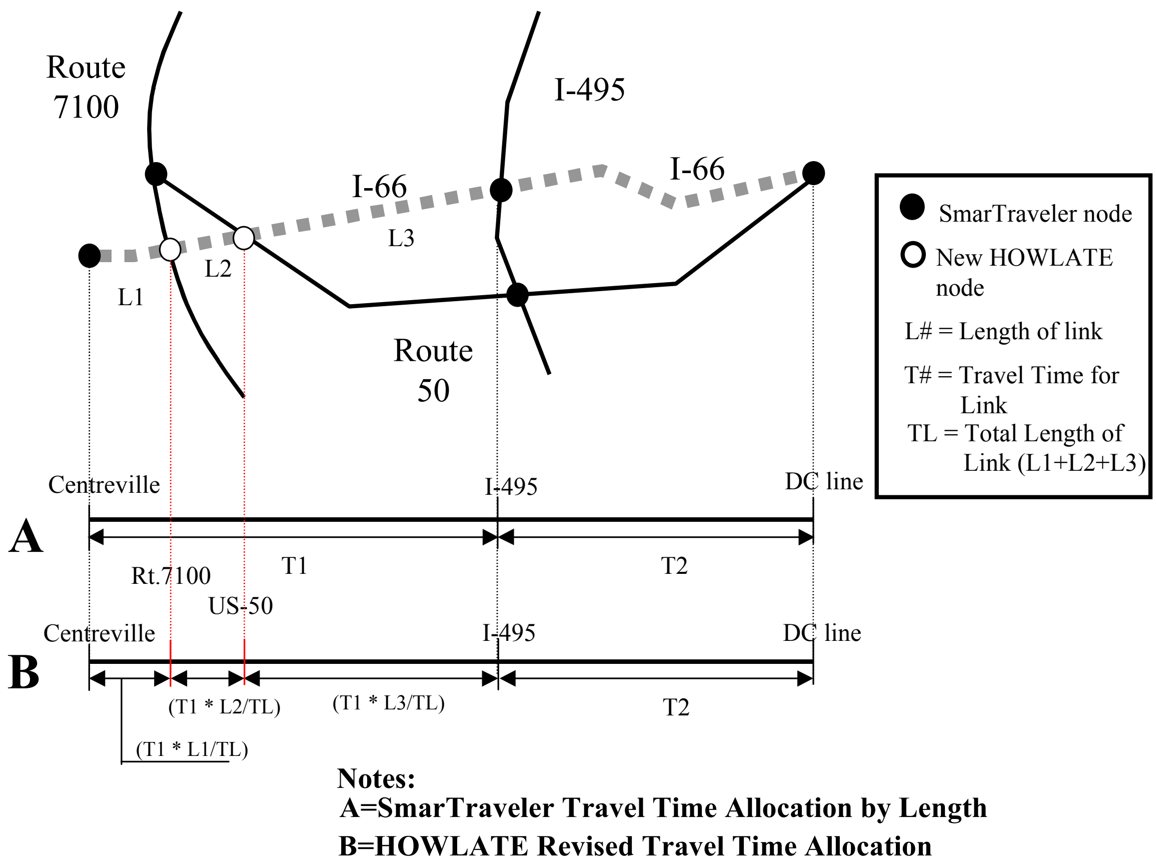

Figure 3-2. Transformation of High-Level Link Data

The detailed HOWLATE network features 55 nodes, each of which represent a potential trip origin or trip destination; and 169 links, corresponding to freeway, expressway and major arterial facilities. The longest trips in the network are 80 km or longer, significantly longer than those considered in the field tests and traffic simulations conducted for ATIS evaluation.

3.1 Case Study Input Parameters

Travel times were archived for 18 weekdays in the month of August 1999 and 21 weekdays in the month of September 1999. These daily profiles include travel times for each of the 169 links in the Washington DC regional network at five-minute intervals from 6:30 AM to 6:30 PM derived from SmarTraveler. All together, the travel time archive for the two-month period represents a collection of over 100,000 link travel time reports.

Estimates of link travel time error are derived from preliminary estimates provided in Hardy *et al.* (2000), attached as Appendix A to this report. Hardy *et al.* collected travel time data using test vehicles along the I-66 and US-50 facilities in the region, while the supplementary Mitretek travel time runs were conducted outside this corridor. SmarTraveler personnel were not alerted ahead of time as to the location or timing of the travel time measurement tests. Analyzing preliminary results from Hardy *et al*., we found the reporting error on the freeway segments under congested conditions (below 70 kph) to be normally distributed with a mean error of zero and a coefficient of variation of 10% (relative to the observed link travel time). On uncongested freeway segments, a similar distribution was found with the exception that the mean error was –10%, that is, the service reported a travel time that was on average 10% longer than the observed travel time. This overestimation of uncongested travel time is related to a SmarTraveler policy not to issue a travel time estimate that implied faster than speed limit travel. The test car drivers in Hardy *et al.*, directed to follow the flow of traffic, therefore experienced lower travel times than the SmarTraveler estimates. Mitretek supplemented the findings of Hardy with additional travel time runs on other facilities. Error distributions on both freeway and arterial facilities used for the DC case study are provided in Table 3-1.

	Congested Regime		**Uncongested Regime**	
Facility	Skew	Coefficient of Variation	Skew	Coefficient of Variation
freeway	0%	10%	-10%	25%
arterial	-10%	20%	-5%	5%

Table 3-1. Link Travel Time Error Distribution

Simulated yoked studies were conducted with ATIS users and two types of ATIS non-users, with target times of arrival at 15-minute intervals between 6:30 AM and 6:30 PM. The first ATIS non-user type is considered *conservative* with respect to on-time reliability and chooses habitual time of trip start corresponding to a 95% on-time arrival rate based on the conditions seen in August 1999. The second ATIS non-user type is more *aggressive*, and chooses a later habitual time of trip start corresponding to a 80% on-time arrival rate. ATIS users are configured with a route diversion threshold of three minutes. This implies that ATIS users will not choose to divert off of the habitual route unless the alternative route suggested by the traveler information service is reported to be less than three minutes faster than the habitual route.

To cover all combinations of origin-destination pairs (55 x 54) for each of the 49 target times of departure entails the conduct of 3.06 million simulated yoked trials over the 21 day evaluation period. Further, 10 Monte Carlo realizations in each day in the evaluation period were evaluated, bringing the total number of simulated yoked studies considered to over 30 million. Results reported in Section 3.2 represent average performance measures with respect to these independent trials, and all differences reported are statistically significant unless otherwise noted. With C++ code implemented on a 733-MHz processor PC with 256 MB of RAM, the three million yoked trials associated with a single realization requires roughly 8 hours to complete.

3.2 Results

Figure 3-3 illustrates the results of 49 simulated yoked trials for a realization of 9 September 1999 for ATIS users and conservative ATIS non-users traversing the 84 km commute from Laurel, Maryland to Dale City, Virginia. The plot shows target arrival time on the x-axis and arrival offset (number of minutes early at destination) on the y-axis. Note that because of two incidents on the habitual path, one in the AM peak and the other shortly before 11:00 AM, the ATIS non-user record shows a series of late arrivals. In fact, the simulated ATIS non-user with target arrival time in Dale City of 11:00 AM is almost 25 minutes late. In comparison, the ATIS user (who takes a different path for that target arrival time) is about 10 minutes early. In the PM peak period, travel on the habitual path is actually less congested than normal, and ATIS non-users arrive significantly early with respect to the target arrival time. Here, too, ATIS users compensate, but instead of changing route, they postpone trip starts. The result is a set of arrivals that are closer to the target arrival time. The sample results illustrate that *ATIS users can respond to both worse-than-normal conditions and better-than-normal congestion conditions* to reduce lateness risk and early schedule delay, respectively. When congestion conditions deviate significantly from normal (e.g., under worst-case congestion) the likelihood that ATIS use will be beneficial is quite high. The result is

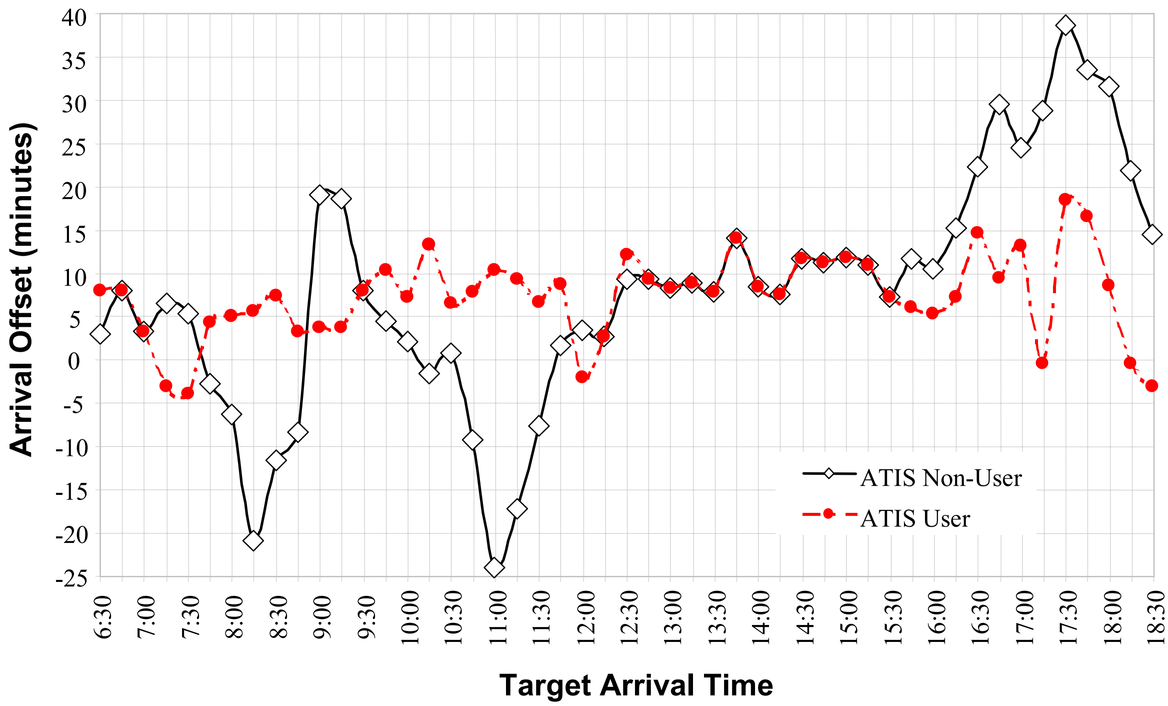

Figure 3-3. Simulated Yoked Trial Results:
9 September 1999 -- Laurel, Maryland to Dale City, Virginia

that ATIS users significantly reduce both maximum late schedule delay and maximum early schedule delay.

The observation of improved on-time reliability with reduced early schedule delay on 9 September 1999 is also borne out when we look at a summary of travel performance throughout the month of September for the Laurel to Dale City commute (Table 3-2). Note that the ATIS users have a better on-time performance than even the conservative non-users, while experiencing only 20% of the late schedule delay experienced by the aggressive non-users. The average monthly schedule delay figures are averaged over all target times of arrival and over the total number of realizations generated for the day in the evaluation period. The maximum observed schedule delay figure is the maximum delay experienced by any one simulated yoked trial participant. Travel for ATIS users is far more predictable in terms of rate of late shock, cut by 40 and 67 percent compared to conservative and aggressive non-users, respectively. These improvements in on-time reliability and predictability are achieved with marginal or no change in average travel time (or travel distance). This implies that for the Laurel-to-Dale City trip, the behavior of the ATIS User results in improved on-time reliability even though this results in only small reductions in in-vehicle travel time when averaged over periods as long as a month.

Commuter	On-Time Reliability	Lateness Risk	Early Schedule Delay Average Monthly ESD	Early Schedule Delay Maximum Observed ESD	Late Schedule Delay Average Monthly LSD	Late Schedule Delay Maximum Observed LSD	Rate of Late Shock	In-Vehicle Travel Time	Trip Distance
Conservative Non-User	90%	10%	2.8 hours	43 min	13 min	28 min	10%	62.1 min	80.8 km
Aggressive Non-User	78%	22%	1.4 hours	29 min	36 min	43 min	18%	63.1 min	80.8 km
ATIS User	92%	8%	1.6 hours	32 min	7 min	19 min	6%	62.2 min	81.2 km
Optimal Performance	100%	0%	0 min	0 min	0 min	0 min	0%	61.3 min	80.8 km

Table 3-2. Performance Summary for September 1999:
Laurel to Dale City, 6:30 AM – 6:30 PM Target Arrivals

Aggregate Results. The Laurel-to-Dale City trip is one of the longest in the network, so we may expect that the benefits of ATIS may not be indicative of all possible trips in the network. However, when the complete network is analyzed, ATIS users still experience significantly improved travel reliability and predictability relative to either the conservative or aggressive ATIS non-users (Table 3-3). Note that these figures are not weighted by the number of travelers making each trip, but equally among all trips. Again, the performance of ATIS users is superior to non-users in most metrics. ATIS users are more frequently on-time and have a dramatically reduced rate of late shock. However, the dramatic reduction in early schedule delay seen against the conservative non-user for Laurel-to-Dale City is not observed here. In addition, the worst performing ATIS user with respect to late schedule delay is over 20 minutes later than the worst performing conservative non-use.

A check of performance in mid-day and peak periods is revealing with respect to ATIS performance when all trips are considered. In Table 3-4, the performance in the mid-day period (9:30 AM – 3: 30 PM) is presented. Note that on-time reliabilities are quite high while travel times are low. This is because during the mid-day period the DC roadway network sees off-peak travel demand and infrequent congestion. Therefore, the archived travel times are likely to over-estimate travel time based on the distributions found in Hardy *et al.*. This implies that ATIS users are likely to budget more time than needed and arrive at their destinations too early when the network is relatively free-flowing.

Conversely, when congested conditions prevail in the peak periods, ATIS users are not consistently receiving overestimated travel time reports. As shown in Table 3-5, the result is that ATIS users again see significant reductions in early schedule delay (with respect to conservative non-users) and late schedule delay (with respect to aggressive non-users). Therefore, we can conclude that ATIS users gain more benefit in terms of improved travel reliability during the peak periods than in

			Early Schedule Delay		Late Schedule Delay				
Commuter	On-Time Reliability	Lateness Risk	Average Monthly ESD	Maximum Observed ESD	Average Monthly LSD	Maximum Observed LSD	Rate of Late Shock	In-Vehicle Travel Time	Trip Distance
Conservative Non-User	94%	6%	59 min	50 min	5 min	40 min	6%	30.2 min	33.6 km
Aggressive Non-User	86%	14%	17 min	12 min	17 min	125 min	14%	30.5 min	33.6 km
ATIS User	98%	2%	53 min	35 min	1.5 min	61 min	1%	30.2 min	34.1 km
Optimal Performance	100%	0%	0 min	0 min	0 min	0 min	0%	30.0 min	34.1 km

Table 3-3. Performance Summary for September 1999:
All DC Trips, 6:30 AM – 6:30 PM Target Arrivals

			Early Schedule Delay		Late Schedule Delay				
Commuter	On-Time Reliability	Lateness Risk	Average Monthly ESD	Maximum Observed ESD	Average Monthly LSD	Maximum Observed LSD	Rate of Late Shock	In-Vehicle Travel Time	Trip Distance
Conservative Non-User	95%	5%	53 min	31 min	4 min	36 min	5%	28.6 min	33.6 km
Aggressive Non-User	90%	10%	13 min	25 min	8 min	116 min	10%	28.6 min	33.6 km
ATIS User	99%	1%	65 min	35 min	4 min	61 min	1%	28.8 min	33.8 km
Optimal Performance	100%	0%	0 min	0 min	0 min	0 min	0%	28.4 min	33.8 km

Table 3-4. Performance Summary for September 1999:
All DC Trips, 9:30 AM – 3:30 PM (Mid-Day) Target Arrivals

			Early Schedule Delay		Late Schedule Delay				
Commuter	On-Time Reliability	Lateness Risk	Average Monthly ESD	Maximum Observed ESD	Average Monthly LSD	Maximum Observed LSD	Rate of Late Shock	In-Vehicle Travel Time	Trip Distance
Conservative Non-User	92%	8%	66 min	50 min	6 min	40 min	8%	31.5 min	33.6 km
Aggressive Non-User	81%	19%	25 min	41 min	24 min	125 min	19%	32.1 min	33.6 km
ATIS User	97%	3%	41 min	35 min	2 min	37 min	2%	31.4 min	34.3 km
Optimal Performance	100%	0%	0 min	0 min	0 min	0 min	0%	30.0 min	34.1 km

Table 3-5. Summary: All DC Trips,
AM Peak (6:30-9:30) and PM Peak (3:30-6:30) Target Arrivals

the mid-day period. This makes intuitive sense as well, when one considers that the peak period contains the highest overall variability in travel times across the region.

Another key observation is that the differences in travel time and trip distances are very small, not only between ATIS users and non-users but between optimal travel performance and non-users. ATIS users do see a marginal improvement in in-vehicle travel time compared to aggressive non-users, but no improvement whatsoever with respect to conservative non-users. The reason why ATIS users see improved travel reliability without much change in in-vehicle travel time is that under the travel decision-making rules we have implemented, travelers do not optimize for in-vehicle travel time reduction. This implies, for example, that an ATIS user exploits the knowledge about better-than-normal conditions to postpone trip departure rather than to pursue the lowest possible travel time. The decision to depart later may in fact result in higher in-vehicle travel time. However, the ATIS user is far more likely to arrive close to the target arrival time. In fact, if travel behavior rules were implemented in HOWLATE without respect to target arrival times at trip destination, ATIS users would gravitate immediately to off-peak travel and avoid all peak travel.

3.3 ATIS User Expectations and Outcomes

The framework of arrival time adopted in this study is different from the traditional yoked study in that the yoked pairs do not necessarily depart at the same time. As shown in Section 3.2, however, we can readily quantify the impact of regular ATIS use in terms of time management benefits. This subsection explores the notion of travel *predictability* (how well pre-trip commuter expectation and actual arrival were matched) beyond the simple "late shock" metric used in Section 3.2.

When making a trip, experienced commuters base their departure time on their expectation of likely trip duration to arrive at the their trip destination prior to a target time of arrival. In the absence of pre-trip information, commuter arrival expectation is fixed; that is, they initiate their trip with the expectation of arriving close to or just prior to the target arrival time. A commuter's experience may be different from the expectation because of unexpected changes in road capacity (incidents, roadwork, etc.) or travel demand (sporting event, holiday, etc.). Commuters may experience arrivals that are late, just-in-time, or early with respect to their desired arrival times. Definitions of late, just-in-time or early appear in Section 2.3.

The outcomes of a trip repeated across many days can be represented with a probability mapping the pre-trip expectation of the traveler against the experience of the traveler. For example, a commuter with no pre-trip information during the home-to-work commute will expect to be on-time 100% of the trips and may experience 70% just-in-time, 20% early, and 10% late arrivals over a one month period.

With the use of pre-trip information, a commuter's expectation of on-time arrival may change to an earlier or later arrival based on the current projected fastest travel time. The arrival experience may still be different from expectation because current travel times were inaccurately estimated or because traffic conditions changed during the course of the trip. Figure 3-4 graphically illustrates the concepts of the expectation-experience relationship with a sample, qualitative expectation-experience probability mapping for commuters with and without pre-trip information. Note that the expectation-experience mapping is more complex for the ATIS user than the ATIS non-user.

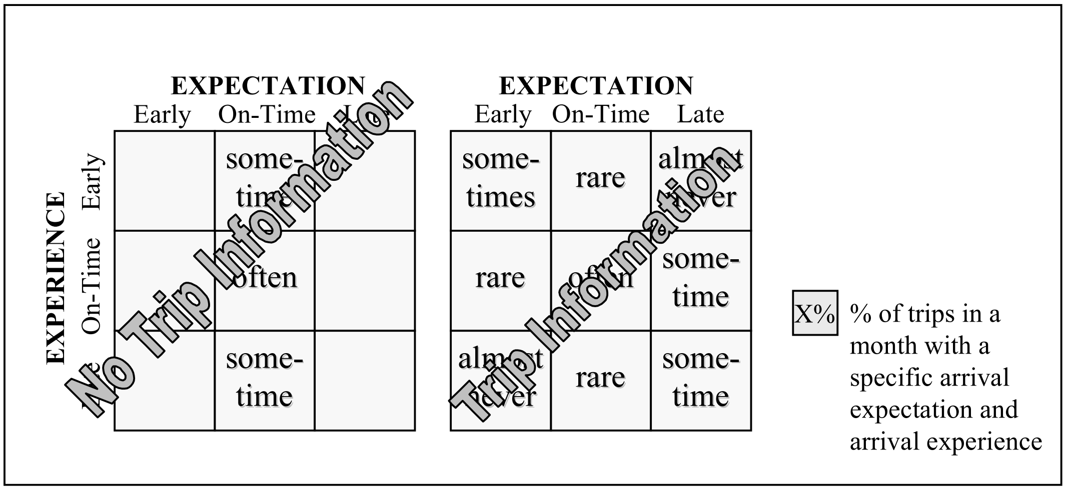

Figure 3-4. Illustration of the Arrival Expectation-Experience Probability Mapping

The mapping and comparison of ATIS users and non-users for a trip allow us to define additional metrics of predictability. Metrics capturing travel predictability include late shock and ATIS reliability. ATIS reliability is the frequency with which a commuter's pre-trip expectation is met. Late shock is a late arrival when expecting to be either early or just-in-time pre-trip. Metrics capturing travel reliability include the frequency of early and late arrivals, the amount of early and late schedule delay, and the frequency of on-time arrivals.

A unique opportunity provided by this simulated yoked pair study is the ability to determine whether ATIS users correctly perceive impacts of ATIS use. For example, a particular ATIS user who expects to arrive just-in-time and actually arrives early may perceive the ATIS service to be less than useful. However, if the same user is made aware that a counterpart commuter not using ATIS arrives late, the ATIS user's informed perception of ATIS usefulness may be positive.

To quantify whether ATIS users correctly perceive impacts of ATIS use, we qualitatively define either as positive or negative each possible outcome of the ATIS user arrival expectation-experience and corresponding non-user experience set (see Table 3-6, last 2 columns). Based on the outcome definition, we can calculate the percent of ATIS users that correctly or incorrectly perceive benefits of ATIS use.

Figure 3-5 presents the probability mapping and average schedule delay of ATIS users and non-users over all trips in the DC network. Here, a negative schedule delay number indicates an early arrival while a positive number indicates a late arrival. Pre-trip ATIS users

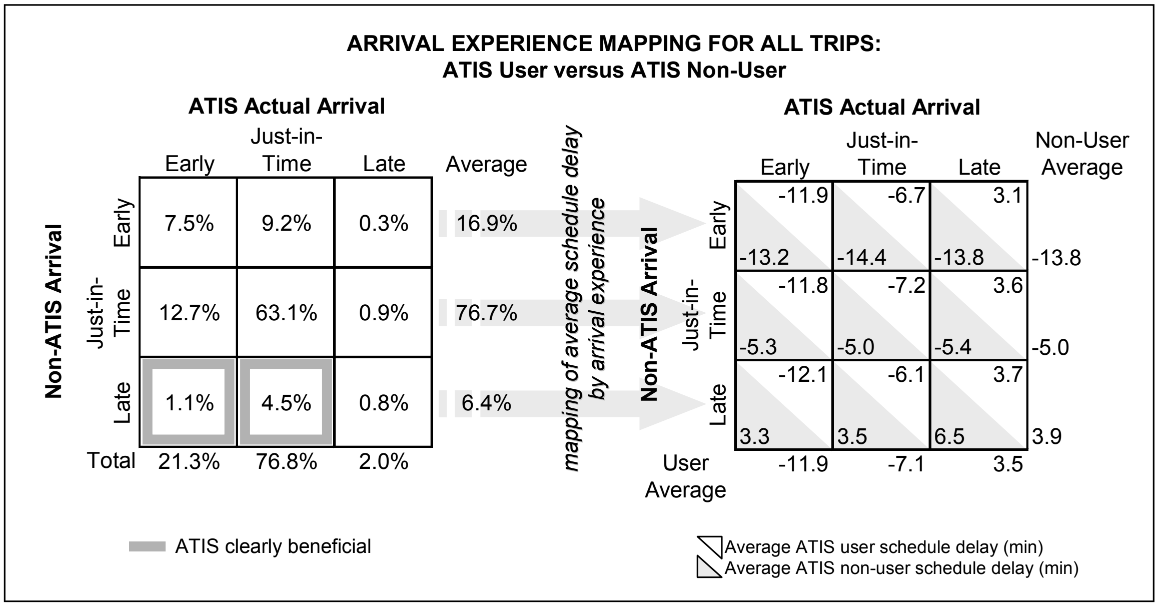

Figure 3-5. Mapping of ATIS User and Non-User Arrival Performance

benefit significantly from the evaluated service; however, sometimes the opposite effect does occur. In approximately 5.6% of the occasions ATIS is used, there is a clear benefit from the pre-trip service by fostering an arrival that is either early or just-in-time while counterparts arrive late. On the other side, in approximately 1.2% of the cases where pre-trip ATIS is used, users arrive late when their counterparts do not. The ratio of the number of occurrences of clear benefit to the number of occurrences of clear disbenefit for ATIS use is about 5:1. Cases where the benefits of ATIS are not as clear-cut include occasions when both users and non-users have the same arrival event or when their arrivals are near the border of the just-in-time and early categories.

ATIS users also experienced improvements in travel predictability. Figure 3-6 provides a mapping of ATIS expectation and experience. ATIS non-users experience late shock five times as often as ATIS users. In approximately 30% of the trials resulting in late arrivals, ATIS users are aware pre-trip that they will arrive late. ATIS-based expectation matches experience in 77.2% of the trials. Thus, the ATIS service can be rated as 77.2% reliable.

By far, ATIS error is on the side of early arrival. In 20.6% of the yoked trials ATIS users expect to arrive just-in-time, but actually arrive early. This is because the ATIS service evaluated in this study has a policy that precludes reporting link travel times that require travel speeds faster than the

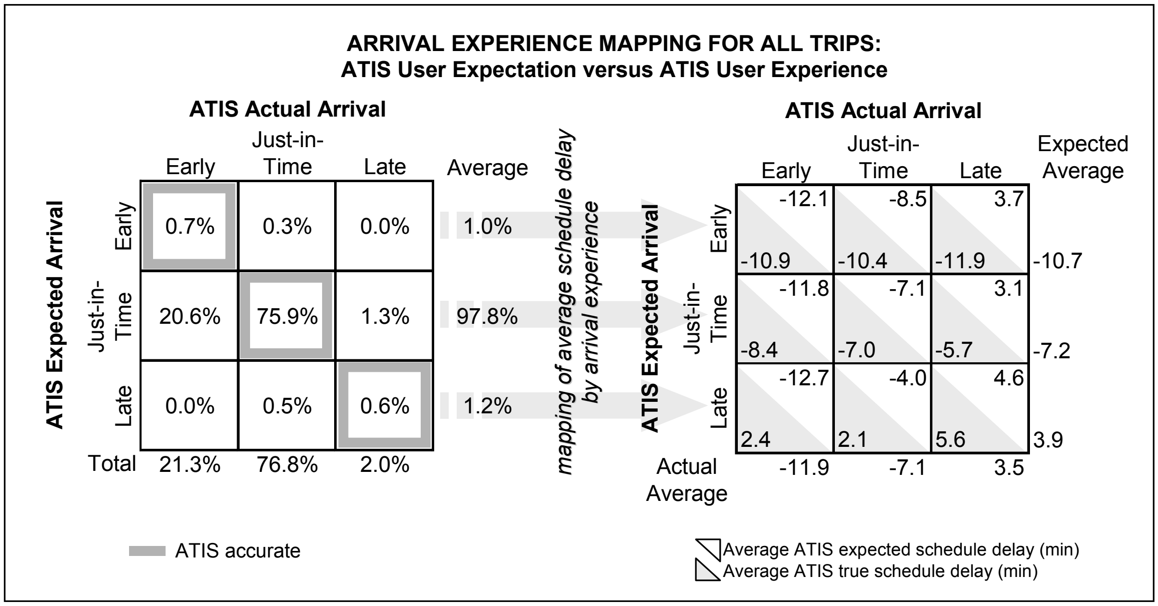

Figure 3-6.   ATIS Arrival Expectation and Experience for All Trips

speed limit. As such, during uncongested times ATIS users base their trip start decision on larger than true travel times, thereby arriving early. Across the 3.06 million trials with ATIS use, ATIS prediction of travel time is about 0.8 minutes off from the ATIS experienced travel time.

Table 3-6 maps the 27 possible outcomes of the 3.06 million simulated paired trials in terms of ATIS user expectation, experience, and the experience of the counterpart ATIS non-user. This mapping provides some instructive relations between ATIS user perception with and without the knowledge of non-user counterpart commuter performance. From Table 3-6, of the 98% of ATIS users who have a pre-trip expectation that they will arrive on-time, 21% arrive early instead. However, for 5% of these trials where the ATIS user is presumably unpleasantly surprised to be early, the counterpart commuter not using ATIS arrives late. In this circumstance, the impact of ATIS is beneficial whereas the perception of benefit is poor. Conversely, when commuters are informed pre-trip that a late arrival is likely by the ATIS service and then experience a late arrivals, they might perceive a significant benefit from this information in terms of stress reduction. However, in approximately 57% of these circumstances, the commuters' ATIS non-user counterparts actually arrive on-time for the evaluation month. Here, the perception of significant benefit without counterpart comparison information is likely to be far more positive compared to the perception of ATIS benefit with counterpart comparison information.

ARRIVAL MAPPING OF ALL SIMULATED YOKED PAIRS										
ATIS users expect to arrive		ATIS users arrive		ATIS non-users arrive		Average Schedule Delay (minutes)			ATIS Users' Perceived Utility of the Service	
						ATIS expects	ATIS actual	ATIS non-user	No Counterpart Information[1]	Knowledge of Counterpart Arrival[1]
Early	1.0%	Early	67.0%	Early	37%	-12	-13	-22	+	+
				JIT	60%	-10	-12	-6		-
				Late	3%	-10	-12	2		++
		JIT	32.4%	Early	22%	-12	-7	-23	-	--
				JIT	74%	-10	-9	-5		-
				Late	4%	-10	-8	3		+
		Late	0.7%	Early	70%	-13	4	-21	- -	--
				JIT	21%	-10	3	-5		--
				Late	10%	-10	5	7		-
JIT	97.8%	Early	21.0%	Early	35%	-8	-12	-13	-	-
				JIT	60%	-9	-12	-5		--
				Late	5%	-8	-12	3		+
		JIT	77.6%	Early	12%	-7	-7	-14	+	++
				JIT	82%	-7	-7	-5		+
				Late	6%	-7	-6	3		++
		Late	1.4%	Early	14%	-6	3	-14	-	-
				JIT	44%	-6	3	-5		--
				Late	41%	-6	3	5		-
Late	1.2%	Early	2.9%	Early	19%	1	-12	-13	-	-
				JIT	42%	2	-13	-4		--
				Late	39%	3	-12	5		+
		JIT	45.9%	Early	18%	2	-4	-14	-	+
				JIT	53%	1	-4	-5		-
				Late	29%	4	-4	8		-
		Late	51.2%	Early	10%	5	4	-13	+	-
				JIT	47%	5	4	-5		--
				Late	43%	7	5	10		+

[1] + implies positive utility, - implies disutility

Table 3-6. Yoked Pair Expectation, Experience, and Non-User Experience for All Trips

Based on these qualitative definitions of ATIS impact by arrival outcome, we can observe from Table 3-6 that circumstances in which the ATIS user's perception of ATIS utility would be significantly altered by the knowledge of counterpart performance is quite small – representing about 2% of all the simulated yoked trials conducted as a part of the DC case study.

In roughly two-thirds of these cases (approximately 1.2% of all trials), ATIS users perceive a benefit from the service without counterpart performance information but would likely not perceive a benefit when informed of a counterpart non-user's performance. Conversely, in roughly one-third of these cases (approximately 0.7% of all trials) ATIS users perceive a disbenefit from the service in the absence of counterpart performance information, but would likely perceive a benefit when informed of a counterpart non-user's performance.

4.0 Conclusions

The HOWLATE methodology offers a new, valuable tool to the ATIS evaluator that complements the existing field study, traffic simulation and survey research techniques. It can quantify and precisely categorize benefits of time management, trip predictability, and travel reliability that other techniques cannot. Survey research can only provide qualitative assessments of ATIS user time savings or improved on-time reliability. Traffic simulation analysis cannot efficiently assess the implications of complex ATIS user behaviors. HOWLATE can be applied at a fraction of the cost of a comparable field study. This said, the benefits quantified by HOWLATE are restricted to consideration of user, not system impact. HOWLATE cannot be easily extended to assess system-level impacts of increasing ATIS market penetration nor can HOWLATE address impacts of ramp metering or other traffic control strategies. These applications are best considered using field studies or traffic simulation models. Likewise the perceived benefit of ATIS to a user cannot be measured nor quantified within HOWLATE. Field studies of ATIS are still required to examine the effect of having a "human-in-the-loop" for travel decision-making. HOWLATE adds a new dimension of potential analysis that can be conducted in conjunction with these other techniques.

The implications of the HOWLATE methodology development and the findings in of the Washington DC case study do have ramifications for any future assessment of ATIS, regardless of the research technique applied. In Section 4.1, the implications of this work and key findings are summarized. In Section 4.2, extensions of the HOWLATE methodology for both ATIS evaluation and the assessment of travel reliability at a network level over time are presented.

4.1 Key Findings

The key finding of this work is that the evidence from survey and field research does not in fact conflict. As survey research suggests, ATIS users do realize significant benefits in terms of time management – better on-time reliability, reduced early and late schedule delay, as well as more predictable travel. They do this, however, without significantly reducing the amount of in-vehicle travel time accumulated over a month or year of regular trip-making. Therefore, the field trials constructed to measure reduced in-vehicle travel time have likely accurately reflected the reality of day-to-day ATIS use.

Traditional cost-benefit analysis in the transportation area is geared primarily at the monitization of in-vehicle travel time measures. Therefore, if ATIS deployments are evaluated purely on these time-savings, the benefits of ATIS will likely be grossly underestimated. ATIS users value improved travel reliability and this benefit can be quantified through simulated yoked studies. The value of improved on-time reliability is not the same for all roadway network users, but it is clear that many types of travelers can benefit from ATIS. Trucks delivering auto parts in a just-in-time manufacturing process may highly value any improvement in on-time reliability or reduction in early schedule delay. Commuters face an on-time requirement not only on the home-to-work leg of their daily trip-making, but increasingly on the work-to-home return trip in order to meet daycare pickup requirements and other commitments. Improved reliability and predictability of travel are also likely good surrogates for reduced commuter stress. From this common sense perspective, it is clear that the benefit of improved travel reliability and predictability from ATIS will dwarf whatever small return is generated from the monitization of aggregate in-vehicle travel time reductions.

Overall, ATIS use proved advantageous in efficiently managing the traveler's time. Specific quantitative examples selected from the Washington DC case study include:

- Peak-period commuters who do not use ATIS were three to six times more likely to arrive late compared to counterparts who use ATIS;
- Cases where ATIS clearly benefits the user (e.g., ATIS user on-time, non-user late) outweighed cases where ATIS clearly disadvantages the user by five to one;
- ATIS users in peak periods are more frequently on-time than conservative non-users, yet they experience only two-thirds as much early schedule delay as non-users;
- Late shock, the surprise of arriving late, is reduced by 81% through ATIS use; and
- User perception of when ATIS is helpful or unhelpful is approximately 98% accurate.

Another implication from the Washington DC case study is that the ATIS users, compared to either the conservative or aggressive non-user types, are the only users to have both high on-time reliability and low early schedule delay. This effect is more pronounced when long trips like Laurel-to-Dale City are considered (Table 3-2) or for trips in the peak travel periods (Table 3-5). If a conservative non-user becomes dissatisfied with the amount of early schedule delay accrued in a month, the only behavior available is to become more aggressive and reduce the amount of extra time afforded as a buffer against travel time variability. This will invariably be accompanied by a drop in on-time reliability. Likewise, if an aggressive non-user wants to improve on-time reliability, the only option is to become more conservative and leave habitually earlier to add more buffer against travel time variability. This will invariably result in an increase in early schedule delay. Only the ATIS user in our framework of travelers can react to the congestion conditions identified pre-trip, and this ability to change behavior results in far more effective management of travel in an highly unpredictable urban roadway environment.

Finally, the application of HOWLATE should be considered as a highly cost-effective alternative or supplement to any future ATIS field experiment. As an example, a rough rule-of-thumb for the conduct of a yoked field trial is $50 per trial for driver wages, auto rental, gas, and the overhead of experimental design, planning and data collection equipment. Using this rough figure as a guide, the conduct of the 3 million yoked trials in the Washington DC region results in a potential $150 million study – an prohibitively expensive proposition. However, based on the labor hours and other expenses required to conduct a HOWLATE simulated yoked study, we estimate that starting a new analysis in another city (archiving data, generating error bands, defining a network and conducting a simulated yoked study) would cost under $200,000. This implies a 750:1 ratio of cost savings for public sector entities considering an evaluation of their current or prototype ATIS system through field trials.

4.2 Extensions and Future Work

A key area where HOWLATE can be extended is in the consideration of more detailed behavior in the simulated yoked study simulator. For example, our current ATIS non-user behavior reflects the experience of a highly familiar, seasoned commuter who has a good quantitative handle on the rise and fall of travel time on the habitual route during the day. Clearly, a commuter with less experience or an unfamiliar driver is unlikely to be able to determine a trip start time and path with the precision of the seasoned commuter. We plan to implement changes in the habituation module to address the unfamiliar traveler choice in the absence of ATIS. In addition, the ability to address potential en route behaviors of non-users will be incorporated. This implies potential reaction to radio traffic reports, message signs, or unexpected congestion.

We also plan to implement a behavioral model of a "savvy" ATIS user who incorporates the experience of long-time use of ATIS into decision making. A simple example of this is the seasoned ATIS user who has seen from experience that travel times in the mid-day peak are typically overestimated by SmarTraveler and discounts those reports based on their experience.

The evaluation of en route ATIS is also a possibility within HOWLATE, as is the evaluation of systems that estimate future link travel times based on current trends and historical experience.

Beyond changes to the yoked study simulator, the travel time archiver could be extended to collect data from a number of sources and store it in a central archive for analysis. For example, incident reports or weather conditions could also be identified and stored with the travel time data itself. Our understanding of the accuracy of the ATIS travel time reports will also continue to improve beyond the preliminary samples provided by Hardy *et al*. Mitretek is currently conducting a network-wide travel time collection study on over three dozen roadways in the region. We expect to be able to identify error distributions much more precisely by facility, link, or time-of-day when this study is completed in March 2001. The impact of ATIS identified by HOWLATE is expected to be quite sensitive to the level of error in the travel time estimates.

Probable future work with HOWLATE includes the analysis of other cities to provide a counterpoint to the Washington DC case study. Of the roughly 48 candidate cities with ATIS services, archived data already exists in at least five other cities we have identified: Minneapolis/St. Paul, San Diego, San Antonio, Seattle, and Milwaukee. A key component of the HOWLATE analysis methodology, a study of ATIS accuracy, has already been completed in Minneapolis/St. Paul (Jeannote et al., 2000).

Another area in which we are already extending HOWLATE is using the simulated yoked study results to track changes in travel reliability over time. As an example, Figure 4-1 illustrates the decline in travel time reliability for ATIS users and non-users across the entire DC network over the two month period September-October 1999. HOWLATE may offer a low-cost technique for the measurement and tracking of network-level metrics like on-time reliability.

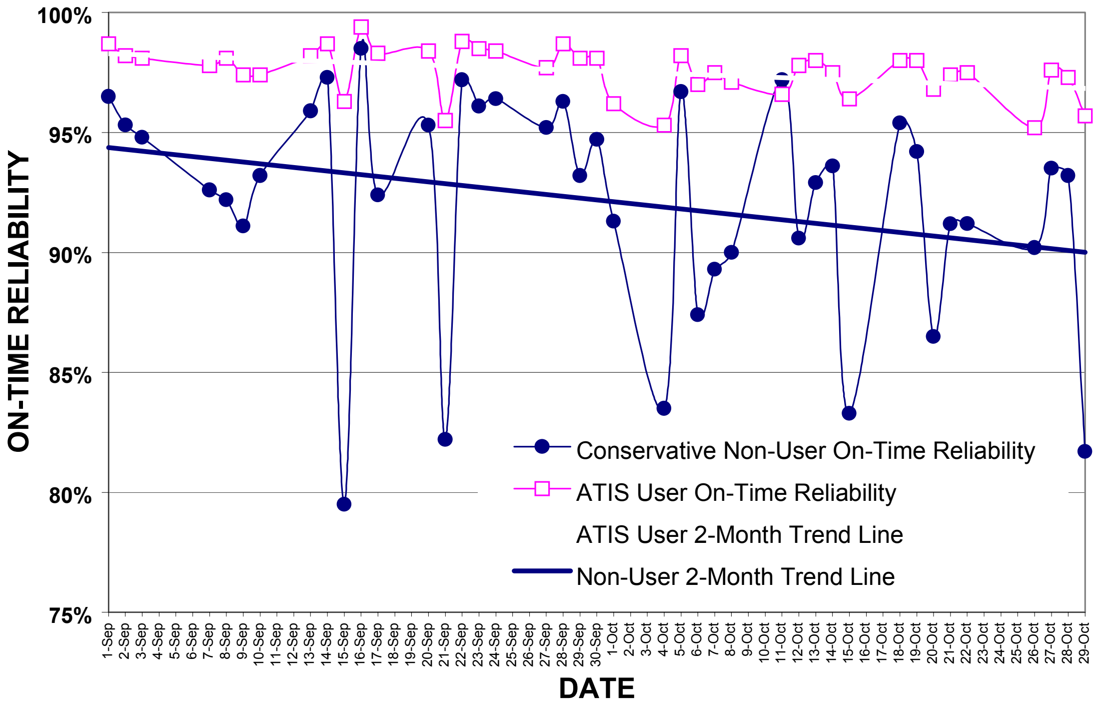

Figure 4-1. Decline of On-Time Reliability In DC Network, 9-10/1999

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APPENDIX A:

Accuracy of Travel Time Estimates Obtained from Advanced Traveler Information Services

A. 1 Background

Public and private entities over the past decade have invested significantly in Advanced Traveler Information Services (ATIS). These systems provide real-time roadway speed, travel time, incident, and construction information. Some sites are beginning to provide predictive or trip-based services through the Internet, telephone, in-car devices, and other media. Most of the data currently provided by ATIS systems is not archived for later use; rather, it is overwritten as soon as more recent data is available. In recent years, there has been significant interest in archiving the data provided by these services in order to provide more accurate information for later use in planning, safety, operations, and by research communities. Within the research community, there has always been interest in utilizing archived data to provide a more accurate means to calibrate regional transportation models, provide data inputs for model simulations, assist in quantifying the benefits of ATIS systems, and evaluate the accuracy of the travel time data provided by ATIS systems.

A. 2 Introduction

Recently, George Mason University (GMU) conducted a regional evaluation of the Partners In Motion ATIS project for the National Capital Region. GMU provided an evaluation of the impact of the ATIS project on travel conditions along the Interstate 66 (I-66) corridor utilizing the Process for Regional Understanding and Evaluation of Integrated ITS Networks (PRUEVIIN) model. (Bunch *et al.,* 1999) Mitretek Systems, tasked to provide technical support to GMU for calibrating their model, wanted to assess the accuracy of the SmarTraveler data for use in the model calibration.

In support of this effort, Mitretek Systems conducted a study to assess the use of the SmarTraveler travel time data for the calibration of GMU's PRUEVIIN model. In addition, Mitretek Systems also required estimates of the accuracy of an Internet-based ATIS service for the HOWLATE project.

The follow section presents the process by which field and internet travel time data was collected on both US-50 (arterial roadway) and I-66 (freeway). The subsequent and final section compares the measured travel time data with travel time data provided by SmarTraveler on their web site (http://www.smartravler.com/washington) for the same time period.

A. 3 Approach

The study approach is presented in three sections: GPS-Based Odograph Prototype, Corridor Description, and Data Collection. The GPS-Based Odograph Prototype section provides a summary of how actual traffic data was collected for comparison to the data downloaded from the SmarTraveler web site. The Corridor Description section provides a discussion of the make-up of both the US-50 corridor and I-66 corridor. The Data Collection section describes data that was collected and for each traffic run within the corridor. For the collection of the web-based travel time data, Mitretek Systems developed a travel time archiving software package that automatically downloads travel time data from the SmarTraveler web site on a daily basis into a text file for later use (see Section 2.1).

A. 3.1 GPS-Based Odograph Prototype

It was determined that the best method in which to collect actual travel time data for both the US-50 and I-66 corridors was to use the GPS-Based Odograph Prototype (GOP) developed by Mitretek Systems in 1996 (Harding *et al.*, 1996; Nystrom *et al.*, 1996) The GOP generates classical speed and time vs. distance plots automatically using real-time GPS data. The GOP software uses a GPS receiver mounted on an automobile and interfaced to a laptop computer through the computer's serial port. The laptop computer is used to process the GPS data, produce the plots, and optionally store the collected data for further processing.

The GOP operation mimics the manual process of collecting travel time data. The GOP records speed, time, heading, and calculates traveled distance. Having speed and distance data on the order of every second, provides a very detailed picture of the roadway segment operational characteristics, from which very accurate travel times can be derived. On the other hand, manually-collected travel time data only supplies information averaged over each delineated roadway segment and is often rife with transcription errors and other inaccuracies. Through the use of GPS satellites, the GPS receiver supplies the parameters that enable the determination of vehicle location, speed and direction of travel. The message from the GPS receiver is sent to the laptop via the serial port. The laptop computer supports the GPS message input, input from the user and is the platform by which the collected data is processed and output to the user. The laptop also houses the software, user input files and facilitates that recording of the collected data output files to disk.

The GOP requires a user input file, called a Roadway Profile, that includes twelve data parameters. The most important of these data parameters are the interim segment points that break the entire corridor into smaller segments for more detailed analysis. These interim points are designated by the user and should be approximately every mile or half-mile as the user sees fit. Usually, the interim points consist of either major cross-streets or traffic signals so that the GOP software can associate delays with those cross-street and traffic signals. A listing of the interim points used for the US-50 and I-66 corridors are discussed in Section A.3.3.

The GOP provided two advantages over manual speed and travel time calculation. First, the GPS data is much richer in content than the manual point data. The GPS data for each US-50 and I-66 corridor run was collected once per second, far more often than was possible with manual methods. This allowed a more detailed profile of operating conditions along both corridors and allowed the identification of bottlenecks and congested areas.

A. 3.2   Corridor Description

The GOP runs were conducted on two major east-west corridors in the Northern Virginia area—US-50 and I-66—which were selected by GMU as part of their ATIS evaluation (Figure A-1). Both corridors run from western Fairfax County eventually connecting with each other at the Roosevelt Bridge as they enter Washington, D.C. I-66 is the major freeway and carriers a majority of the traffic, with US-50 carrying less traffic. However, during evening and morning rush hours, I-66 has High Occupancy Vehicle (HOV) restrictions from I-495 (Capital Beltway) to the Roosevelt Bridge and US-50 is the major alternative route in and out of Washington, D.C from western Fairfax County.

Figure A-1 US-50 and I-66 Corridors

The US-50 corridor used for this analysis is approximately 19 miles long with over 30 signalized intersections and five grade-separated interchanges. Starting at the eastern edge, the US-50 corridor begins at the Roosevelt Bridge and bisects Arlington County. It continues through Seven Corners, a major shopping destination, and underneath I-495. Once outside of the beltway, the corridor continues for another 10 miles through commercial and residential areas. The study corridor terminates at the Fairfax County Parkway, a major north-south arterial in Fairfax County.

There are no HOV restrictions on US-50 and the number of lanes vary between six lanes in the west and east to four lanes in the center portion. The AM peak period for US-50 is in the eastbound direction and the PM peak period is in the westbound direction. However, during all times of the day there is a significant amount of local or non-commuter traffic using the road. There are no ITS elements, such as VMS signs, located on US-50. While there currently is a region-wide traffic signal timing system, this system had not been implemented when the travel time data collection was conducted in the summer of 1999.

The I-66 corridor used for this analysis is very similar to the US-50 Corridor and is also approximately 19 miles long. Starting at the eastern edge, I-66 begins at the Roosevelt Bridge and diverges from US-50 soon after. I-66 runs parallel to US-50, offset by approximately 1.5 miles and also through the northern edge of Arlington's Rosslyn-Ballston corridor. The I-66 study corridor crosses over US-50 in the Fair Oaks area and terminates at the Fairfax County Parkway south of the US-50 corridor termination with the Fairfax County Parkway. Grade separated interchanges are located approximately every mile along the study corridor, although these are not shown in Figure A-1.

Like many other interstates in the United States, HOV restrictions are located all along the I-66 study corridor. Inside the Capital Beltway there are HOV-2 restrictions for the AM and PM peak periods for all lanes of traffic. Outside the Capital Beltway there are HOV-2 restrictions for the left most lane only during AM and PM peak periods. The AM peak period for I-66 is generally in the eastbound direction and the PM peak period is the westbound direction. However, I-66 does has reverse commute congestion during the AM and PM peak periods inside the Capital Beltway. ITS elements such as VMS signs are located throughout the corridor as are CCTV cameras to monitor traffic flow.

A. 3.3 Data Collection

The procedures for collecting the data were fairly simple and included driving each facility in both directions while using the GOP to collect the speed and travel time data. During the GOP runs, weather conditions and abnormalities in roadway conditions were noted, such as traffic incidents. In addition to collecting travel time data with the GOP, on some of the GOP runs, the travel time data provided through the SmarTraveler telephone service were documented for later comparison.

Before conducting the GOP runs on US-50 and I-66, the identification of interim segment points along each road had to be determined. After making an initial drive along both US-50 and I-66, interim segment points were selected based upon direction (eastbound or westbound) and distance. Tables A-1 through A-4 present a summary of the interim segment points for both US-50 and I-66 in each direction. While it would be logical that both the westbound and westbound interim segment points should be the same, it is important to note that the segments for I-66 are not due to the design of the roadway. The exit numbers and names are different for each direction especially between the Roosevelt Bridge and I-495 (Capital Beltway). Segments for US-50 are more consistent since each is a signalized cross-street and not an exit or interchange.

After a series of GOP runs was completed, the data was then analyzed using the GOP software to insure that all of the necessary data was collected and that it had been stored properly on the laptop computer. In some cases, the GPS signal received by the GOP was either too weak or unavailable due to weather conditions or location on the roadway. While these types of situations were limited, they did have the potential to ruin all of or part of a GOP run. However, this did not turn out to be a major issue. After all the GOP runs were completed, the GOP travel time data was compared with the travel time data downloaded from the SmarTraveler web site.

I-66 Interim Segment Points

Table A-1 I-66 Eastbound

Name	Description	Miles
Rt. 7100	Start	0
Exit 57B	Rt. 50	1.6
Exit 60	Rt. 123	3.5
Exit 62	Nutley Street	5.55
Exit 64A	Beltway	8.5
Exit 66	Rt. 7	10.3
Exit 69	Rt. 29	12.5
Exit 71	Fairfax Drive	14.9
Exit 72	Rt. 29	16.5
Exit 73	Key Bridge	17.5
Roosevelt Bridge	End	18.9

Table A-2 I-66 Westbound

Name	Description	Miles
Roosevelt Bridge	Start	0
Exit 71	Glebe Road	3.4
Exit 69	Sycamore Street	5.7
Exit 67	Dulles Toll Road	7.85
Exit 66B	Rt. 7	8.35
Exit 64	Beltway	9.6
Exit 62	Nutely Street	11.9
Exit 60	Rt. 123	14.7
Exit 57B	Rt. 50	16.7
Rt. 7100	End	18.9

US-50 Interim Segment Points

Table A-3 US-50 Eastbound

Cross Street	Miles
Roosevelt Bridge	0
Washington Boulevard	1.9
Glebe Road	3.1
Carlin Springs	4.6
Seven Corners	6.2
Annandale Road	7.2
Graham Road	8.4
Gallows Road	10.1
Nutley Street	12
Chain Bridge Road	14.5
Waples Mill Road	16.2
West Ox Road	18
Rt. 7100	19.1

Table A-4 US-50 Westbound

Cross Street	Miles
Rt. 7100	0
West Ox Road	1.1
Waples Mill Road	2.9
Chain Bridge Road	4.6
Nutley Street	7.4
Gallows Road	8.9
Graham Road	10.7
Annandale Road	12
Seven Corners	12.9
Carlin Springs Road	14.5
Glebe Road	16
Washington Boulevard	17
Roosevelt Bridge	19.1

Data collection occurred over a two month period between the end of May 1999 and July 1999. Within the two-month period, data collection was performed during both the AM and PM peak periods for both US-50 and I-66 in various types of weather conditions. A total of 11 Eastbound and 11 Westbound GOP runs were conducted for US-50 and 15 Eastbound and Westbound GOP runs for I-66. The following section presents the outcomes of the various GOP runs and compares the GOP-observed travel times to those posted on the SmarTraveler web site for the same day and trip time.

A. 4 Results

Section A.4.1 presents the detailed results of the GOP run and compares trip performance by direction and facility. Section A.4.2 presents the results of a paired comparison of GOP runs with archived internet-based ATIS reports during the same day and time of day. Section, A.4.3, describes how the findings of this study can be applied to regional modeling.

A. 4.1 GOP Results

Table A-5 and Table A-6 present the details of the GOP runs for US-50 Eastbound and Westbound respectively. Travel times on US 50 varied by direction, time of departure, and day of week. For the eastbound direction, during the AM peak period, the greatest travel time variability occurred on July 27, 1999 with a minimum time of 26.12 minutes and a maximum time of 51.45 minutes. For the westbound direction, during the PM peak period, the maximum and minimum travel times also occurred on July 27, 1999 and were 29.00 minutes and 31.68 minutes respectively. The average travel times eastbound and westbound for US 50 are 36.21 and 30.67 minutes respectively. The travel time standard deviations for eastbound and westbound are 8.2 and 1.2 minutes respectively.

Table A-5 US-50 GOP Runs Eastbound

Number	Direction	Date	Day	Start Time	Weather	Travel Time (min)
1	Eastbound	7/26/99	Monday	2:10PM	Sunny	33.90
2	Eastbound	7/26/99	Monday	3:28 PM	Sunny	29.58
3	Eastbound	7/27/99	Tuesday	6:11 AM	Cloudy	26.12
4	Eastbound	7/27/99	Tuesday	7:24 AM	Cloudy	51.45
5	Eastbound	7/27/99	Tuesday	9:16 AM	Cloudy	30.69
6	Eastbound	7/27/99	Tuesday	4:09 PM	Sunny	34.52
7	Eastbound	7/28/99	Wednesday	6:44 AM	Sunny	35.21
8	Eastbound	7/28/99	Wednesday	8:17 AM	Sunny	49.06
9	Eastbound	7/28/99	Wednesday	9:53 AM	Sunny	31.08
10	Eastbound	7/29/99	Thursday	7:37 AM	Light Rain	43.36
11	Eastbound	7/29/99	Thursday	9:25 AM	Cloudy	33.38

Table A-6 US-50 GOP Runs Westbound

Number	Direction	Date	Day	Start Time	Weather	Travel Time (min)
1	Westbound	7/6/99	Tuesday	10:34 AM	Sunny	29.26
2	Westbound	7/26/99	Monday	1:20 PM	Sunny	32.44
3	Westbound	7/26/99	Monday	2:51 PM	Sunny	30.76
4	Westbound	7/27/99	Tuesday	6:43 AM	Cloudy	29.57
5	Westbound	7/27/99	Tuesday	8:23 AM	Cloudy	31.16
6	Westbound	7/27/99	Tuesday	3:35 PM	Sunny	29.00
7	Westbound	7/27/99	Tuesday	5:03 PM	Sunny	31.68
8	Westbound	7/28/99	Wednesday	7:28 AM	Sunny	30.91
9	Westbound	7/28/99	Wednesday	9:14 AM	Sunny	30.25
10	Westbound	7/28/99	Wednesday	3:44 PM	Cloudy	29.77
11	Westbound	7/29/99	Thursday	8:28 AM	Cloudy	32.59

Table A-7 and Table A-8 present the details for the GOP runs for I-66 Eastbound and Westbound respectively. Travel times here also varied by direction, time of departure, and day of week. For the eastbound direction, during the AM peak period, the greates travel time variability occurred on July 8, 199 with a minimum time of 17.11 minutes and a maximum time of 34.93 minutes. For the westbound direction, during the PM peak period, the maximum and minimum travel times also occurred on July 8, 1999 and were 22.82 minutes and 30.76 minutes respectively. The average travel times on I-66 eastbound and westbound are 24.68 and 21.20 minutes respectively. The travel time standard deviations for eastbound and westbound are 5.3 and 4.3 minutes respectively.

As expected, travel time on US-50 is generally about ten minutes greater than on I-66. This is attributed to the fact that HOV restrictions are enforced on on I-66, and the lower speed limits and abundance of traffic signals along US-50.

Table A-7 I-66 GOP Runs Eastbound

Number	Direction	Date	Day	Start Time	Weather	Travel Time (min)
1	Eastbound	5/28/99	Friday	5:57 AM	Sunny	21.25
2	Eastbound	7/9/99	Friday	6:07 AM	Sunny	22.92
3	Eastbound	7/8/99	Thursday	6:20 AM	Sunny	26.32
4	Eastbound	5/28/99	Friday	7:22 AM	Sunny	27.50
5	Eastbound	7/8/99	Thursday	7:26 AM	Sunny	34.93
6	Eastbound	7/9/99	Friday	7:29 AM	Sunny	32.25
7	Eastbound	5/28/99	Friday	8:54 AM	Sunny	19.92
8	Eastbound	7/8/99	Thursday	8:57 AM	Sunny	17.11
9	Eastbound	7/7/99	Wednesday	9:21 AM	Sunny	30.75
10	Eastbound	6/28/99	Monday	10:17 AM	Sunny	20.79
11	Eastbound	7/7/99	Wednesday	10:38 AM	Sunny	29.61
12	Eastbound	6/28/99	Monday	12:18 PM	Sunny	20.28
13	Eastbound	7/6/99	Tuesday	1:24 PM	Sunny	20.02
14	Eastbound	7/8/99	Thursday	4:25 PM	Sunny	24.50
15	Eastbound	7/26/99	Monday	4:51 PM	Sunny	21.53

Table A-8 I-66 GOP Runs Westbound

Number	Direction	Date	Day	Start Time	Weather	Travel Time (min)
1	Westbound	5/28/99	Friday	6:21 AM	Sunny	18.25
2	Westbound	7/8/99	Thursday	6:54 AM	Sunny	18.89
3	Westbound	7/9/99	Friday	7:00 AM	Sunny	17.43
4	Westbound	5/28/99	Friday	8:00 AM	Sunny	19.04
5	Westbound	7/9/99	Friday	8:09 AM	Sunny	19.20
6	Westbound	7/8/99	Thursday	8:15 AM	Sunny	25.48
7	Westbound	7/7/99	Wednesday	8:27 AM	Sunny	22.75
8	Westbound	6/28/99	Monday	9:05 AM	Sunny	17.72
9	Westbound	7/7/99	Wednesday	11:18 AM	Sunny	18.97
10	Westbound	6/28/99	Monday	11:40 AM	Sunny	17.86
11	Westbound	7/6/99	Tuesday	12:55 PM	Sunny	18.30
12	Westbound	7/8/99	Thursday	3:50 PM	Sunny	22.82
13	Westbound	7/8/99	Thursday	4:58 PM	Sunny	30.76
14	Westbound	7/26/99	Monday	4:05 PM	Sunny	27.51
15	Westbound	7/26/99	Monday	6:34 PM	Sunny	24.68

A. 4.2 Paired Analysis of GOP and SmartTraveler Runs

The analysis of the GOP and SmarTraveler paired data was conducted in aggregate and by grouping paired observations into two subsets representing a congested and uncongested traffic flow regime. The following three criteria defines whether a paired observation data is classified as being in the congested grouping:

1. The GOP travel time is equal to or less than 80% of the travel time based on the posted speed limit.
2. The SmartTraveler web site states that there was congestion based upon their estimate of travel time.
3. The GOP run drivers recorded observing significant congestion during the GOP run.

All paired observations not belonging to the congested grouping are classified as uncongested. Overall, for US 50 and I-66, SmarTraveler overestimates travel time by 8% and 17% respectively. The variability in SmarTraveler reporting accuracy for US 50 and I-66 are 17% and 14% respectively. This is expected because there is greater information on freeway facilities available to SmarTraveler than on arterial facilities.

Table A-9 presents the number of observations belonging to the congested and uncongested subsets by route and direction. Table A-10 presents the average and variance of the percent difference between the GOP and SmarTravler paired data for both roadway facilities by congestion level. The percent difference between the two observations is calculated as (travel time$_{\text{SmartTraveler}}$ - travel time$_{\text{GOP}}$)/ travel time$_{\text{GOP.}}$

Table A-9 GOP Run Data

		Congested	Non-Congested	Total
US-50	Eastbound	4	7	11
	Westbound	0	11	11
I-66	Eastbound	6	9	15
	Westbound	8	6	14
Total		18	33	51

Table A-10 SmarTraveler Error Distribution

Facility	Congested		Non-Congested	
	Skew	COV	Skew	COV
US-50	18%	26%	-14%	6%
I-66	-13%	17%	-21%	9%

The travel time reported by SmarTraveler on I-66 during the congested period is on average 13% higher than observed during the GOP runs. This changes to 21% for uncongested periods. SmarTraveler accuracy during the congested period for the freeway facility is greater than during the uncongestion regime primarily for one reasons. SmartTraveler adopted a policy of not reporting travel times faster than the posted speed limit, reducing their accuracy during un-congested regimes. For example, travelers tend to exceed the speed limit during their late morning and early afternoon commutes characterized by free flow roadway conditions. As such, actual travel time is much lower than those posted by SmarTraveler.

SmarTraveler reporting accuracy for I-66 has much greater variability during congested periods (17%) than during uncongested periods (9%). This is because traffic conditions are often rapidly changing during congested regimes and SmarTraveler reported data becomes rapidly outdated.

For US 50, on average during the congested regime, SmarTraveler significantly over estimated travel time (by 18%) while during the uncongested regime SmarTraveler significantly under estimated travel time (by 14%). As with I-66, SmarTraveler reporting accuracy has much greater variability during congested periods than during uncongested periods for US 50. Of note is the fact that SmarTraveler on average overestimates travel time for I-66 regardless of congestion regime, but not for US 50.

Overall, the error distributions identified in Table 10 are worse than the preliminary figures employed in the DC case study (see Table 3-1). Although the precise impact of this less accurate ATIS service will not be known until a parallel set of HOWLATE runs can be conducted, it is likely that ATIS users will perform more poorly under these final numbers than under the preliminary assessment.

A. 4.3 Application of Findings

Based upon the results presented in Sections A.4.1 and A.4.2, it was concluded that this data could be used in two ways in the GMU PRUEVIIN model. First, the travel time measured by the GOP runs can by used to calibrate the travel times for the simulation model. Second, the travel time reports by SmarTraveler can by adjusted by the measured skew and then used as a larger base for calibrating travel time data. Moreover, the variance of travel time measured by the GOP runs can be used as a basis to determine how well the simulation model represents actual roadway conditions. Finally, the use of the travel time data provided by the SmarTraveler web site, combined with the error distributions presented in this analysis, can be used as part of HOWLATE process for evaluating the impacts of using ATIS reports with varying levels of accuracy.

Appendix A References

1. Bunch, J., Hatcher, S., Larkin, J., Nelson, G., Proper, A., Roberts, D., Shah, V., and Wunderlich, K., Integrating ITS Into Corridor Planning: Seattle Case Study, U.S. Department of Transportation, ITS Joint Program Office, August 1999.
2. Harding, J., Salwin, A., Shank, D., and Ghaman, R. GPS Applications for Traffic Engineering Studies. Transportation Research Board Annual Meeting, Washington, DC, January 1996.
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APPENDIX B:

HOWLATE Support Algorithms

1.0 Forward A-STAR Dynamic Program: D'

$\mathrm{D}'(o, d, t^0, c_\ell(t))$: The subroutine takes the following arguments:

o	trip origin
d	trip destination
t^0	time of trip start
$c_\ell(t)$	set of estimated arc costs to be used, defined $\forall\ \ell, t$

Plus, it uses the following array already constructed:

$H_d'(n)$ heuristic estimate of minimum time required to go from n to d.

1. Define the following:

   O the set of open nodes, set $\mathbf{O} = o$.

   C the set of closed nodes, set $\mathbf{C} = \varnothing$.

   $\mathrm{F}(n)$ estimate of fastest path time from o to d through n, departing n at earliest possible time,

   $$\mathrm{F}(n) = G(n) + H_d'(n)$$

   $\mathrm{G}(n)$ earliest possible arrival time at node n, $G(o) = t^0$.

   $\mathrm{S}(n)$ set of successor nodes for n, i.e., nodes reached in one arc from n

   $\overleftarrow{N}(n)$ pointer for node n to previous node along fastest path

2. if $\mathbf{O} = \varnothing$, exit with FAILURE. Otherwise, recover or calculate $\mathrm{F}(n) \forall n \in \mathbf{O}$.

3. a. find $n = \min\limits_{n' \in \mathbf{O}} \{\mathrm{F}(n')\}$; $a = \mathrm{G}(n)$.

   b. if $n = d$, then GOTO Step 5.

   c. for each $n' \in \mathrm{S}(n)$:

   Let $\ell = (n, n')$ and $a' = a + c_\ell(a)$.

   if $n' \notin \mathbf{O} \cup \mathbf{C}$ then

   Set $\mathbf{O} = \mathbf{O} + n'$, GOTO (*).

   if $n' \in \mathbf{O}$ AND $a' < G(n')$ then GOTO (*).

   if $n' \in \mathbf{C}$ AND $a' < G(n')$ then

   Set $\mathbf{C} = \mathbf{C} - n'$, $\mathbf{O} = \mathbf{O} + n'$, GOTO (*).

   Else GOTO (**).

   (*) Set $G(n') = a'$ and $\overleftarrow{N}(n') = n$.

   Update $F(n') = G(n') + H_d'(n')$.

(**) Next n'.

d. Set $\mathbf{C} = \mathbf{C} + n$, $\mathbf{O} = \mathbf{O} - n$.

4. GOTO Step 2.
5. DONE. Retrace pointers to find optimal path, path travel time is $G(d) - t^0$.

2.0 Reverse-Time Dynamic Program: `D

`D$(d, t, c_\ell(t))$: The subroutine takes the following arguments:

d trip destination
t target time of arrival at d
$c_\ell(t)$ set of actual arc costs to be used, defined $\forall\, \ell, t$

Plus, it uses the following array already constructed:

c_ℓ^0 free-flow arc travel times $\forall\, \ell$

1. Define the following:

O the set of open nodes, set $\mathbf{O} = d$.
C the set of closed nodes, set $\mathbf{C} = \varnothing$.
$\mathrm{G}(n)$ latest possible departure time from node n to get to d at time t, $G(d) = t$.
$P(n)$ set of predecessor nodes for n, i.e., nodes from which n is reached in one arc
$\vec{N}(n)$ pointer for node n to next node along fastest path

2. if $\mathbf{O} = \varnothing$ and **C** contains all nodes in the network, GOTO Step 5.
Otherwise, recover or calculate $G(n) \forall n \in \mathbf{O}$.

3. a. find $n = \max_{n' \in \mathbf{O}} \{G(n')\}$; set $a = \mathrm{G}(n)$.

b. for each $n' \in P(n)$:

Let $\ell = (n', n)$ and $a'' = a - c_\ell^0 - REM\left(\dfrac{a - c_\ell^0}{\Delta}\right)$.

(b*) if $a'' + c_\ell(a'') \le a$ then

$$a' = a'' + \frac{[a - a'' - c_\ell(a'')]\Delta}{\Delta + c_\ell(a'' + \Delta) - c_\ell(a'')}$$

else set $a'' = a'' - \Delta$, GOTO (b*).

if $n' \notin \mathbf{O} \bigcup \mathbf{C}$ then
Set $\mathbf{O} = \mathbf{O} + n'$, GOTO (*).

if $n' \in \mathbf{O}$ AND $a' > G(n')$ then GOTO (*).

if $n' \in \mathbf{C}$ AND $a' > G(n')$ then
Set $\mathbf{C} = \mathbf{C} - n'$, $\mathbf{O} = \mathbf{O} + n'$, GOTO (*).

Else GOTO (**).

(*) Set $G(n') = a'$ and $\vec{N}(n') = n$.

(**) Next n'.

e. Set $\mathbf{C} = \mathbf{C} + n$, $\mathbf{O} = \mathbf{O} - n$.

4. GOTO Step 2.
5. DONE. Retrace pointers to find optimal path, latest departure from any node is $G(n)$, travel time on optimal path from any node is $t - G(n)$.

3.0 Forward Path Traversal Under Estimated Travel Times: $\mathrm{T}'(\cdots, \hat{c}_\ell(t))$

$\mathrm{T}'\left(\mathbf{P}_{o,d}, t^0, c_\ell\left(t^0\right)\right)$: The subroutine takes the following arguments:

$\mathbf{P}_{o,d}$ Path to be traversed from origin to destination, an array of links

t^0 time of trip start

c_ℓ set of estimated arc costs fixed at time t^0, defined $\forall\, \ell$

Return $p_{o,d} = \sum_{\ell \in \mathbf{P}_{o,d}} c_\ell$, defined as the total path cost from origin to destination.

4.0 Forward Path Traversal Under Actual Travel Times: $\mathrm{T}'(\cdots, \widehat{c}_\ell(t))$

$\mathrm{T}'\left(\mathbf{P}_{o,d}, t^0, c_\ell(t)\right)$: The subroutine takes the following arguments:

$\mathbf{P}_{o,d}$ Path to be traversed from origin to destination, an array of links

t^0 time of trip start

$c_\ell(t)$ set of actual arc costs, defined $\forall\, \ell, t$

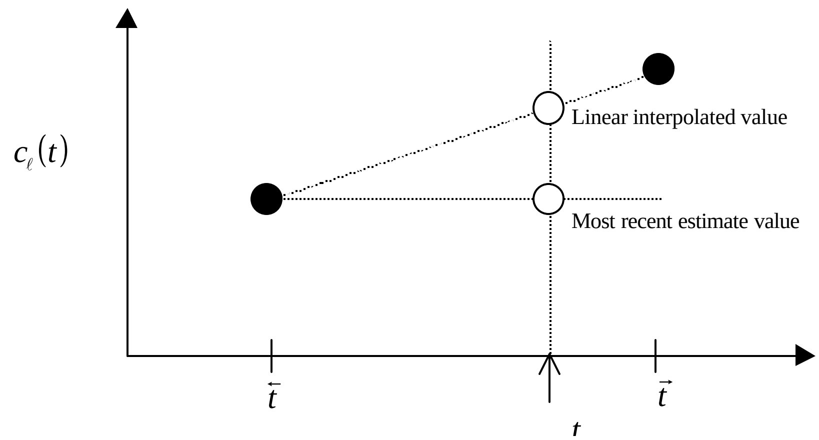
1. Set $p_{o,d} = 0$, defined as the cumulative path cost from origin to destination.
   Set the intermediate time $a = t^0$.
2. Find $\ell \in \mathbf{P}_{o,d}$, the next link in sequence from origin to destination.

$$\widehat{c}_\ell(t) = \widehat{c}_\ell(\bar{t}) + (t - \bar{t}) \frac{\left(\widehat{c}_\ell(\vec{t}) - \widehat{c}_\ell(\bar{t})\right)}{(\vec{t} - \bar{t})} \qquad \text{(see Appendix E)}$$

$$p_{o,d} = p_{o,d} + c_\ell(a)$$

3. If $\ell \equiv (a, b)$; $b \neq d$ then set GOTO step 2 with $a = p_{o,d} + t^0$.
   Else return $p_{o,d}$ as the travel time on the path.

5.0 Evaluating Arc Costs Between Lattice Points



1. For traversals and DP applications using estimated data, let $\hat{c}_\ell(t) = c_\ell(\overleftarrow{t})$.
2. For traversals and DP applications using actual data, $\widehat{c}_\ell(t)$, use linear interpolation:

$$\widehat{c}_\ell(t) = \widehat{c}_\ell(\overleftarrow{t}) + (t - \overleftarrow{t}) \frac{\left(\widehat{c}_\ell(\overrightarrow{t}) - \widehat{c}_\ell(\overleftarrow{t})\right)}{(\overrightarrow{t} - \overleftarrow{t})}.$$